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DEPARTMENT OF ENERGY

ALBUQUERQUE OPERATIONS OFFICE

ENVIRONMENT, SAFETY AND HEALTH DIVISION

ENVIRONMENTAL PROGRAMS BRANCH

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COMPREHENSIVE ENVIRONMENTAL ASSESSMENT AND RESPONSE PROGRAM

PHASE 2:

ROCKY FLATS PLANT

INSTALLATION GENERIC MONITORING PLAN

(Comprehensive Source and Plume Characterization Plan)

February 1987

DRAFT

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SYNOPSIS

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1. INTRODUCTION

Rocky Flats Plant is an installation of the U.S. Department of Energy (DOE) Albuquerque Operations Office. It is one of several DOE-Albuquerque Operations Office installations being evaluated under the Comprehensive Environmental Assessment and Response Program (CEARP) pursuant to the Comprehensive Environmental Resource Compensation Liability Act (CERCLA) Implementation Order (DOE 5480.14). CEARP investigations at Rocky Flats Plant are being integrated with other RCRA and CERCLA issues pursuant to the Compliance Agreement signed by representatives of the DOE, the U.S. Environmental Protection Agency (EPA), and the State of Colorado (Colorado Department of Health) on July 31, 1986 (DOE 1986a). The Compliance Agreement addresses hazardous and radioactive mixed waste management at Rocky Flats Plant.

The program developed by DOE in response to the Compliance Agreement is being addressed by the CEARP program.. CEARP is being implemented in five phases, which exactly parallel DOE CERCLA Order 5480.14. CEARP Phase 1 (Installation Assessment [This encompasses all EPA CERCLA preremedial activities through site inspections.]) has already been completed at Rocky Flats Plant. CEARP Phase 1 evaluated present compliance with environmental laws and ascertained the magnitude of potential environmental concerns. CEARP Phase 2 (Confirmation [Monitoring Plan and Remedial Investigation]) will complete the environmental evaluation of potential environmental concerns identified in CEARP Phase 1, and plan and carry out sampling programs, as required, to understand potential contaminant sources and environmental pathways. CEARP Phase 3 (Technological Assessment [Feasibility Study]) will develop remedial action plans to mitigate environmental problems identified as needing correction in CEARP Phase 2. CEARP Phase 4 (Remedial Action) will implement recommended site-specific remedial actions identified in CEARP Phase 3. CEARP Phase 5 (Compliance and Verification) will document the adequacy of remedial actions carried out under CEARP Phase 4 and plan for continued monitoring requirements.

CEARP Phase 2 consists of CEARP Phase 2a, Monitoring Plan, and CEARP Phase 2b, Site Characterization (Remedial Investigation). CEARP uses a three-tiered approach in preparing monitoring plans: the CEARP Generic Monitoring Plan (CGMP)

(DOE 1986c), the Installation Generic Monitoring Plan (IGMP), and the Site Specific Monitoring Plans (SSMPs). The Monitoring Plan typically consists of five parts: Synopsis, Sampling Plan, Technical Data Management Plan, Health and Safety Plan, and Quality Assurance/Quality Control (QA/QC) Plan. Pursuant to the Compliance Agreement, a Feasibility Study Plan has been added as a sixth section to the CEARP Phase 2a IGMP Monitoring Plan for Rocky Flats Plant.

This revised IGMP serves as the Comprehensive Source and Plume Characterization Plan required by the Compliance Agreement. Therefore, the acronym used to refer to this plan is IGMP/CSPCP.

The SSMPs will serve as work plans for performing site characterizations (remedial investigations) for all sites requiring characterization at Rocky Flats Plant and will be tiered from the IGMP/CSPCP. Each tier of CEARP monitoring plans contains the five plans mentioned above: Synopsis, Sampling Plan, Technical Data Management Plan, Health and Safety Plan, and Quality Assurance/Quality Control (QA/QC) Plan. The Rocky Flats Plant IGMP/CSPCP and SSMPs will also contain a Feasibility Study Plan. A list of acronyms used in this IGMP/CSPCP is provided in Appendix A.

As stated in the CGMP monitoring plans, CEARP Phase 2 site characterizations (remedial investigations) will be implemented in stages. Thus, knowledge gained in each stage of sampling will be used to guide successive stages. To maintain uniformity in the site characterization (remedial investigation) process, Los Alamos National Laboratory will review all CEARP-related documentation for the DOE-Albuquerque Operations Office. In addition, at the end of each site characterization (remedial investigation), Los Alamos National Laboratory will prepare a site characterization (remedial investigation) report that will be forwarded to the DOE-Albuquerque Operations Office for review and concurrence. In the future if program implementation is delegated to Rockwell International, Los Alamos National Laboratory will review all reports for conformance with previously established program guidelines. In the latter case, Los Alamos National Laboratory will document their evaluation for DOE-Albuquerque Operations Office use in report concurrence prior to its release to the public or regulatory agencies. Appropriate CEARP-related information (e.g., validated reconnaissance and site characterization [remedial investigation] information) will be archived at Los Alamos National Laboratory and at Rocky Flats Plant.

2. DESCRIPTION OF CURRENT SITUATION

This section provides a brief summary of the current environmental situation at Rocky Flats Plant. More detailed discussions are found in the primary documents used as input to this Synopsis: the CEARP Phase I Installation Assessment (DOE 1986b), the RCRA Part B Operating Permit Application (DOE 1986f), the RCRA Post-Closure Care Permit Application (DOE 1986g), and Appendix 1 of the RCRA Part B Operating Permit Application (3004[u] Waste Management Units) (DOE 1986f).

2.1. SITE DESCRIPTION AND BACKGROUND

Rocky Flats Plant is a government-owned, contractor-operated (GOCO) facility. It is part of a nationwide nuclear weapons research, development, and production complex administered by the DOE-Albuquerque Operations Office. Rockwell International is the prime operating contractor for Rocky Flats Plant. Rockwell International has served as the prime contractor since July 1, 1975. Prior to that date, Dow Chemical Company was the prime operating contractor, and served in this capacity from inception of the plant in 1951 until 1975.

2.1.1. Rocky Flats Plant Mission

The primary mission of Rocky Flats Plant is producing metal components for nuclear weapons. The plant is involved in fabricating components from plutonium, uranium, beryllium, and stainless steel. Production activities include metal fabrication, assembly, and chemical recovery and purification of recyclable transuranic radionuclides. Other activities include research and development work in metallurgy, machining, nondestructive testing, coatings, remote operations engineering, chemistry, and physics. Parts made at Rocky Flats Plant are shipped elsewhere for final assembly.

2.1.2. Physical Environs

Plant Location. Rocky Flats Plant is located in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver (Fig. 2.1). The plant covers almost 11 mi^2 (approximately 6550 acres), occupying Sections 1-4 and 9-15 of R.70W.,

T.2S. Major plant structures are located within a fenced security area approximately 400 acres in size surrounded by a buffer zone of approximately 6150 acres. The plant is centered at 105° 11' 30" west longitude and 39° 53' 30" north latitude.

Site Environment and Climate. Rocky Flats Plant is located on an eastward sloping plain of coalescing alluvial fans deposited at the base of the Rocky Mountain Front Range. The gravels of the Rocky Flats Alluvium form a terrace that is dissected by eastward draining perennial and ephemeral streams. This terrace is known locally as Rocky Flats.

Geology beneath the plant site consists of the poorly-sorted Rocky Flats Alluvium, several other alluvial materials in the valleys, and colluvium on the terrace side slopes. Underlying these recent deposits are claystones and sandstones of the Laramie and Arapahoe Formations. Groundwater occurs in the various alluvial deposits as well as in the bedrock claystones and sandstones.

The climate at Rocky Flats Plant is characterized by dry, cool winters with some snow cover, and warm, somewhat moister summers. There is considerable sunshine, and the average precipitation and relative humidity are low. The annual average precipitation for the plant is slightly over 15 inches (water equivalent) with more than 80 per cent falling between the months of April and September. Winds at the plant, although variable, are predominantly westerly, with stronger winds occurring during the winter (RI 1986a).

2.1.3. Current Environmental Status

Rockwell International conducts an extensive environmental surveillance program at Rocky Flats Plant. The local environs are monitored for penetrating radiation and for radioactive, chemical, and biological pollutants. Air, surface water, groundwater, and soil are sampled at the plant and throughout the surrounding region. Results of the Rockwell International surveillance program are summarized in an annual environmental monitoring report in compliance with DOE Order 5484.1.

Several federal, state, and local government agencies independently conduct audits and additional environmental surveys at and adjacent to Rocky Flats Plant. The Colorado Department of Health samples air, soil, and water at the plant and in

surrounding communities. It also operates an onsite, continuous, particulate air sampler for the Jefferson County Health Department. The DOE Environmental Measurements Laboratory conducts particulate air sampling at the plant and periodically performs special studies, including sediment and soil analyses. Other special analyses have been performed by Region VIII of the EPA.

In addition to routine monitoring performed, a comprehensive, phased program of site characterizations, remedial investigations, feasibility studies, and remedial/corrective actions is in progress at Rocky Flats Plant. These CEARP Phase 2 activities are pursuant to the DOE CERCLA Implementation order (DOE 5480.14) and encompass the requirements of the Compliance Agreement (DOE 1986a).

In response to the Compliance Agreement, some CEARP Phase 2 activities were conducted during 1986 in conjunction with RCRA permitting activities. These activities were designed to characterize geology, hydrology, and water quality at Rocky Flats Plant, with the site characterization (remedial investigation) efforts focusing on areas of suspected contamination. These activities included a characterization of groundwater flow and quality in the vicinity of the solar evaporation ponds, preparation of the groundwater monitoring and protection section of the RCRA Part B Operating Permit Application (DOE 1986f), and preparation of closure plans and a RCRA Post-Closure Care Permit Application (DOE 1986g). The initial CEARP Phase 2 site characterization (remedial investigation) activities included geologic mapping of bedrock and surficial materials, sediment, and surface water at various locations on the plant site, and installation of approximately 70 monitoring wells.

2.1.4. CEARP Phase 1 Assessment

The CEARP Phase 1 Installation Assessment Report for Rocky Flats Plant (DOE 1986b) provided documentation for Phase 1 of the DOE CERCLA program (DOE Order 5480.14) and for the following EPA CERCLA preremedial activities: (1) Federal Facility Site Discovery and Identification Findings, (2) Preliminary Assessment, (3) Site Inspection, and (4) Hazard Ranking System evaluation. Sites at Rocky Flats Plant were recommended for no further action when the evaluation indicated (1) negative findings for the CERCLA Federal Facility Site Discovery and Identification Findings process (e.g., potential sites that were found not to exist or spills that

were completely removed through remedial action), or (2) sites initially requiring notification for the Federal Facility Site Discovery and Identification Findings process that were later found to pose no significant threat of release (e.g., potential sites where the hazardous substance initially identified, because of its stability, no longer persists in the environment). Consequently, sites at Rocky Flats Plant that no longer posed a significant threat of release were not included in the EPA Hazard Ranking System and DOE Modified Hazard Ranking System. This procedure is consistent with guidance provided to federal facilities by EPA (*Federal Facility Program Manual for Implementing CERCLA Responsibilities of Federal Agencies, final draft*).

The CEARP Phase 1 Installation Assessment at Rocky Flats Plant included analyses of current operational activities, controlled active and inactive waste sites, current and past waste management practices, and potential environmental pathways through which contaminants could be transported. These findings were then compared with applicable federal, state, and local environmental regulations.

Sites with positive findings for the CERCLA preremedial activities that had sufficient information for EPA Hazard Ranking System evaluation were scored according to the following criteria: (1) for the nonradioactive sites the EPA Hazard Ranking System and (2) for the radioactive sites the EPA Hazard Ranking System and the DOE-Modified Hazard Ranking System. Typically, sites that met EPA criteria to be listed on the National Priorities List were recommended for future action under DOE CERCLA Phase 2, Confirmation.

Sites that did not meet EPA criteria to be listed on the National Priorities List but exceeded other applicable DOE remedial action criteria/guidelines (e.g., guidelines for the DOE Surplus Facilities Management Program) and/or sites posing potential regulatory compliance concerns (e.g., RCRA-related remedial activities) were recommended for future action under CEARP. No further action was recommended for those sites not meeting these criteria.

Sites for which remedial activity had recently occurred or was scheduled were placed into CEARP Phase 4 (Remedial Action), which encompasses requirements of the DOE CERCLA Order (Phase 4) and the remedial implementation program elements of EPA CERCLA (Design and Action). These sites will require CEARP Phase 5 (Compliance and Verification) activities, encompassing the requirements of the DOE

CERCLA Order (Phase 5) and EPA CERCLA final site inspection/closeout and monitoring.

2.2. NATURE AND EXTENT OF THE PROBLEM

CEARP Phase 1 identified three viable environmental pathways (air, surface water, and groundwater) with potential to transport contaminants away from Rocky Flats Plant (DOE 1986b). However, CEARP Phase 1 concluded that the air pathway had been adequately characterized by past activities. Additional characterization of the surface water and groundwater pathways is being performed as part of CEARP Phase 2.

CEARP Phase 1 identified approximately 70 sites or grouping of sites that could potentially have adverse impacts on the environment (DOE 1986b). These sites were prioritized for future activities under CEARP; and these prioritizations were presented in the initial draft CEARP Phase 2 Installation Generic Monitoring Plan for Rocky Flats Plant released to the public in July of 1986.

Additional data were collected during preparation of the RCRA Part B Operating Permit Application that identified several additional potential sites. Therefore, all potential sites at Rocky Flats Plant were designated as solid waste management units assigned a reference number, and located on an aerial photograph base map of the plant site (IGMP/CSPCP Sampling Plan, Plate 1). A list of solid waste management units is presented in Appendix 1 of the RCRA Part B Permit Operating Application (3004[u] Solid Waste Management Units) (DOE 1986f). These solid waste management units are divided into three categories. The first category includes those hazardous waste management units which will continue to operate and which require a RCRA Operating Permit. The second category includes those hazardous waste management units which are being closed under RCRA Interim Status. The third category includes those inactive waste management units (RCRA continuing release sites) that are identified under Section 3004(u) of RCRA. Another class of sites is regulated under CERCLA. These CERCLA areas contain only radioactive wastes (DOE 1986b). However, for ease in referencing these units and/or areas, they have been collectively termed Solid Waste Management Units. Table 2.1 is a listing of all solid waste management units at Rocky Flats Plant with their solid waste management

unit identification numbers and CEARP Phase 1 identification numbers for easy cross reference between the various documents.

2.3. HISTORY OF RESPONSE ACTIONS

A number of remedial actions have occurred at Rocky Flats Plant in response to accidental leaks, spills and releases of hazardous materials. Appendix 1 of the RCRA Part B Operating Permit Application (3004[u] Waste Management Units) (DOE 1986f) provides descriptions of remedial actions to date at the inactive solid waste management units.

2.4. EVALUATION OF EXISTING DATA

This section summarizes existing environmental data for Rocky Flats Plant and presents the current hydrogeochemical conceptual model of the plant. More detailed discussions of regional and site geology, hydrology, water quality, climate, and biota are presented in the RCRA Part B Operating Permit Application (DOE 1986f), the Rocky Flats Plant Final Environmental Impact Statement (RFEIS 1980), the CEARP Phase 1 report (DOE 1986b), the RCRA Post-Closure Care Permit Application (DOE 1986g), the annual monitoring reports, and the Rocky Flats Plant Radioecology and Airborne Pathway Summary Report (RI 1986b). Table 2.2 lists the Hazardous Substances List volatile organics that have been found in groundwater, surface water, and soil/sediments at Rocky Flats Plant.

As part of the CEARP Phase 2b site characterizations (remedial investigations) of Rocky Flats Plant, existing data will be quality controlled and incorporated into the technical data base as appropriate (see IGMP/CSPCP Technical Data Management Plan). These existing data along with data collected during CEARP Phase 2b site characterizations (remedial investigations) will be evaluated using the analytical tools discussed in the IGMP/CSPCP Technical Data Management Plan.

2.4.1. Soils and Geology

2.4.1.1. Soils

Annual soil sampling is conducted at Rocky Flats Plant to characterize distribution of plutonium in soils surrounding the plant. A total of 40 soil samples are collected along two rings surrounding the plant at distances of approximately 1 and 2 mi from the center of the plant. Ten subsamples are collected from each sampling location and composited for plutonium analysis.

Results of this sampling effort are summarized annually in an annual environmental monitoring report. In 1985, plutonium concentrations generally ranged from 0.02 to 1.9 pCi/g inside the plant security area. Plutonium concentrations in the buffer zone, outside the plant security area, ranged from 0.01 to 2.5 pCi/g. The maximum plutonium value measured in 1985 (13 pCi/g) occurred due east of the 903 Pad Area inside the plant security area (RI 1986a).

Soil sampling was conducted at the solar evaporation ponds as part of the initial CEARP Phase 2 site characterization (remedial investigation). A total of 15 core samples were collected from five boreholes in the vicinity of the solar evaporation ponds (wells 18-86, 20-86, 22-86, 25-86, and 27-86). Each core sample was analyzed for Hazardous Substances List metals, Hazardous Substances List organics, and radionuclides. Based on these data, elevated concentrations of strontium, 1,1-dichloroethane, 1,1,1-trichloroethane and tritium occur in the alluvium and weathered bedrock around the solar evaporation ponds. None of these parameters were elevated in borehole 18-86 (IGMP/CSPCP Sampling Plan, Plate 2) suggesting the impacts of the solar evaporation ponds on subsurface materials is limited to the immediate vicinity of the ponds (DOE 1986f).

2.4.1.2. Geology

Rocky Flats Plant is located on the northwestern flank of the Denver Basin and is underlain by several thousand feet of Paleozoic and Mesozoic sedimentary rocks. Bedrock immediately beneath the plant consists of the Cretaceous Laramie and

Arapahoe Formations, which are composed primarily of fluvial claystones with interbedded lenticular sandstones and siltstones. These formations strike generally north-south and dips vary from 5 to 50 degrees east.

Surficial materials overlying the bedrock formations consist of the Quaternary Rocky Flats Alluvium, several Quaternary alluviums in the valleys, and colluvium. The Rocky Flats Alluvium forms a flat terrace upon which the plant is located. It is a poorly sorted deposit of granitic sand, gravel, cobbles and boulders, which is locally cemented with calcium carbonate. Although the thickness of the Rocky Flats alluvium varies, it is thickest west of the plant (up to 100 feet) and thinnest at the eastern edge of the plant (about 7 feet). Various other alluvial deposits and colluvium occur in the onsite drainages. These materials are primarily composed of reworked Rocky Flats Alluvium with the addition of some bedrock materials.

2.4.1.3. Wastes

As required by the Compliance Agreement, an active waste stream characterization program is in progress as part of RCRA permitting activities at Rocky Flats Plant. This program consists of active waste stream identification, sampling, and analysis. The waste stream identification survey consisted of reviewing each manufacturing process and identifying each waste stream generated by that process. Based on the waste surveys, waste stream sampling and analysis plans were developed. Actual waste stream sampling and confirmation of identified waste streams is currently in progress.

As previously stated, a list of solid waste management units is presented in Appendix 1 of the RCRA Part B Permit Operating Application (3004[u] Solid Waste Management Units) (DOE 1986f).

2.4.2. Groundwater

2.4.2.1. Hydrology

There are two hydraulically connected groundwater systems at Rocky Flats Plant. These occur in the Rocky Flats Alluvium and other surficial materials, and in the bedrock (primarily in the claystones and sandstones of the Arapahoe Formation).

There is a strong downward gradient between the shallow and bedrock flow systems (DOE 1986f).

The shallow groundwater system, in the Rocky Flats Alluvium and other surficial materials, occurs under unconfined conditions. The shallow system is recharged by infiltration of incident precipitation, irrigation, and surface water diversion canals. Shallow groundwater flow generally follows topography to the east and toward the drainages. The system discharges to springs and seeps at the alluvium/bedrock contact and into the drainages. The shallow groundwater system appears to be quite dynamic as large water level fluctuations occur in response to seasonal and other stresses (DOE 1986f).

Most of the groundwater flow in the Arapahoe Formation occurs in the lenticular sandstone bodies contained within the claystones. Recharge to the sandstones occurs at areas of direct contact with alluvium or valley fill (subcrop areas) or by leakage through claystones in contact with alluvium. Groundwater in the sandstones flows to the east toward the point of regional discharge along the South Platte River (DOE 1986f).

2.4.2.2. Quality

Groundwater quality data available to date consist of

- analytical data from monitoring of groundwater and surface water conducted by the plant beginning in 1961,
- results of an electromagnetic survey performed in 1985,
- results of a soil gas survey performed in 1986, and
- results from the initial CEARP Phase 2 site characterization (remedial investigation) conducted in 1986.

Groundwater conditions at the plant have been monitored since 1961, and chemical data exist from monitoring over the past ten years. As part of the initial CEARP Phase 2 site characterization (remedial investigation), approximately 70 new monitor wells were installed around the plant site, and initial sampling of these wells was performed. Results of this sampling effort and historical groundwater quality

data are presented in detail in Section E of the RCRA Part B Operating Permit Application (DOE 1986f).

Based on the initial CEARP Phase 2 site characterizations (remedial investigations) background alluvial groundwater quality is characterized by low total dissolved solids and variable radionuclides and Hazardous Substances List metal concentrations (DOE 1986f).

Alluvial groundwater quality downgradient of various inactive waste management units is discussed by unit in Section E of the RCRA Part B Operating Permit Application. Downgradient water quality is characterized by elevated Hazardous Substances List volatile organics, radionuclide concentrations, and total dissolved solids. However, groundwater contaminants appear to be relatively close to their sources. No Hazardous Substances List volatile organics were detected, and radionuclide concentrations were similar to background values in groundwater at the downgradient plant boundary (Indiana Street) (DOE 1986f).

2.4.3. Surface Water

2.4.3.1. Hydrology

Three intermittent streams drain the plant site flowing generally from west to east. Rock Creek drains the northwestern corner and flows to the northeast toward its offsite confluence with Coal Creek. Woman Creek drains the southern portion of the plant and flows eastward to Standley Lake. North and South Walnut Creeks and an unnamed tributary drain the remainder of the site. The three forks of Walnut Creek join in the buffer zone (approximately 0.7 miles downstream of the eastern edge of the plant security fence) and flow to Great Western Reservoir approximately one mile east of the confluence. A series of dams, retention ponds, diversion structures and ditches have been constructed at the plant to control runoff from plant operations (DOE 1986f).

2.4.3.2. Quality

Surface water quality is characterized in Section E of the RCRA Part B Operating Permit based on a one-time sampling event conducted during the initial CEARP

Phase 2 site characterization (remedial investigation) performed in 1986 and NPDES monitoring. Many of the surface water monitoring stations were dry during the 1986 sampling (August and September 1986). In general, Hazardous Substances List organics were not detected, and major ion concentrations were low. Radionuclide concentrations were slightly elevated at downstream sampling locations, and metals such as strontium, manganese, molybdenum, zinc, and nickel were slightly elevated at select sampling locations. At the downstream (eastern) plant boundary (Indiana Street), Hazardous Substances List organics were not detected and radionuclides were within background concentrations (DOE 1986f). Surface water discharged from retention ponds is monitored regularly at the downstream boundary and other locations to document compliance with NPDES permit requirements.

2.4.4. Biota

2.4.4.1. Vegetation

A variety of vegetation exists at Rocky Flats Plant. Species of flora representing the tall grass prairies, the short grass plains, the lower montane, and the foothill ravine regions are found. Eurasian weeds that have been introduced to the area make up a significant portion of the vegetative cover, indicating that human-induced activities, primarily overgrazing by cattle, have radically altered the vegetative cover. Lands within the original 2520 acre site boundary have not been grazed since 1951, and lands within the buffer zone have not been grazed since their acquisition in 1975. The presence of grasses such as big bluestem and side-oats gramma within the protected areas indicate that vegetation is recovering from previous overgrazing.

2.4.4.2. Wildlife

Animals associated with the western prairie regions of the U.S are found in the undeveloped areas of Rocky Flats Plant. No rare or endangered species have been reported or found among the wildlife inhabiting or migrating through the area (RFEIS 1980).

2.4.5. Air

The elevation of Rocky Flats Plant and the slopes of the Front Range mountains are the primary influences on the semi-arid climate found at the plant. Winds, although variable, are predominantly westerly with stronger winds occurring in the winter. The 24-year average (1952 to 1976) for mean wind velocity was 8.24 miles per hour. Temperature extremes recorded at the plant have ranged from 102°F on July 12, 1971 to -26°F on January 12, 1963. The 24-year average maximum temperature was 76°F, the average minimum was 22°F, and the average annual mean was 49.6^{o}F. The average annual precipitation is slightly over 15 inches, and the 24-year average relative humidity was 46% (RFEIS 1980).

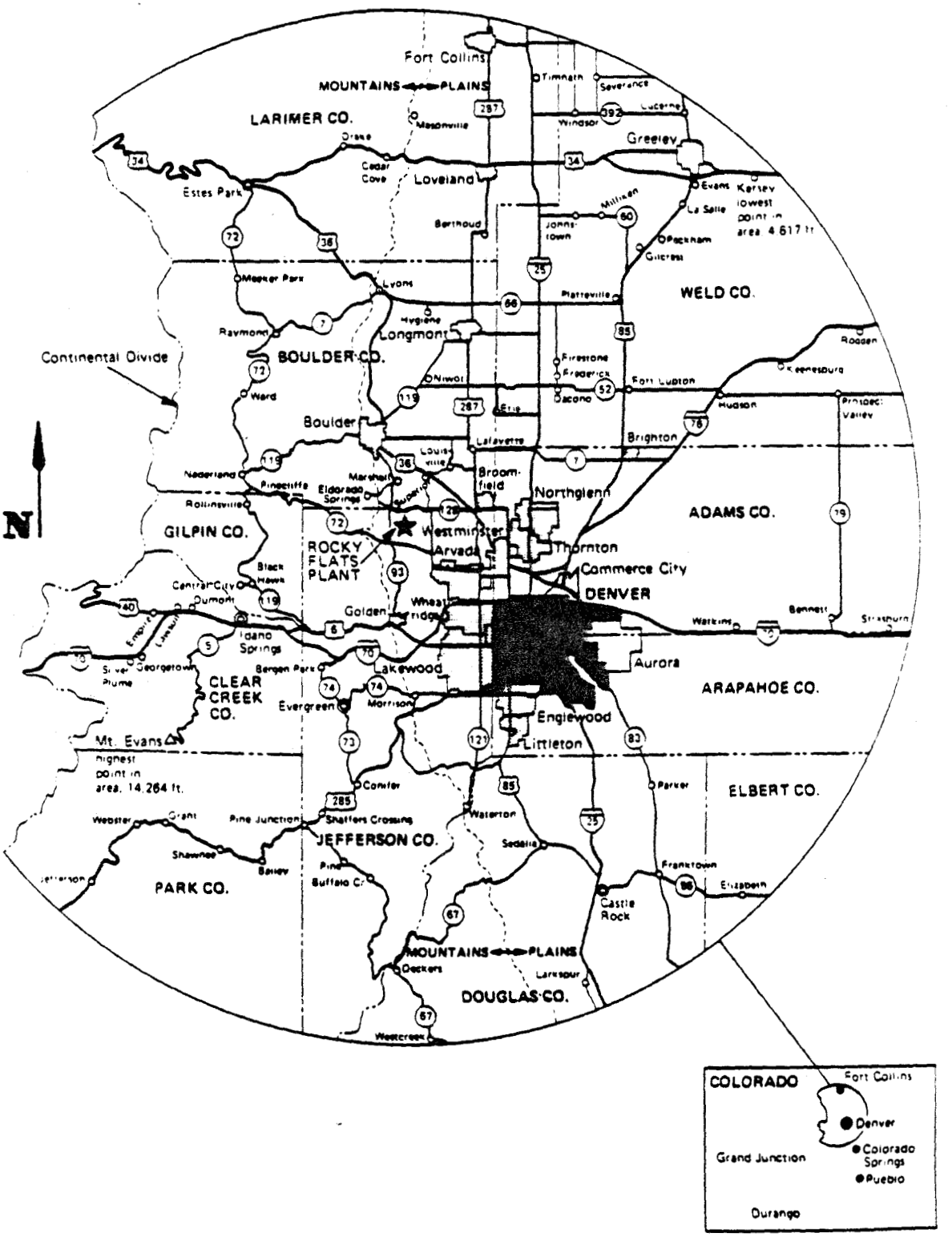

Figure 2.1. General Location of the Rocky Flats Plant.

Table 2.1. Solid Waste Management Units (SWMUs) at Rocky Flats Plant

SWMU Reference Number	SWMU Designation[a]	CEARP Phase 1 Reference Number[b]	Current CEARP Phase[c]	Prioritization Category[d]
101	207 Solar Evaporation Ponds	V.A.3.h	2	1
102	Oil Sludge Pit	V.A.4.e	2	2
103	Chemical Burial	V.A.4.m	1	2
104	Liquid Dumping	V.A.4.l	1	2
105	Out-of-Service Fuel Tanks	V.A.4.o	1	2
	105.1: Westernmost Tank			
	105.2: Easternmost Tank			
106	Outfall	V.A.4.n	1	2
107	Hillside Oil Leak	V.A.4.c	1	2
108	Trench T-1	V.A.3.d	2	3
109	Trench T-2	V.A.3.e	2	3
110	Trench T-3	V.A.3.f	2	3
111	Trenches T-4 to T-11	V.A.3.g	2	3
	111.1: Trench T-4			
	111.2: Trench T-5			
	111.3: Trench T-6			
	111.4: Trench T-7			
	111.5: Trench T-8			
	111.6: Trench T-9			
	111.7: Trench T-10			
	111.8: Trench T-11			
112	903 Drum Storage Area	V.A.3.k	2	4
113	Mound Area	V.A.3.l	1	4
114	Present Landfill	V.A.3.c	2	5
115	Original Landfill	V.A.3.b	2	5

Table 2.1. (Continued)

SWMU Reference Number	SWMU Designation[a]	CEARP Phase 1 Reference Number[b]	Current CEARP Phase[c]	Prioritization Category[d]
116	Multiple Solvent Spills	V.A.4.v	1	6
	116.1: West Loading Dock Area			
	116.2: South Loading Dock Area			
117	Chemical Storage	V.A.4.j	1	6
	117.1: North Site			
	117.2: Middle Site			
	117.3: South Site			
118	Multiple Solvent Spills	V.A.4.w	1	6
	118.1: West of Building 730			
	118.2: South End of Building 776			
119	Multiple Solvent Spills	V.A.4.x	1	6
	119.1: West Area			
	119.2: East Area			
120	Fiberglassing Areas	V.A.4.k	1	7
	120.1: North of Building 664			
	120.2: West of Building 664			
121	Original Process Waste Lines	V.A.3.a	1	8
122	Underground Concrete Tank	V.A.3.dd	1	8
123	Valve Vault 7	V.A.3.q	1	8
	123.1: Valve Vault 7			
	123.2: Valve Vault West of Building 707			
124	Radact Lqd Waste Storage Tanks	V.A.3.o	1	8
	124.1: 30,000 Gallon Tank (#68)			
	124.2: 14,000 Gallon Tank (#66)			
	124.3: 14,000 Gallon Tank (#67)			
125	Holding Tank	V.A.3.p	1	8
126	Out-of-Service Process Waste Tanks	V.A.3.m	1	8
	126.1: Westernmost Tank			
	126.2: Easternmost Tank			
127	Low-Level Radioactive Waste Leak	V.A.3.v	1	9

Table 2.1. (Continued)

SWMU Reference Number	SWMU Designation[a]	CEARP Phase 1 Reference Number[b]	Current CEARP Phase[c]	Prioritization Category[d]
128	Oil Burn Pit No. 1	V.A.3.y	1	10
129	Oil Leak	V.A.4.d	1	10
130	Radioactive Site - 800 Area Site #1	V.A.2.f	2	11
131	Radioactive Site - 700 Area Site #1	V.A.2.e	1[g]	12
132	Radioactive Site - 700 Area Site #4	V.A.2.e	1	12
133	Ash Pits	V.A.3.w	1	13
	133.1: Ash Pit I-1			
	133.2: Ash Pit I-2			
	133.3: Ash Pit I-3			
	133.4: Ash Pit I-4			
	133.5: Incinerator			
	133.6: Concrete Wash Pad			
134	Lithium Metal Destruction Site	V.A.4.h	2	13
135	Cooling Tower Blowdown	V.A.4.a	1	13
136	Cooling Tower Ponds	V.A.3.j	1	13
	136.1: Northeast Corner of Building 460			
	136.2: West of Building 460			
	136.3: South of Bldg 460, West of Bldg 444			
137	Cooling Tower Blowdown - Bldg 774	V.A.4.b	1	13
138	Cooling Tower Blowdown - Bldg 779	V.A.4.b	1	13
139	Caustic/Acid Spills	V.A.4.s	1	13
	139.1: Hydroxide Tank Area			
	139.2: Hydrofluoric Acid Tanks			
140	Reactive Metal Destruction Site	V.A.4.i	1	13
141	Sludge Dispersal	V.A.3.aa	1	13

Table 2.1. (Continued)

SWMU Reference Number	SWMU Designation[a]	CEARP Phase 1 Reference Number[b]	Current CEARP Phase[c]	Prioritization Category[d]
142	Retention Ponds (A,B,C-Series)	V.A.3.i	1	14
	142.1: A-1 Pond			
	142.2: A-2 Pond			
	142.3: A-3 Pond			
	142.4: A-4 Pond			
	142.5: B-1 Pond			
	142.6: B-2 Pond			
	142.7: B-3 Pond			
	142.8: B-4 Pond			
	142.9: B-5 Pond			
	142.10: C-1 Pond			
	142.11: C-2 Pond			
143	Old Outfall	V.A.3.x	1	17
144	Sewer Line Break	V.A.3.r	1	14
145	Sanitary Waste Line Leak	V.A.3.cc	1	14
146	Concrete Process Waste Tanks	V.A.3.n	5[e]	15
	146.1: 7,500 Gallon Tank (#31)			
	146.2: 7,500 Gallon Tank (#32)			
	146.3: 7,500 Gallon Tank (#34W)			
	146.4: 7,500 Gallon Tank (#34E)			
	146.5: 3,750 Gallon Tank (#30)			
	146.6: 3,750 Gallon Tank (#33)			
147	Process Waste Leaks	V.A.3.t	5[e]	15
	147.1: Maas Area			
	147.2: Owen Area			
148	Waste Spills	V.A.3.bb	5[e]	15
149	Effluent Pipe	V.A.3.u	5[e]	15

Table 2.1. (Continued)

SWMU Reference Number	SWMU Designation[a]	CEARP Phase 1 Reference Number[b]	Current CEARP Phase[c]	Prioritization Category[d]
150	Radioactive Liquid Leaks (8)	V.A.3.a	5[e]	15
	150.1: North of Building 771			
	150.2: West of Building 771			
	150.3: Between Buildings 771 and 774			
	150.4: East of Building 750			
	150.5: West of Building 707			
	150.6: South of Building 779			
	150.7: South of Building 776			
	150.8: Northeast of Building 779			
151	Fuel Oil Leak	V.A.4.f	5[e]	15
152	Fuel Oil Tank	V.A.4.g	5[e]	15
153	Oil Burn Pit No. 2	V.A.3.z	5[e]	15
154	Pallet Burn Site	V.A.3.ee	5[e]	15
155	903 Lip Area	V.A.2.g	4	15
156	Radioactive Soil Burial	V.A.2.a	5[e,g]	15
	156.1: Building 334 Parking Lot			
	156.2: Soil Dump Area			
157	Radioactive Site	V.A.2.b	5[e]	15
	157.1: North Area			
	157.2: South Area			
158	Radioactive Site - Bldg 551	V.A.2.c	5[e]	15
159	Radioactive Site - Bldg 559	V.A.2.c	5[e]	15
160	Radioactive Site - Bldg 444 Parking Lot	V.A.2.d	5[e,g]	15
161	Radioactive Site - Bldg 664	V.A.2.d	5[e,g]	15
162	Radioactive Site - 700 Area Site #2	V.A.2.e	5[e,g]	15
163	Radioactive Site - 700 Area Site #3	V.A.2.e	5[e]	15
	163.1: Wash Area			
	163.2: Buried Slab			

Table 2.1. (Continued)

SWMU Reference Number	SWMU Designation[a]	CEARP Phase 1 Reference Number[b]	Current CEARP Phase[c]	Prioritization Category[d]
164	Radioactive Site - 800 Area Site #2	V.A.2.f	5[e,g]	15
	164.1: Concrete Slab			
	164.2: Building 886 Spills			
	164.3: Building 889 Storage Pad			
165	Triangle Area	V.A.2.h	5[e]	15
166	Trenches	6*		
	166.1: Trench A			
	166.2: Trench B			
	166.3: Trench C			
167	Spray Fields - Three Sites	6*		
	167.1: North Area			
	167.2: Pond Area			
	167.3: South Area			
168	West Spray Field			
169	Waste Drum Peroxide Burial	7*		
170	P.U.&D Storage Yard - Waste Spills	7*		
171	Solvent Burning Ground	7*		
172	Central Avenue Waste Spill	7*		
173	Radioactive Site - 900 Area	7*		
174	P.U.&D. Container Storage Facilities (2)	7*		
175	S&W Bldg 980 Container Storage Facility	7*		
176	S&W Contractor Storage Yard	7*		
177	Building 885 Drum Storage Area	7*		
178	Building 881 Drum Storage Area	7*		
179	Building 865 Drum Storage Area	7*		

Table 2.1. (Continued)

SWMU Reference Number	SWMU Designation[a]	CEARP Phase 1 Reference Number[b]	Current CEARP Phase[c]	Prioritization Category[d]
180	Building 883 Drum Storage Area	7*		
181	Building 334 Cargo Container Area	7*		
182	Building 444/453 Drum Storage Area	7*		
183	Gas Detoxification Area	7*		
184	Building 991 Steam Cleaning Area	7*		
185	Solvent Spill	7*		
186	Valve Vault 12	7*		
187	Acid Leaks (2)	V.A.4.p	NFA[f]	
188	Acid Leak	V.A.4.q	NFA[f]	
189	Multiple Acid Spills	V.A.4.r	NFA[f]	
190	Caustic Leak	V.A.4.t	NFA[f]	
191	Hydrogen Peroxide Spill	V.A.4.u	NFA[f]	
192	Antifreeze Discharge	V.A.4.y	NFA[f]	
193	Steam Condensate Leak	V.A.4.z	NFA[f]	
194	Steam Condensate Leak	V.A.4.aa	NFA[f]	
195	Nickel Carbonyl Disposal	V.A.4.bb	NFA[f]	
196	Water Treatment Plant Backwash Pond	V.A.4.cc	NFA[f]	
197	Scrap Metal Sties	V.A.4.dd	NFA[f]	
198	VOCs in Groundwater	9* V.A.4.ee	2	
199	Contamination of the Land's Surface	10* V.A.5.a	5[e]	

Table 2.1. (Continued)

SWMU Reference Number	SWMU Designation[a]	CEARP Phase 1 Reference Number[b]	Current CEARP Phase[c]	Prioritization Category[d]
200	Great Western Reservoir	10* V.A.5.b	5[e]	
201	Standley Reservoir	10* V.A.5.c	5[e]	
202	Mower Reservoir	10* V.A.5.d	5[e]	

[a]Solid Waste Management unit designations used in the CEARP Phase 1 report, except for sites identified since its issuance. Some sites have been split into more than one area for purposes of assessment.

[b]Section number where the unit is discussed in the CEARP Phase 1 report.

[c]Phase of CEARP a solid waste management unit is currently in. Ultimately, each unit will be taken through CEARP Phase 5, or evaluated as needing no further action.

[d]From the preliminary prioritization of sites (DOE 1986h).

[e]Sites in this category only require compliance and verification as indicated in the CEARP Phase 1 report.

[f]No further action required as indicated in the CEARP Phase 1 report.

[g]CERCLA regulated area.

6* - Identified on aerial photographs. Further evaluation is required.

7* - Not previously identified. Further evaluation is required.

9* - Volatile organic compounds in groundwater are not a discernible unit.

10* - These are offsite locations that have received radioactive material from the plant. Radioactivity levels are below proposed EPA screening levels derived from proposed EPA dose limits for transuranium element in soil in uncontrolled areas.

Table 2.2. Volatile organic HSL Compounds Found in Groundwater, Surface Water, and Soils at the Rocky Flats Plant*

Compound	Groundwater	Surface Water	Soils/Sediments
Vinyl Chloride	X	X	
Methylene Chloride	X	X	X
Acetone	X	X	X
Carbon Disulfide	X	X	X
1,1-Dichloroethylene	X		
1,1-Dichloroethane	X		X
trans-1,2-Dichloroethylene	X	X	X
Chloroform	X	X	
1,2-Dichloroethane	X		
2-Butanone	X	X	X
1,1,1-Trichloroethane	X	X	X
Carbon Tetrachloride	X	X	
Trichloroethylene	X	X	X
1,1,2-Trichloroethane	X	X	
4-Methyl-2-pentanone		X	
Tetrachloroethylene	X		
Toluene	X		
Total Xylenes		X	

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*Some of these compounds may be attributed to laboratory contamination (DOE 1986f).

3. POSSIBLE REMEDIAL ALTERNATIVES

The integrated approach used for monitoring (see the Synopsis, Section 5.2) stresses the need for interaction between sampling plans and consideration of alternative remedial actions. Complete definition of alternative remedial actions requires site-specific data and will be accomplished on a site-specific basis; however, plausible remedial actions have been used to guide the development of the IGMP/CSPCP Sampling Plan. Alternative remedial actions that have been considered (Table 3.1) are detailed in the IGMP/CSPCP Feasibility Study Plan. Table 3.2 lists remedial technologies, Table 3.3 lists site characteristics that may affect the selection of remedial technologies, and Table 3.4 lists waste characteristics that may affect the selection of remedial technologies.

Table 3.1. General Response Actions and Associated Remedial Technologies

General Response Action	Typical Technologies
No Action	Some monitoring and analyses may be performed
Containment	Capping, groundwater containment barrier walls, bulkheads, gas barriers
Pumping	Groundwater pumping, liquid removal, dredging
Collection	Sedimentation basins, French drains, gas vents, gas collection systems
Diversion	Grading, dikes and berms, stream diversion ditches, trenches, terraces and benches, chutes and downpipes, levees, seepage basins
Complete Removal	Tanks, drums, soils, sediments, liquid wastes, contaminated structures, sewers and water pipes
Partial Removal	Tanks, drums, soils, sediments, liquid wastes
Onsite treatment	Incineration, solidification, land treatment, biological, chemical, and physical treatment
Offsite Treatment	Incineration, biological, chemical, and physical treatment
In Situ Treatment	Permeable treatment beds, bioreclamation, soil flushing, neutralization, land farming
Storage	Temporary storage structures
Onsite Disposal	Landfills, land application
Offsite Disposal	Landfills, surface impoundments, land application
Alternative Water Supply	Cisterns, above-ground tanks, deeper or upgradient wells, municipal water system, relocation of intake structure, individual treatment devices
Relocation	Relocate residents temporarily or permanently

Source: EPA 1985a

Table 3.2. Remedial Technologies

A. Air Pollution Controls
--Capping:
- Synthetic membranes
- Clay
- Asphalt
- Multimedia cap
- Concrete
- Chemical sealants/stabilizers
--Dust Control Measures:
- Chemical fixatives
- Water

B. Surface Water Controls
--Capping (see A)
--Grading:
- Scarification
- Tracking
- Contour furrowing
--Revegetation:
- Grasses
- Legumes
- Shrubs
- Forbs
- Trees
--Diversion and Collection Systems:
- Dikes and berms
- Ditches and trenches
- Terraces and benches
- Chutes and downpipes
- Seepage basins
- Sedimentation basins and ponds
- Levees
- Addition of freeboard
- Floodwalls

C. Leachate and Groundwater Controls
--Capping (see A)
--Containment Barriers:
Function Options:
- Downgradient placement
- Upgradient placement
- Circumferential placement
Material and Construction Options (vertical barriers):
- Soil-bentonite slurry wall
- Cement-bentonite slurry wall
- Vibrating beam
- Grout curtains
- Steel sheet piling

Source: EPA 1985a

Table 3.2. (Continued)

Horizontal Barriers (bottom sealing):
- Block displacement
- Grout injection
- Liners

--Groundwater Pumping (generally used with capping and treatment):

Function Options:
- Extraction and injection
- Extraction alone
- Injection alone

Equipment and Material Options:
- Well points
- Deep wells
- Suction wells
- Ejector wells

--Subsurface Collection Drains:
- French drains
- Tile drains
- Pipe drains (dual media drains)

D. Gas Migration Controls (generally used with treatment)

--Capping (gas barriers) (see A)

--Gas Collection and/or Recovery:
- Passive pipe vents
- Passive trench vents
- Active gas collection systems

E. Excavation and Removal of Waste and Soil

--Excavation and Removal:
- Backhoe
- Cranes and attachments
- Front-end loaders
- Scrapers
- Pumps
- Industrial vacuums
- Drum grapplers
- Forklifts and attachments

--Grading (see B)

--Capping (see A)

--Revegetation (see B)

F. Removal and Containment of Contaminated Sediments

--Sediment Removal:

Mechanical Dredging:
- Clamshell
- Dragline
- Backhoe

Hydraulic Dredging:
- Plain suction
- Cutterhead
- Dustpan

Table 3.2. (Continued)

Pneumatic Dredging:
- Airlift
- Pneuma
- Oozer

--Sediment Turbidity Controls and Containment:
- Curtain barriers
- Coffer dams
- Pneumatic barriers
- Capping

G. In Situ Treatment
--Chemical Treatment
--Soil Aeration
--Solvent Flushing
--Bioreclamation
--Permeable Treatment Beds

H. Direct Waste Treatment
--Incineration:
- Rotary kiln
- Fluidized bed
- Multiple hearth
- Liquid injection
- Molten salt
- High temperature fluid wall
- Plasma arc pyrolysis
- Cement kiln
- Pyrolysis/starved combustion
- Wet air oxidation
- Industrial boiler or furnace

--Gaseous Waste Treatment:
- Activated carbon
- Flares
- Afterburners

--Treatment of Aqueous and Liquid Waste Streams:
Biological Treatment:
- Activated sludge
- Trickling filters
- Aerated lagoons
- Waste stabilization ponds
- Rotating biological disks
- Fluidized bed bioreactors

Chemical Treatment:
- Neutralization
- Precipitation
- Oxidation
- Hydrolysis
- Reduction
- Chemical dechlorination
- Ultraviolet/ozonation

Table 3.2. (Continued)

Physical Treatment:
- Flow equalization
- Flocculation
- Sedimentation
- Activated carbon
- Kleensorb
- Ion exchange
- Reverse osmosis
- Liquid-liquid extraction
- Oil-water separator
- Steam distillation
- Air stripping
- Steam stripping
- Filtration
- Dissolved air flotation

Discharge to Publicly Owned Treatment Works

--Handling and Treatment of Solids:

Dewatering:
- Screens, hydraulic classifiers, scalpers
- Centrifuges
- Gravity thickening
- Flocculation, sedimentation
- Belt filter presses
- Drying or dewatering beds
- Vacuum-assisted drying beds

Treatment:
- Neutralization
- Solvent
- Oxidation
- Reduction
- Composting

--Solidification, Stabilization, or Fixation:
- Cement-based
- Lime-based
- Thermoplastic
- Organic polymer
- Self-cementing techniques
- Surface encapsulation
- Gassification
- Solidification (i.e., to fly ash, polymers, sawdust)

I. Land Disposal Storage

--Landfills
--Surface Impoundments
--Land Application
--Waste Piles
--Deep Well Injection
--Temporary Storage

Table 3.2. (Continued)

J. Contaminated Water Supplies and Sewer Lines
--In situ Cleaning
--Removal and Replacement
--Alternative Drinking Water Supplies:
- Cisterns or tanks
- Deeper or upgradient wells
- Municipal water systems
- Relocation of intake

--Individual Treatment Units

Table 3.3. Site Characteristics That May Affect Selection of Remedial Technology

Waste volume and areal extent
Site Area
Site configuration
Climate (precipitation, temperature, and evaporation)
Topography
Soil texture and permeability
Soil moisture
Surface drainage
Site geology
Land use
Vegetation
Thickness of unsaturated zone
Depth to groundwater
Depth to bedrock
Depth to aquicludes
Degree of contamination of unsaturated zone, surface water, and groundwater
Direction and rate of groundwater flow
Receptors/discharge areas
Water use
Surface water
Ecological areas
Risk Assessment

Table 3.4. Waste Characteristics That May Affect Selection of Remedial Technology

Quantity/concentration
Chemical composition
Acute toxicity
Persistence
Biodegradability
Radioactivity
Ignitability
Reactivity/corrosivity
Infectiousness
Solubility
Volatility
Density
Partition coefficient
Compatibility with other chemicals
Treatability

4. DATA REQUIREMENTS

The acquisition of environmental data at Rocky Flats Plant for CEARP will support various decisions:

- CEARP Phase 1: Whether a CEARP Phase 2 site characterization (remedial investigation) is necessary or if the "no further action" alternative is appropriate.

- CEARP Phase 2: Whether a CEARP Phase 3 technological assessment (feasibility study) is necessary or if the "no further action" alternative is appropriate.

- CEARP Phase 3: Selection of an appropriate remedial technology and remedial action, if necessary.

- CEARP Phase 4: At what point the remedial action can be considered complete.

- CEARP Phase 5: Whether the site is in compliance with the CERCLA Implementation Order (DOE 5480.14), whether remedial action has been effective, and what long-term monitoring may be required.

Data needs will be identified, revised, and satisfied in a staged manner in accordance with the integrated approach (IGMP/CSPCP Synopsis, Section 5.2) being used by CEARP. Waste sites that have similar characteristics (i.e., trenches) will be grouped as appropriate. This leads to a more effective investigation by eliminating inappropriate and wasteful methodology.

Detailed site characterization (remedial investigation) may be conducted first at a priority or representative site chosen from within each group. The characterization (investigation) of representative sites will yield data that may lead to a revised sampling plan for other sites within groups, and may eliminate certain pathways from consideration and/or restrict the sampling methods required for site characterization (remedial investigation).

One goal of CEARP is to define boundary conditions that identify the physical areas for site investigations. Boundary conditions are established by properties of physical systems (e.g., air, soil, water) or mechanisms, which control the movement of hazardous substances away from their source. Boundary condition needs already identified at Rocky Flats Plant include

- the vertical and horizontal extent of subcropping Arapahoe sandstones,
- seasonal flow and quality changes of surface seeps, and
- sorptive properties of geologic materials.

4.1. DATA NEEDS

General data needs are identified here for CEARP Phase 2 site characterizations (remedial investigations). These data needs address the installation-wide source and plume characterization efforts and generic site-specific needs, as appropriate. The detailed site-specific data needs will be addressed in the individual SSMPs. The installation-wide data needs presented here are divided on the basis of specific media or potential pathways (e.g., hydrogeochemical, air, soils/wastes, biota, surface water, and climatological).

Identification of data needs is the starting point for sampling plan design. As part of the CEARP Phase 2 site characterizations (remedial investigations), the hydrogeochemical setting will be evaluated. This evaluation will help refine the conceptual model of contaminant migration at Rocky Flats Plant by identifying data gaps.

4.1.1. Soils and Geology

This section discusses data needs for soils and for wastes that are part of the soil matrix. Geotechnical data for soils, needed to support consideration of remedial alternatives, are also discussed.

4.1.1.1. Soils

Visual soil descriptions will be completed during soil sampling and installation of monitoring wells. Qualitative screening of soil samples for organics will facilitate the choice of soil samples for laboratory analysis.

4.1.1.2. Wastes

Waste site locations are known in a general manner. Additional data are needed to confirm specific locations and the extent of the waste sites. Geophysical

surveys will be used to delineate subsurface boundaries and to locate buried objects. The geophysical data will be used along with land surveys to describe the waste sites. The geophysical surveys will be followed by selective sampling of the waste sites to confirm the characteristics and extent of the wastes.

4.1.1.3. Geotechnical

Additional geotechnical data may be required to aid in selecting alternative remedial actions. Evaluation of geotechnical data will proceed parallel to a staged investigation at Rocky Flats Plant. An alternative remedial actions become more definite, data needs will be refined and the existing data base will be re-evaluated against these needs. Analyses of soil samples for geotechnical properties are anticipated, including tests such as grain-size distribution and laboratory permeability, to support hydrogeochemical characterization of Rocky Flats Plant. These data needs will be refined after the initial site-specific sampling has been completed and evaluated.

4.1.2. Groundwater

4.1.2.1. Climatology

Climatological data will be used as input to the conceptual model of the hydrogeochemical setting. Climatological data have been collected at the site, over a considerable time span, by Rocky Flats Plant personnel. Therefore, additional climatological data needs are not anticipated.

4.1.2.2. Saturated Zone

The extent of the alluvial groundwater system is reasonably well defined; however, data are needed to additionally characterize the nature and extent of the bedrock groundwater system. The needed data include

- sufficient water level measurements to prepare a potentiometric map for the bedrock system, if possible, including temporal changes,
- water-quality data to confirm the presence or absence of contaminants in the bedrock system,

- stratigraphic information to describe the lower boundary and areal extent of the bedrock system, and

- hydraulic conductivity data to characterize the bedrock system.

4.1.2.3. Vadose Zone

Data may be needed for the vadose (unsaturated) zone above the water table. These needs may include characterization of the hydraulic properties and water quality in the vadose zone, as discussed for soils/wastes, but at depths below surficial soils.

4.1.3. Surface Water

Surface water at Rocky Flats Plant is hydraulically connected to groundwater. Seasonal data on surface water quality and flow are needed to complete the hydrogeochemical characterization of Rocky Flats Plant.

4.1.4. Biota

Additional sampling of biota is not anticipated. As documented by the Rocky Flats Plant Environmental Impact Statement, the potential for significant human exposure through the foodchain is very low (RFEIS 1980, RF 1986b). However, biological data needs will be re-evaluated based on the results of the hydrogeochemical characterization.

4.1.5. Air

Data collected at Rocky Flats Plant indicate that the potential for significant human exposure to radioactive and nonradioactive airborne emissions from the plant site is low. All perimeter and community ambient air samplers have recorded mean annual plutonium concentrations at less than 0.4% of the Derived Concentration Guide (based on the DOE interim standard dose limit for all pathways of 0.1 rem/yr for a 50-yr committed effective dose equivalent) (RI 1986a). This level is indistinguishable from fallout. Volatile organic compounds have not been detected in the ambient air using photoionization detectors at sites known to contain high concentrations of volatile solvents. The CEARP Phase 1 report did not designate any sites for

characterization of air quality in CEARP Phase 2. Thus, additional characterization of the air pathway beyond that required for the annual environmental monitoring program is not anticipated. Data collected during health and safety monitoring will be used to confirm that sampling activities are not causing air pollution. These data will be incorporated into CEARP documentation as appropriate.

5. CEARP PHASE 2 - IMPLEMENTATION

CEARP Phase 2b will be implemented at Rocky Flats Plant using the integrated approach outlined by this IGMP/CSPCP. CEARP Phase 2b site characterizations (remedial investigations) will be conducted in staged, iterative steps. Data collection and analysis will be coupled with possible alternative remedial actions to drive the sampling program and allow modification of the site characterization (remedial investigation) activities as appropriate.

5.1. IMPLEMENTATION RESPONSIBILITIES

Los Alamos National Laboratory has the primary responsibility to implement CEARP under the guidance of DOE-Albuquerque Operations Office. However, operational responsibilities have been assigned to Rockwell International at Rocky Flats Plant for the site characterizations (remedial investigations). The DOE-Rocky Flats Plant Area Office is responsible for the function of the Rocky Flats Plant. Because of this responsibility, the DOE-Rocky Flats Plant Area Office will provide additional guidance to its contractor, Rockwell International, in implementation of the CEARP Phase 2b site characterizations (remedial investigations).

5.2. INTEGRATED APPROACH

CEARP Phase 2b site characterizations (remedial investigations) at Rocky Flats Plant will be conducted using an integrated approach. This approach breaks site characterization (remedial investigation) activities into stages, in which the results from previous stages of sampling are used to refine the conceptual model used to design successive stages of sampling. This iterative process incorporates the experience and knowledge gained from each stage to minimize the total number of samples required to adequately characterize the site and to provide the necessary data base to prepare feasibility studies for alternative remedial actions. The benefit of staged sampling is greater flexibility within the sampling program with a minimum of cost.

The integrated approach will be implemented at the site-specific level of data collection. Each SSMP will detail the minimum but adequate level of effort required to characterize each site; further investigation will be maintained at that level unless

an evaluation of the data indicates that a major modification is required. The integrated approach will use knowledge gained on an installation-wide basis or from similar sites to minimize the cost of successive site characterizations (remedial investigations).

At Rocky Flats Plant, formulation of a "conceptual model" for site characterization (remedial investigation) has begun that includes the physical framework and hydrogeochemical conditions. The conceptual model is a coherent set of ideas about the properties and processes occurring in the local ecosystem. Using a variety of tools, it is described by written ideas, concepts, tabulations of data, maps, graphs, and mathematical models. The conceptual model is the basic tool used to prepare sampling plan designs and to refine field operations.

Detailed SSMPs will be prepared and agreed upon by all participating parties and regulatory agencies. Field investigations will be sequenced by progressing from lower cost/resolution to higher cost/resolution methods until the data needs are satisfied. The ultimate goal is development of a quality assured/quality controlled data suite to evaluate the following:

- nature and extent of contamination,
- local hydrogeological system,
- feasibility assessment/alternatives,
- remedial engineering design,
- regulatory compliance/concurrence,
- long-term monitoring and verification, and
- physical and chemical characteristics and volumes of waste sources.

5.3. CEARP PHASE 2A - MONITORING PLAN

This Rocky Flats Plant IGMP/CSPCP contains (1) a description of current situation, which is the CEARP Phase 1: Installation Assessment for Rocky Flats Plant that is incorporated by reference and (2) a description of plans--Sampling Plan; Technical Data Management Plan; Health and Safety Plan; and Quality Assurance/Quality Control Plan. In addition, this IGMP/CSPCP contains a Feasibility Study Plan that includes a Risk/Endangerment Assessment as required by the Compliance Agreement. The Rocky Flats Plant IGMP/CSPCP is tailored to those sites and situations identified during CEARP Phase 1 that require CEARP Phase 2 site characterization (remedial investigation). Potential sites identified during CEARP Phase 1

that require supplemental CEARP Phase 1 field reconnaissance are incorporated as appropriate. A detailed discussion of all sites identified during CEARP Phase 1 is found in the CEARP Phase 1: Installation Assessment for Rocky Flats Plant (DOE 1986b).

5.4. PRIORITIZATION OF SITES

Application of the integrated approach and the possible need to first address those sites at which prompt remedial action could significantly reduce the spread of contamination and/or reduce risks to human health or the environment, made it necessary to prioritize sites requiring characterization (remedial investigation). Site prioritization was accomplished by using existing information to rank the sites. The existing information was obtained from the CEARP Phase 1 report and details of the prioritization is provided in a report titled "Preliminary Prioritization of Sites" (DOE 1986h).

5.5. REPORTING REQUIREMENTS

CEARP Phase 2b site characterization (remedial investigation) data will be consolidated and reported in site characterization (remedial investigation) reports. Because of the integrated approach to be used for site characterizations (remedial investigations) at the Rocky Flats Plant, the Monitoring Plans (IGMP/CSPCP and SSMPs) may be revised as appropriate. The site characterization (remedial investigation) reports will follow the format outlined in the CGMP (Synopsis, Section 3.2) and derived from DOE Order 5480.14 (CERCLA Implementation). The CGMP requires that the site characterization (remedial investigation) reports include elements of an EPA Remedial Investigation (RI) Report. These requirements will result in a site characterization (remedial investigation) report formatted as follows, with the section numbers corresponding to those in the CGMP:

1. Executive Summary. A synopsis of the content and findings of the site characterization (remedial investigation) incorporating material regarding the current situation from the CGMP, IGMP/CSPCP and SSMP as appropriate.

2. Sampling and Analytical Measurement Plan. The CGMP, IGMP/CSPCP, and SSMP will be incorporated by reference, including sampling strategy (2.1 Rationale), sampling methods (2.2 Methods and Techniques), and QA/QC Plan (2.3 Quality Assurance).

3. Summary of Data and Findings. Data will be summarized in the site characterization (remedial investigation) report. It will include discussion of waste types and concentrations on an areal and temporal basis (3.1 Sources and Quantities of Contamination), and a characterization of the potential contaminant migration (3.2 Extent of Pathways for Migration).

4. Interpretation of Analysis. The conceptual model of the physiographic setting will be discussed in the site characterization (remedial investigation) report. Data interpretation will be based on observations (4.1 Existing Conditions), and will be extended to predict the future distribution of contaminants (4.2 Future Implications), resulting in an impact evaluation (4.3 Hazard Assessment).

5. Recommendations. The Hazard Assessment will lead to recommendations for remediations that include necessity (5.1 Need for Corrective Action), a ranking of sites requiring remediation (5.2 Priorities), and consideration of technical, logistical, and operational limitations to remediation (5.3 Constraints).

6. Appendices. The site characterization (remedial investigation) report will include supporting data as appendixes. This will consist of a description of sampling locations (6.1 Sampling Locations), in the form of a map and supporting detail regarding sampling sites. Data will be summarized in the Summary of Data and Findings including individual analytical results (6.2 Sample Analysis Data) referencing Quality Assurance/Quality Control documentation. Supporting calculations summarized elsewhere will be included (6.3 Pathways Calculations), along with numerical modeling results.

6. REFERENCES

DOE 1986a: "Compliance Agreement Regarding Hazardous Waste Management at Rocky Flats Plant," Signed by the US Environmental Protection Agency, the State of Colorado, and the Department of Energy, July 1986.

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DOE 1986f: "Resource Conservation and Recovery Act Part B - Operating Permit Application for USDOE Rocky Flats Plant, Hazardous and Radioactive Mixed Wastes," US Department of Energy unnumbered report, November 1986.

DOE 1986g: "Resource Conservation and Recovery Act Part B - Post-Closure Care Permit Application for USDOE Rocky Flats Plant, Hazardous and Radioactive Mixed Wastes," US Department of Energy unnumbered report, November 1986.

DOE 1986h: "Draft Preliminary Prioritization of Sites," US Department of Energy unnumbered draft report, July 1986.

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RI 1986a: "Annual Environmental Monitoring Report: January-December 1985," Rockwell International Rocky Flats Plant, Golden, Colorado report RFP-ENV-85, April 1986.

RI 1986b: "Rocky Flats Plant Radioecology and Airborne Pathway Summary Report," Rockwell International, Rocky Flats Plant, Golden, Colorado unnumbered report, December 1986.

APPENDIX A -ACRONYMS

This IGMP/CSPCP contains acronyms and terms that will not be familiar to some users and reviewers. Therefore, this section is included to assist the reader.

AL: Albuquerque Operations Office
ALARA: As low as reasonably achievable
BNA: Base, neutral, Acid (semivolatile organics)
CAA: Clean Air Act
CEARP: Comprehensive Environmental Assessment and Response Program
CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act
CGMP: CEARP Generic Monitoring Plan
CLP: EPA Contract Laboratory Program
CWA: Clean Water Act
DOD: U.S. Department of Defense
DOE: U.S. Department of Energy
EPA: U.S. Environmental Protection Agency
FFSDIF: Federal Facility Site Discovery and Identification Findings
FIFRA: Federal Insecticide, Fungicide, and Rodenticide Act
FS: Feasibility Study
GOCO: Government-Owned, Contractor-Operated
HRS: Hazard Ranking System CERCLA
HSE: Health, Safety, and Environment Division, LANL and Rockwell International
HSL: Hazardous Substances List
IGMP: Installation Generic Monitoring Plan
IGMP/CSPCP: Installation Generic Monitoring Plan/Comprehensive Source and Plume Characterization Plan
LANL: Los Alamos National Laboratory
MHRS: USDOE Modified HRS
NEPA: National Environmental Policy Act
NESHAPS: National Emission Standards for Hazardous Air Pollutants
NPDES: National Pollutant Discharge Elimination System
NPL: National Priorities List
NRC: U.S. Nuclear Regulatory Commission
OSHA: Occupational Safety and Health Administration
OVA: Organic vapor analyzer
PA: Preliminary Assessment
PFA: Planned Future Action
PSI: Preliminary Site Inspection
QAO: Quality Assurance Officer
QAPP: Quality Assurance Project Plan
QC: Quality Control
RCRA: Resource Conservation and Recovery Act
RMCL: Recommended Maximum Concentration Limit
SCBA: Self-Contained Breathing Apparatus
SCR: Site Characterization Report
SDWA: Safe Drinking Water Act

SFMP: Surplus Facilities Management Program
SHSC: Site Health & Safety Coordinator
SI: Site Inspection
SOW: Scope of Work
SSMP: Site Specific Monitoring Plan
SSMP/RIFS: Site Specific Monitoring Plan/Work Plan for Performance of Remedial Investigations and Feasibility Studies for all High-Priority Sites
SSP: Site Survey Program
SWMU: Solid Waste Management Unit
TDM Plan: Technical Data Management Plan
TMC: Technical Measurements Center, GRJ AO
TSCA: Toxic Substances Control Act
UST: Underground Storage Tank

DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
ENVIRONMENT, SAFETY AND HEALTH DIVISION
ENVIRONMENTAL PROGRAMS BRANCH

COMPREHENSIVE ENVIRONMENTAL ASSESSMENT AND RESPONSE PROGRAM

PHASE 2:
ROCKY FLATS PLANT
INSTALLATION GENERIC MONITORING PLAN
(Comprehensive Source and Plume Characterization Plan)

SAMPLING PLAN

February 1987

DRAFT

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1. INTRODUCTION

CEARP Phase 2 Confirmation consists of CEARP Phase 2a, Monitoring Plan, and CEARP Phase 2b, Site Characterization (Remedial Investigation). This Sampling Plan is one component of the Monitoring Plan for Rocky Flats Plant. The Monitoring Plan typically consists of five parts: Synopsis, Sampling Plan, Technical Data Management Plan, Health and Safety Plan, and Quality Assurance/Quality Control (QA/QC) Plan. Because of the Compliance Agreement between the State of Colorado, the Environmental Protection Agency, and the Department of Energy (DOE), this Monitoring Plan also includes a Feasibility Study Plan.

CEARP uses a three-tiered approach in the preparation of monitoring plans: the CEARP Generic Monitoring Plan (CGMP), the Installation Generic Monitoring Plan (IGMP), and the Site Specific Monitoring Plans (SSMPs). This revised IGMP serves as the Comprehensive Source and Plume Characterization Plan required by the Compliance Agreement. Therefore, the acronym used to refer to this plan is IGMP/CSPCP.

This IGMP/CSPCP Sampling Plan details specific guidance for implementation of CEARP Phase 2b site characterizations (remedial investigations) at Rocky Flats Plant and follows the guidance provided in the CGMP. The Sampling Plan is complemented by and inseparable from the Technical Data Management Plan and the Quality Assurance/Quality Control (QA/QC) Plan. Sections of the Sampling Plan are supported by reference to the other plans, and to the Synopsis. Emphasis is placed on integration of efforts for each of the CEARP Phases: Phase 3 (Technological Assessment), Phase 4 (Remedial Action), and CEARP Phase 5 (Compliance and Verification).

This IGMP/CSPCP Sampling Plan provides the following basic components of sample/measurement collection and analysis at Rocky Flats Plant:

- objectives and goals of the investigation,
- methods and procedures and their justification,
- transportation and shipping information, and
- guidance for the site-specific investigations.

The initial CEARP Phase 2 site characterization (remedial investigation) has provided considerable data to define regional and installation-wide geology, hydrology, and water quality. These data will be further analyzed and interpreted as a first step of the site characterization (remedial investigation) being performed under this IGMP/CSPCP Monitoring Plan. This analysis will define additional installation-wide data needs to enhance understanding of the surface water and groundwater pathways. Some of these data needs have been identified, and are presented in Section 3 of this Sampling Plan. Additional installation-wide sampling locations, soils boring locations, and monitoring well locations may be identified based on the results of these analyses.

Current understanding of the hydrogeological system and contaminant sources at Rocky Flats Plant has resulted in definition of several high-priority sites (DOE 1986f). These sites appear to be the primary sources of the known groundwater plumes. Therefore, the installation-wide source and plume characterization (remedial investigation) will be accomplished by first evaluating these high-priority sites, tracing the contaminant plumes originating from these sites, and integrating these data on an installation-wide basis. Second, all lower-priority sites will also be characterized and these data incorporated into the data base. The details of the site-specific plume characterizations will be presented in the SSMPs. The installation-wide characterization (remedial investigation) presented in this IGMP/CSPCP may be modified based upon the results of these site-specific analyses.

The premise of this Sampling Plan is that installation-wide data needs are mostly satisfied by site-specific requirements. Installation-wide needs encompass additional clarification of the sources contributing to and contaminant levels within the groundwater plumes, definition of interconnections and contaminant transport within the hydrogeologic system, and identification of gaps within the data base. To address these needs, this Sampling Plan was organized as follows:

- The remainder of the introduction outlines the objectives of the site characterization.
- Section 2 presents the site survey and mapping criteria that ensure a common frame of reference.
- Section 3 identifies installation-wide and site-specific data requirements.

- Section 4 presents the sampling plan and rationale to be followed.
- Section 5 identifies the sample numbering system.
- Section 6 identifies sampling equipment and procedures.
- Section 7 discusses sample analysis and handling.
- Section 8 presents sample documentation and tracking procedures.

1.1. INTEGRATED APPROACH

Sampling at Rocky Flats Plant will be conducted using an integrated approach. The integrated approach is summarized in the Synopsis (Section 5.2) and detailed here. The integrated approach breaks site characterization (remedial investigation) activities into stages, in which the results from previous stages of sampling are used to refine the conceptual model used to design successive stages of sampling. This iterative process incorporates the experience and knowledge gained from each stage to minimize the total number of samples required to adequately characterize the site and to provide the necessary data base to prepare feasibility studies for alternative remedial actions. The benefit of staged sampling is greater flexibility within the sampling program with a minimum of cost.

1.2. OBJECTIVES OF THE SAMPLING PROGRAM

The overall objectives of CEARP Phase 2b site characterizations (remedial investigations) are to

- verify and characterize contaminant sources,
- determine the present areal and vertical extent of groundwater contamination plumes,
- estimate potential for contaminant migration (including rate and direction) to support risk assessment studies,
- support identification and technology assessments (feasibility studies) of alternative response actions, including the alternative of "no action," and
- support of long term monitoring and verification.

These objectives are detailed for particular elements of the sampling program, as follows.

1.2.1. Location of Waste Sites

The locations and boundaries of waste sites will be defined under CEARP Phase 2b site characterizations (remedial investigations) in order to delineate source areas for potential cleanup (e.g., removal or containment). This will enable evaluation of the potential for migration of contaminants into the environment and evaluation of alternative remedial actions.

1.2.2. Soils and Geology

Sampling of geologic materials at Rocky Flats Plant will include sampling of soils and waste materials found within the soils and bedrock. The objective of this sampling is to confirm the types, concentrations, and extent of wastes and/or contaminant migration.

Geotechnical characterization at Rocky Flats Plant will be performed to support the evaluation of waste migration (e.g., sampling and testing for hydraulic properties) and to support the technological assessments (feasibility studies) of alternative remedial actions.

1.2.3. Groundwater

The CEARP Phase 1 Assessment of Rocky Flats Plant recommended hydrogeochemical investigations of the aquifer systems in the immediate vicinity of the plant based on the ongoing hydrogeological studies. An initial CEARP Phase 2b site characterization (remedial investigation) was conducted in 1986 with the objective of supplementing the existing hydrogeochemical understanding of the location, direction, rate of movement, recharge, and discharge of the hydrogeologic systems. Under the revised IGMP/CSPCP, this investigation will be expanded to fill area-wide and site-specific hydrogeologic data gaps. Ultimately, the investigation has the objective of providing a comprehensive data base for evaluating remedial actions.

Existing groundwater quality data indicate that radioactive and chemical contaminants have entered the groundwater flow system. As a result of this information, radioactive and chemical contamination in groundwater will be a major focus of the site characterization (remedial investigation) activities. The objectives of groundwater sampling are as follows:

- Identify and characterize the source(s) of contaminants in the groundwater.
- Determine the present areal and vertical extent of groundwater contamination.
- Estimate the potential for contaminant migration (including rate and direction) to support risk assessment studies.
- Support the identification and technology assessments (feasibility studies) of alternative remedial actions.

1.2.4. Surface Water

Surface water was not identified as an important pathway for contaminant migration in the CEARP Phase I Installation Assessment. All available surface water data are presented in the Geological and Hydrological Data Summary for Rocky Flats Plant (RI 1986c). The additional 42 surface water sampling locations used in the initial CEARP Phase 2 site characterization were selected based on these data and perceived data gaps. Approximately half of these 42 stations were dry during the 1986 sampling season. These stations will be sampled as part of the site characterization (remedial investigation) being conducted under this IGMP/CSPCP Monitoring Plan. The primary objective of surface water sampling under this IGMP/CSPCP Sampling Plan is to support the characterization of the hydrogeochemical setting at Rocky Flats Plant by providing data on the interconnection between surface water and groundwater.

1.2.5. Biota

The CEARP Phase I Assessment for Rocky Flats Plant and the Radioecology and Airborne Pathway Summary Report (RI 1986b) did not identify biota as a significant pathway for contamination. There are no current plans for biological sampling.

1.2.6. Air

The CEARP Phase I Assessment of Rocky Flats Plant and the Radioecology and Airborne Pathway Summary Report (RI 1986b) did not identify air as a significant pathway for contamination. Existing air monitoring programs appear to have adequately characterized the air pathway, and there are no current plans for additional air pathway characterization. However, air will be monitored under the health and safety program. If this monitoring indicates that sampling activities are impacting the air pathway, more characterization data will be collected as appropriate.

1.3. SCOPE

The sampling activities outlined in this Sampling Plan will be completed in two or more stages in line with the integrated approach being used by CEARP. The scope of sampling and subsequent stages of sampling will be refined based on data analyses. The anticipated scope of sampling corresponds to the data needs described in the Synopsis. SSMP Sampling Plans will be prepared for each site or group of sites, as appropriate.

Data collection activities that apply generically to all or most sites include the following:

- geophysical and soil gas surveys to locate waste sites and describe metallic objects within wastes,
- land surveying to tie in geophysical surveys and provide precise locations of sites, and to provide a baseline for the location of sampling at sites, and
- aerial photography to identify waste sites and past waste disposal practices.

1.3.1. Soils and Geology

Sampling of geologic materials and wastes will be conducted during the CEARP Phase 2b site characterizations (remedial investigations). Sampling may include both soil and soil gas sampling. The scope of anticipated sampling includes the following:

- sampling of soil gases using a field gas chromatograph, photoionization detector and/or organic vapor analyzer,
- sampling and analysis of soil to determine the presence, concentration, and distribution of potential contaminants, and
- sampling, analysis, and testing of soil in support of hydrogeochemical characterizations and engineering studies.

1.3.2. Groundwater

Groundwater samples will be taken to refine the site-wide hydrogeological conceptual model and to determine the extent of contaminant migration within groundwater of the plant.

The scope of groundwater characterization includes investigation of the quality of water within both the alluvium and bedrock. This includes borings and monitoring well installation in areas adjacent to waste sites. Surface geophysical methods and soil gas investigations are within the scope of this characterization.

1.3.3. Surface Water

The scope of surface water characterization at Rocky Flats Plant includes sampling of streams, ditches, and seeps which might be impacted by contaminants.

1.4. SCHEDULE

CEARP Phase 2b sampling activities at Rocky Flats Plant will begin at high-priority sites under the Site-Specific Monitoring Plan. The sampling schedule is presented separately.

2. SITE SURVEY AND MAPPING

Surveying and mapping will be conducted at an installation level to assure a common frame of reference for all site characterizations (remedial investigations). All monitoring stations will be surveyed unless a high degree of accuracy is determined unnecessary for a particular station. Additional detail and guidance regarding site surveys and mapping is provided in the Technical Data Management Plan.

2.1. INSTALLATION COORDINATE SYSTEM

All monitoring locations will be described in accordance with the Rocky Flats Plant Installation Coordinate System. The plant coordinate system has been tied into the Colorado State Coordinate System using benchmarks established by the USGS. Horizontal survey data will be reported in both Rocky Flats coordinates and State coordinates so data collected on plant site can be related to regional data as necessary. Elevations will be reported in English units as feet above mean sea level.

2.2. AREA OF INTEREST

The area of interest to be surveyed and mapped has been established according to the guidelines contained in the Technical Data Management Plan. Rocky Flats Plant is contained within one property boundary. Thus, the area of interest extends to the plant property boundaries.

2.3. SCOPE OF WORK FOR SURVEYING

Tolerances of ± 0.01 ft vertically and ± 0.1 horizontally will be used in locating base stations and control points. Tolerances of ± 0.01 ft vertically and 1 ft horizontally will be allowed when surveying sampling locations.

3. DATA REQUIREMENTS

This section presents an overview of the present situation and data requirements for installation-wide source and plume characterization at Rocky Flats Plant in accordance with the Compliance Agreement. Also included are general requirements for CEARP Phase 2b site characterizations (remedial investigations). Detailed data collection requirements for specific sites will be presented in the appropriate SSMP Sampling Plans. The goal of CEARP Phase 2b efforts is to collect sufficient data to meet the requirements of site characterizations, feasibility studies and risk/endangerment assessments, to identify alternatives for remedial action and to plan long term monitoring and verification.

3.1. INSTALLATION DATA NEEDS

Installation-wide data needs have been identified as necessary to support the characterization of contaminant plumes, and to develop and continually refine conceptual models of contaminant transport. The data required for installation-wide site characterization (remedial investigation) may be broken into four major categories: sources, geology, groundwater, and surface water.

This section presents a brief summary of the current environmental situation at the Rocky Flats Plant and identifies gaps in the existing data base. Section 4 presents the Sampling Plan to fulfill identified data needs.

3.1.1. Solid Waste Management Units

Solid Waste Management Units (SWMUs) were identified in the RCRA Part B Permit Application (DOE 1986b). Each of these solid waste managements units was assigned a reference number and located on an aerial photograph base map (Plate 1). This base map and a tabulation of all solid waste management units cross-referenced to the CEARP Phase I report is presented in the Rocky Flats Plant IGMP/CSPCP Synopsis.

The locations and nature of solid waste management units at Rocky Flats Plant have been defined based on existing information (DOE 1986b, DOE 1986f). Further

investigations of these solid waste management units should include precisely locating each unit and sampling in or near the unit to verify reported locations and contents.

3.1.2. Soils and Geology

3.1.2.1. Geology

Available geologic data at Rocky Flats Plant consists of numerous regional and installation-specific geologic and geotechnical reports. Stratigraphy and lithology are available from geotechnical investigations at the present landfill, the solar ponds, various onsite buildings, and from groundwater monitor well installations. These data are presented in the Geological and Hydrological Data Summary for Rocky Flats Plant (RI 1986c). In addition, detailed mapping of surficial and bedrock geology at the plant was performed as part of the initial CEARP Phase 2b site characterization (remedial investigation) performed in 1986 in response to the Compliance Agreement.

Surficial Geology. Surficial deposits at Rocky Flats Plant consist of Rocky Flats Alluvium, several alluvial materials in the valleys, and colluvium. The valley alluvial materials are Verdos Alluvium, Slocum Alluvium, recent terrace alluviums and recent channel deposits (valley fill). The general composition and lateral extent of surficial deposits were well defined by the 1986 mapping effort (DOE 1986f). The thickness and compositional variations of alluvium and colluvium were well defined where borehole data exist (DOE 1986f).

Additional installation-wide data on surficial geology are not considered necessary. However, additional site-specific surficial geology data will be collected during monitor well installation as presented in the SSMP Sampling Plans.

Bedrock. Bedrock units beneath Rocky Flats Plant consist of Cretaceous Fox Hills Sandstone, Laramie Formation and Arapahoe Formation. The Fox Hills Sandstone and lower Laramie Formation sandstones outcrop in clay pits west of the plant and were characterized by the 1986 geologic mapping (DOE 1986f). The upper Laramie Formation claystones subcrop beneath the Rocky Flats Alluvium in the western plant buffer zone, and the Arapahoe Formation subcrops immediately beneath and east of the plant. Outcrops of these formations were located by the 1986 geologic mapping; however, the contact between the Laramie and Arapahoe Formations could

not be positively identified in the field (DOE 1986f). Based on boring logs, the contact was estimated to be below the the first Arapahoe sandstone that was greater than 5 ft thick (DOE 1986f).

Because the Arapahoe Formation subcrops beneath and east (downgradient) of the plant, the locations and extent of sandstone bodies within the formation are important to an understanding of the bedrock flow system and contaminant transport. During the initial CEARP Phase 2b site characterization (remedial investigation), bedrock wells were cored to the first total sandstone cumulative thickness of 3 ft within a 10-ft interval, and bedrock monitor wells were completed in these sandstones. This drilling program identified numerous sandstone bodies at various depths beneath the plant which were previously unidentified. The sandstones are lenticular, discontinuous and stratigraphically complex (DOE 1986f).

An installation-wide bedrock investigation may be necessary to support the quantification of groundwater flow patterns and solute transport in the groundwater. If warranted, based on plume characterizations, additional core data will be collected to determine the extent of known sandstones and to locate previously unidentified sandstone lenses.

3.1.2.2. Geotechnical

Geotechnical tests have been conducted on materials from many of the onsite borings. Data collected to date include standard penetration tests, Atterburg limits, and grain-size analyses of various materials (RI 1986c). Cores have been collected during the initial CEARP Phase 2b site characterization (remedial investigation) that will be tested to evaluate permeabilities, porosities, and physical properties of bedrock and alluvial units in support of hydrogeologic characterization. Based on the results of these tests, additional installation-wide data needs may be identified.

3.1.3. Groundwater

3.1.3.1 Hydrology

There are two hydraulically-connected groundwater flow systems at Rocky Flats Plant. These occur in the Rocky Flats Alluvium and other surficial materials,

and in the bedrock (primarily in the claystones and sandstones of the Arapahoe Formation).

Presented below is a discussion of each flow system and the data needs to support potential groundwater modeling efforts.

Shallow Flow System. The shallow alluvial groundwater system in the Rocky Flats Alluvium and other surficial materials occurs under unconfined conditions. The system is recharged by infiltration of incident precipitation and surface water. Shallow groundwater flow generally follows topography to the east and toward the drainages. Discharge areas are springs and seeps at the alluvium/bedrock contact and major drainages. The shallow system appears to be quite dynamic, as large water table fluctuations occur in response to seasonal stresses. As a result of these fluctuations, large unsaturated zones within the system occur during certain portions of the year.

Shallow groundwater flow rates were calculated based on single-hole drawdown-recovery test data collected during the initial CEARP Phase 2b site characterization (remedial investigation) (DOE 1986f). Data available to date indicate mean hydraulic conductivities as follows.

Material	Hydraulic Conductivity (cm/sec)
Rocky Flats Alluvium	7×10^{-5}
Walnut Creek Alluvium	3×10^{-5}
Woman Creek Alluvium	3×10^{-3}

The effective porosity of alluvial materials is assumed to be 0.1 (Hurr 1976). Based on the hydraulic conductivities presented above, an assumed effective porosity of 0.1, and gradients determined from the initial CEARP Phase 2 site characterization, groundwater velocities were calculated for each geologic unit listed above. The horizontal velocity is approximately 14 ft per year in the Rocky Flats Alluvium, approximately 900 ft per year in Woman Creek alluvium and approximately 9 ft per year in Walnut Creek alluvium. Dissolved chemical species do not migrate as far as implied by the velocity calculations because the surficial materials are not saturated year-round. Portions of the Rocky Flats Alluvium are probably saturated throughout the year, and conservative (nonattenuated) species in Rocky Flats Alluvium ground-

water could travel annual distances of the order calculated. However, conservative species in valley fill groundwater cannot travel the predicted distances because these materials are dry during portions of the year (1986f).

The shallow flow system at Rocky Flats Plant is generally understood; however, additional flow data are needed for a detailed understanding of the system. Seasonal water level fluctuations and unsaturated zones within the system need to be better defined on an installation-wide scale to describe the dynamic groundwater flow system. Hydraulic conductivity and effective porosity values also need to be determined in the field for the Woman Creek Alluvium to support a quantitative evaluation of solute transport at Rocky Flats Plant.

Bedrock Flow System. Most groundwater flow in the Arapahoe Formation occurs in lenticular sandstone bodies contained within the claystones. Recharge to the sandstones occurs by leakage through the claystones or where the sandstones are in direct contact with saturated surficial materials. Groundwater in the sandstones flows east toward the point of regional discharge along the South Platte River.

Groundwater flow rates estimated by DOE (1986f) were based on the initial CEARP Phase 2 site characterization (remedial investigation) and regional data. Based on single-hole drawdown-recovery tests and packer tests, the sandstones have an average hydraulic conductivity of 2×10^{-6} cm/sec. Average hydraulic conductivity values for weathered and unweathered claystone were developed using packer test data. These values were approximately 5×10^{-7} cm/sec for weathered claystone and 1×10^{-7} cm/sec for unweathered claystone. Assuming an effective porosity of 0.1 and the regional gradient, the horizontal velocity of the sandstones was estimated to be approximately 0.6 ft per year (DOE 1986f).

There is a strong downward gradient between the shallow and bedrock flow systems (DOE 1986f). These gradients range from 0.20 to 1.0 based on onsite water level data from paired bedrock and shallow wells. No vertical conductivity values are available for the claystones; however, a value one-third of the horizontal conductivity of 1×10^{-7} was assumed in order to calculate a downward groundwater velocity of 0.1 ft per year (DOE 1986f).

Additional data are needed to better define bedrock flow directions and velocities at Rocky Flats Plant. Refined horizontal and vertical hydraulic conductivity as well as effective porosity values are needed for the sandstones and claystones to further evaluate groundwater flow velocities and solute transport. Further testing of well pairs is also needed to investigate vertical gradients between the shallow and bedrock flow systems.

3.1.3.2 Quality

Groundwater conditions at Rocky Flats Plant have been monitored since 1961 and chemical data exist for monitoring over the past ten years. In addition, groundwater samples were collected from 27 existing wells and the 69 new wells during the initial CEARP Phase 2 site characterization (remedial investigation) (Plate 2). Based on these data, a one-time characterization of alluvial and bedrock water quality is presented in the RCRA Part B Permit Application (DOE 1986f) and summarized in the IGMP/CSPCP Synopsis. This characterization includes a discussion of background and downgradient water quality. Because the groundwater quality discussion presented by DOE (1986f) is based on a one-time sampling event, seasonal water quality fluctuations need to be evaluated on an installation-wide basis. Quarterly groundwater quality data are being collected as specified in the RCRA Part B Operating Permit Application. In addition, site-specific groundwater quality will be evaluated during CEARP Phase 2b site characterizations.

3.1.4. Surface Water

3.1.4.1. Hydrology

Three intermittent streams drain Rocky Flats Plant. Flow is generally from west to east. Rock Creek drains the northwestern corner of the plant site and flows to the northeast toward its offsite confluence with Coal Creek. Woman Creek drains the southern portion of the plant site and flows eastward to Standley Lake. North and South Walnut Creek and an unnamed tributary drain the remainder of the plant site. A series of dams, retention ponds, diversion structures and ditches have been constructed at the plant to control surface water and limit the potential for release of

poor quality water. A detailed discussion of this system is presented in the RCRA Part B Permit Application (DOE 1986f).

The surface water flow system is well understood and documented (DOE 1986f). Surface water flow needs to be monitored on an installation-wide scale to describe seasonal fluctuations in flows and to support groundwater flow and solute transport modeling.

3.1.4.2. Quality

Surface water quality is characterized in detail in the RCRA Part B Permit Application (DOE 1986b). This characterization is based on a one-time site characterization sampling event and NPDES monitoring. The initial CEARP Phase 2 site characterization (remedial investigation) characterized surface water hydrology by measuring flow rates and sampling surface water at onsite sampling stations (Plate 2).

Surface water discharged from retention ponds is monitored regularly to document compliance with NPDES permit requirements. The NPDES permit is issued and regulated by EPA and requires the plant to monitor for specific pollutants at seven discharge locations. These seven discharge locations are: pond B-3 (discharge 001), pond A-3 (discharge 002), Reverse Osmosis Pilot Plant (discharge 003), Reverse Osmosis Plant (discharge 004), pond A-4 (discharge 005), pond B-5 (discharge 006) and pond C-2 (discharge 007). Sanitary effluent limitations are placed on pond B-3 (sewage effluent), and limitations for nitrate and pH are placed on pond A-3. Discharge limits apply to the Reverse Osmosis Plant, and limitations on sediment release apply to ponds A-4, B-5 and C-2. In addition to NPDES permit requirements, all of these discharges are monitored for pH, nitrate as nitrogen, nonvolatile suspended solids, plutonium, americium, uranium, and tritium (RI 1986a).

Surface water quality was characterized by DOE (1986f). However, continued monitoring of NPDES discharge locations and the other surface water sampling locations is necessary to define seasonal fluctuations in surface water quality.

3.2. SITE-SPECIFIC DATA NEEDS

Data needs at the solid waste management units may be separated into three major categories: soils and geology, groundwater, and surface water.

3.2.1. Soils and Geology

3.2.1.1. Soils and Wastes

Data needs for soils include geotechnical data (e.g., grain size, clay content, moisture content, compaction, and permeability), vadose zone data (e.g., adsorptive capacity, buffering capacity, and pore fluids and soil chemistry), and variability of these parameters. Collection of soil data may be accomplished by detailed soil sampling and testing and/or installation of soil water samplers as necessary. In addition, the extent of surficial contamination may be investigated by collecting surface soils and screening them for radioactive materials.

Data needs for waste characterization will include sources, site boundaries, physical state, composition, and concentrations of waste materials.

3.2.1.2. Geology

Geologic data needs include depth and composition of surficial materials, the local extent and lithology of existing sandstones, and the geotechnical characteristics of both surficial and bedrock materials.

3.2.2. Groundwater

Groundwater data needs include the monitoring of water levels, the determination of water quality and hydraulic conductivity, definition of local stratigraphy and lithology, and quantification of seeps to surface. Tasks designed to fill groundwater data needs at the high-priority sites will include installation of monitoring wells in both alluvium and bedrock, sampling and geotechnical testing of alluvial and bedrock materials, and sampling and analysis of groundwater. The elevation of groundwater

will be measured in wells and at seeps to provide data for determination of groundwater flow directions. A complete description of the tasks to be implemented will be presented in the individual SSMP Sampling Plans.

3.2.3. Surface Water

Surface water data needs include topographic mapping, interceptor ditch flow, surface water flow and quality, and their variability. The surface water investigation will include preparation of detailed topographic maps of each area of investigation to determine drainage area characteristics. Water samples from the interceptor ditches and creeks will be collected from multiple locations upstream, adjacent to, and downstream from the area being investigated. Stream flow data may be collected from existing gauging stations or new installations.

4. SAMPLING PLAN AND RATIONALE

4.1. INSTALLATION-WIDE SAMPLING PLAN

The first task of this Sampling Plan will be to review all available data so that a conceptual understanding (model) of the existing system can be developed. The second task will be to identify specific locations where sampling and testing are to be conducted to test the conceptual model. Discussion of the probable techniques to be used for collecting data is provided below.

4.1.1. Soils and Geology

4.1.1.1. Soils and Wastes

Characterization of suspected waste sites will be conducted on a site-specific basis (Section 4.2). Characterization will include source locations, waste compositions, and evaluation of potential migration pathways. As stated in the introduction, most of the installation-wide characterization (remedial investigation) needs will be satisfied by activities carried out under site-specific investigations. These site-specific data will be used as input to the mathematical model(s) that will be used to evaluate contaminant transport through the various pathways on an installation-wide basis. Additional data needs identified by this modeling effort will then be identified.

4.1.1.2. Geology

Additional investigations of the geology at Rocky Flats Plant are anticipated to be confined to collection of site-specific data. Data to be generated include the thickness and composition of alluvial deposits, the local extent and lithology of sandstone units, and geotechnical parameters of both bedrock and alluvial deposits.

4.1.2. Groundwater

Characterization of groundwater flow and quality has been identified as an installation-wide data need. Characterization of contaminant plumes in either alluvial or bedrock units will be initiated on a site-specific basis.

Techniques to be used in developing these data may include multiple well-pumping tests, slug tests, and tracer tests. Monthly groundwater elevation measurements of all wells will be conducted for at least one year in order to determine seasonal variation in the potentiometric surface. Drilling and installation of additional groundwater monitoring wells in locations where data are lacking may be necessary.

The extent of groundwater quality data needs will be more accurately evaluated following reviews of the available data and the newly acquired site-specific data. All new and existing monitoring wells will be monitored quarterly to adequately characterize seasonal and spatial variation in groundwater quality.

4.1.3. Surface Water and Sediment

Characterization of surface water flow and surface water quality will be investigated on an installation-wide basis. Quarterly sampling of surface water in each drainage will be necessary to detect seasonal variation in surface water quality. Discharge information may be collected and evaluated from multiple locations on each drainage to further characterize surface water flow patterns and to evaluate the relationship between surface water and groundwater.

Sediment quality was characterized during the initial CEARP Phase 2 site characterization (remedial investigation) (DOE 1986f). On an installation-wide basis, additional sediment samples are not deemed necessary.

4.2. GUIDANCE FOR THE SITE-SPECIFIC SAMPLING PLANS

This section provides a brief overview of the planned environmental monitoring and site-specific characterization activities at Rocky Flats Plant. Detailed discussions of the site-specific sampling efforts and rationale will be included in the SSMP Sampling Plans.

4.2.1. Soils and Geology

4.2.1.1. Soils and Wastes

The delineation of waste site boundaries is an identified data need (Section 2 of the Synopsis). Geophysical surveys will be conducted to delimit the boundaries and identify some characteristics of waste sites. The surveys will be tied in to the Installation Coordinate System and established benchmarks. The surveys will include a sampling network specific to each potential waste site identified in the SSMPs, with systematic sampling on a grid basis.

Specific geophysical techniques to be applied at Rocky Flats Plant are expected to include electromagnetic induction (EM), magnetometry, metal detection, and vertical electrical resistivity. Electromagnetic induction and visual inspection will be used as the primary means of locating areas of disturbed soil. It will also be used for reconnaissance of chemical spills. Magnetometry and metal detection will be used to locate buried metallic objects. The location of metallic objects will provide data on past burial operations and will be used as a guide for drilling locations to avoid drilling into those objects. Resistivity will be used, as appropriate, to develop data on the vertical extent of the source areas.

Sampling of soil and wastes will be conducted to confirm the extent and characteristics of potential contaminants and contaminant migration. After waste site boundaries are delineated by the geophysical survey, the waste sites will be sampled using both soil gas sampling and soil borings.

The specific number, location, depth, sampling interval, and requisite analyses for both direct and indirect samples will be specified in the SSMPs.

4.2.1.2. Geology

Detailed investigation of the geology of each site to be characterized is needed in order to evaluate (1) the depth and composition of alluvial materials; (2) the local extent and lithology of sandstones; and (3) the geotechnical characteristics of both the alluvial and bedrock deposits.

Borings and cores at selected locations through the alluvium and into bedrock will be used to generate geologic data. Samples of each unit will be collected and lithologically described to generate data on the composition and extent of geologic materials. Techniques for sample collection and description are included in Appendix A.

4.2.1.3. Geotechnical

Site-specific geotechnical data will include laboratory tests to evaluate permeabilities, effective porosities, and physical properties of bedrock and alluvial units. Installation needs will be identified as appropriate. Falling head permeability tests will be performed on bedrock cores to investigate horizontal and vertical laboratory permeabilities, and capillary moisture tests will be conducted on bedrock cores to estimate effective porosities. At least three samples of each bedrock unit will be tested to account for sample variability.

If existing data does not include physical properties data, physical properties tests will be performed on appropriate bedrock and alluvial materials. Physical properties tests will consist of grain-size analyses, Atterburg limits, and water content tests. Hydrometer tests will be performed if more than 50 percent of a sample passes the 200-mesh sieve. Physical property test results will be used to develop a basis for selecting monitor well screen and filter pack sizes, to compare visual field classifications on boring logs with laboratory results, and to calculate permeability values based on empirical correlations to physical properties.

4.2.2. Groundwater

Specific tasks to be completed in order to characterize the hydrogeology of Rocky Flats Plant are expected to include soil gas surveys, monitor well installation and sampling, and surface water sampling. Soil gas surveys will be completed in order to detect the distribution of volatile organic contaminants within the groundwater as well as to assist in locating source areas. Installation and sampling of groundwater monitoring wells will provide data on the flow and quality of groundwater in the vicinity of the sites.

4.2.3. Surface Water

Sampling of surface water will provide data on the potential impact of groundwater on surface water quality.

4.2.4. Air

Monitoring of air for particulates and organic vapors will be maintained on a site-specific basis during invasive sampling (i.e., soil boring) for the purpose of protecting the health and safety of the sampling team. This monitoring will be used to determine the need, if any, for additional air quality sampling during site characterizations (remedial investigations). Specific air monitoring procedures to be used during invasive sampling will be specified in the SSMP Health and Safety Plans.

5. SAMPLE NUMBERING SYSTEM

Each sample collected for chemical analysis, including replicates, blanks, and quality control check samples, will be identified by a unique sample identification number. Samples are identified by installation (Rocky Flats Plant), location (i.e., well number), sample matrix, sample ID, date, and lot control number (for tracking lots associated with a particular blank, replicate, or quality control check sample). Sample results will be reported by matrix on the same basis.

Location ID and sample ID, including all of the above information, will be assigned by the subcontractor site manager. These data identifiers will be assigned prior to field activities. Field personnel will carry a list of designations, keyed to a map, into the field with them.

Additional locations may be assigned while field teams are onsite, if warranted. If additional locations are assigned during field activities, they will be documented by the field team. It will be the responsibility of the field team leader to make sure a "Location Information" form is completed. A copy of the form is included in Appendix B of the Technical Data Management Plan.

6. SAMPLING EQUIPMENT AND PROCEDURES

This section presents general procedures to be followed during the site characterizations (remedial investigations) at Rocky Flats Plant. Equipment and procedures to be used are presented in Appendix A.

6.1. SURFACE SOIL SAMPLES

Samples of surficial soil material may be collected from onsite areas of Rocky Flats Plant using a spade or scoop. The samples will be placed into the appropriate sample container, labeled, and transported to the laboratory, where they will be screened for radioactive contamination. The sampler will be decontaminated prior to each use in accordance with the standard protocol presented in Appendix A.

6.2. SOIL SAMPLES COLLECTED DURING DRILLING

Soil borings will be performed to characterize the nature and volume of wastes. General drilling and logging procedures are described in Appendix A. Site-specific modifications to these procedures will be included in individual SSMPs.

6.2.1 Samples for Laboratory Analysis

Continuous drive samples will be collected from the ground surface to total depth where possible. Total depth will vary depending on visual description of samples (i.e., presence of stains for metals) and qualitative screening for organics and radionuclides.

In general, up to six samples from each boring at suspected waste sources may be submitted for laboratory analysis. Screening will be used to determine which samples to submit for laboratory analysis. The purpose of screening is to obtain a preliminary indication of the magnitude and distribution of volatile contaminants, metals, and radionuclides in the subsurface. Selection of the samples will be based on the screening (visual, radiation, and organic vapors). Samples from the core at the following locations may be submitted to the laboratory:

- directly above the waste
- in the most contaminated zone of the waste
- directly below the waste
- at the base of the surficial material
- within the bedrock near the bedrock/alluvial contact.

The exact location of the samples will be determined by interpretation of the visual characteristics, and radiation and organic vapor measurements. Two samples characterizing the most contaminated zone of the waste may be submitted should the zones of highest radiation and volatile organics not correlate. Also, a sample directly above the waste may not be submitted for analysis should this zone be at or near the surface, because the surface will adequately demark the upper bounds of the waste. Should the waste be located within the bedrock, only one coring below the waste will be submitted.

Soil samples will be collected from soil borings near waste sources to determine the extent and magnitude of soil contamination. Visual, radiation, and organic vapor screening will be used to determine which samples to submit for laboratory analysis. In general, up to three samples will be submitted for analysis.

Sampling equipment will be decontaminated prior to each use in accordance with the standard protocol presented in Appendix A.

6.3. MONITORING WELL INSTALLATION

Monitoring wells will be installed on a site-specific basis to characterize groundwater quality. Their locations will be based on geophysical and soil gas surveys.

General procedures for the installation of monitoring wells are described in Appendix A.

6.3.1. Installation of Soil Water Samplers

Soil water samplers (lysimeters) may be installed for characterization of the vadose zone. A procedure for the installation of soil water samplers is included in Appendix A.

6.3.2. Installation of Soil Water Monitors

Various devices to monitor soil suction or soil moisture content may be installed (e.g., tensiometers, neutron probe access tubes, thermocouple psychrometers, and resistance blocks). The specific devices will be detailed in the SSMP Sampling Plans. Procedures for installation of tensiometers are included in Appendix A.

6.4. GROUNDWATER SAMPLES

Migration through groundwater has been identified as a significant potential pathway for release of contaminants to the environment at Rocky Flats Plant. Sampling of groundwater is necessary to evaluate the degree of groundwater contamination which has occurred as well as the potential for future contaminant migration.

All wells will be purged before sampling. Procedures for well sampling and purging are presented in Appendix A.

6.5. HYDRAULIC TESTS

Groundwater systems may be tested to characterize hydraulic properties such as hydraulic conductivity and effective porosity, to calculate groundwater flow velocity, and to estimate other properties important to contaminant migration. Procedures for drawdown-recovery tests of monitoring wells are included in Appendix A.

6.6. SURFACE WATER SAMPLES

Surface water samples will be collected from streams, ditches, and seeps to assist in characterizing the hydrogeochemistry of Rocky Flats Plant. The samples will be collected according to the protocol presented in Appendix A.

6.7. STORAGE AND DISPOSAL OF DRILLING AND SAMPLING WASTES

Sampling and drilling activities could generate potentially hazardous solid and liquid "wastes". The activities, anticipated type and amount of waste, and planned handling of the wastes are summarized below.

- Waste boring sampling: solid, auger cuttings and excess soil/cuttings collected but not retained in sample containers--returned to borehole upon completion (bentonite plugs placed at the base of the borehole to approximately 2 ft above the base of waste material and also at the surface of the borehole); liquid--none.

- Surface soil sampling: solid, any excess soil from that collected for the composite--returned to holes created by sample collection; liquid--none.

- Sediment sampling: solid, any excess sediment collected in auger but not retained in jars--left at sampling site; liquid--none.

- Surface water sampling: solid--none; liquid--none.

- Monitoring well installation: solid, bulked in drums for screening and/or composite testing and appropriate disposal when taken from suspect contaminated sites; otherwise left on land surface adjacent to well; liquid--none.

- Vadose zone monitor installation: solid, bulked in drums for composite testing and appropriate disposal when taken from suspect contaminated sites; otherwise, left on land surface adjacent to bore holes; liquid--none.

- Pump testing: liquid, discharged to plant waste treatment system when testing at a suspect contaminated site; otherwise, disposed of on ground surface.

- Groundwater purging/sampling: solid--none; liquid, purged from wells prior to sampling discharged to plant waste treatment system when testing at a suspect contaminated site; otherwise, disposed of on ground surface.

Disposal of any bulked "wastes" will depend on analytical test results of samples taken to characterize the wastes. One composite sample will be taken on a site-by-site basis. Testing will be done for EP toxicity, hazardous characteristics, Hazardous Substance List (HSL) organics, and radioactive materials to determine acceptability at the Rocky Flats Plant waste treatment facilities. If the material cannot be accepted by the Rocky Flats Plant waste treatment and/or disposal facilities, it will be disposed of at an appropriate offsite facility. Solid wastes such as disposable booties, Tyvek, contaminated paper, and Saran Wrap, will be considered hazardous for disposal purposes; the subcontractor site manager will ensure that wastes are disposed of in an approved manner.

7. SAMPLE ANALYSIS AND HANDLING

The testing program for samples collected during implementation of this Sampling Plan will be summarized in individual SSMPs. All water sampled (i.e., surface water, effluents, soil water, and groundwater) will be tested in the field for pH, specific conductance, and temperature. The water, waste, and soil samples will be tested for select organic, inorganic, and radiological parameters using the analytical methods detailed in the IGMP/CSPCP Quality Assurance/Quality Control Plan.

7.1. SAMPLE CONTAINERS AND PRESERVATION

Sample containers and preservation are presented in Tables 7.1 and 7.2. Analytes will be identified on a site-specific basis in the SSMPs. Although initial sampling should not include collection of other than low-hazard environmental samples, guidance regarding high-, medium-, and low-hazard samples is provided.

7.1.1. High-Hazard Samples

High-hazard samples collected for chemical analysis, those collected from drums, tanks, or spills, where they have not been diluted by environmental conditions, will be contained and preserved in accordance with EPA protocols listed in Table 7.1. These samples will be shipped directly to the laboratory for preparation of extracts. The analysis to be performed must be specified at the time the high-hazard sample preparation is scheduled. All high-hazard samples will be placed in 8-oz wide-mouth glass jars, sealed in paint cans, and marked as hazardous. No preservatives are required for high-hazard samples.

Samples collected in locations where radioactive contamination could occur will be screened in the field. It is not anticipated that any samples will qualify as radioactive under DOT regulations.

7.1.2. Medium-Hazard Samples

Medium-hazard samples are those that have originated from drums or concentrated residues, but that have been diluted somewhat by environmental conditions. Medium-hazard samples will be contained, preserved and shipped as appropriate for

testing in accordance with EPA protocols listed in Table 7.2. All medium-hazard sample containers will be placed in paint cans and marked as hazardous. In all other respects, medium-hazard samples are treated in the same manner as low-hazard samples.

7.1.3. Low-Hazard Samples

Low-hazard samples are environmental samples in which contaminants have been significantly diluted by the environment. Low-hazard samples will be contained and preserved as appropriate for testing in accordance with EPA protocols listed in Table 7.2. If necessary, samples will be placed on ice immediately after collection to maintain a temperature of $4^{o}C$.

Most groundwater samples collected for soluble inorganic metals analysis will be filtered in the field or at an onsite laboratory as soon as possible after collection but prior to the addition of nitric acid preservative. Filtering will be done with a pressure filtration device and 0.45-micron filter. Surface water samples and groundwater samples collected for total metals analysis will not be filtered prior to acid preservation.

7.1.4. Radiological Samples

Radioactive contamination of soils and water is of concern at Rocky Flats Plant. Only low-level samples are anticipated; however, samples will be screened in the field to confirm that expectation. All soil samples to be analyzed for radionuclides (e.g., tritium, uranium, plutonium, americium, and strontium) will be collected, contained, and preserved according to protocols specified for metals and cyanide in soil and sediment (Table 7.2). All water samples to be analyzed for these parameters will be collected, contained, and preserved identically to low-concentration minerals in water (Table 7.2).

7.2. SAMPLE PACKAGING AND SHIPMENT

7.2.1. High-Hazard Samples

In preparation for shipment to the analytical laboratories, all high-hazard samples will be packaged in accordance with the following procedures:

- Sample container caps will be tightened securely and sealed with tape; liquid levels will be marked if bottles are partially full.

- Sample labels will be securely attached to the sample container; each sample container will be placed in a zip-loc baggie (TM), ensuring that labels can be read.

- All bagged sample containers will be placed in paint cans, and the cans will be filled with vermiculite.

- The paint cans will be placed in a cooler lined with two inches of vermiculite or equivalent absorbent packing material; each paint can will be surrounded by packing material and all remaining space in cooler will be filed with additional packing material.

- Chain-of-custody forms will be placed in a manila envelope; the envelope will be placed in a zip-loc baggie (TM) and taped to the inside of the cooler lid.

- The cooler will be closed and sealed shut with strapping tape; if the cooler has a drain port, it will be sealed shut with tape; custody seals will be placed across the closure at the front of the cooler.

- The cooler will be marked with labels indicating hazardous substances.

- If shipped offsite, the shipper's and consignee's addresses will be fixed to the top of the cooler; if the samples are liquid, "This End Up" labels will be placed appropriately.

- The cooler will be shipped to a laboratory.

High-hazard samples will be shipped within twenty-four hours of collection if sent to an offsite laboratory.

7.2.2. Medium-Hazard Samples

Medium-hazard samples will be packaged in the same manner as high-hazard samples. Organics samples will be shipped within twenty-four hours of collection if sent to an offsite laboratory. Inorganics samples will be shipped within forty-eight hours if sent to an offsite laboratory.

7.2.3. Low-Hazard Samples

In preparation for shipment to the analytical laboratories, all low-hazard samples will be packaged in accordance with the following procedures:

- The sample will be checked for proper preservation; the sample container cap will be tightened securely and sealed with tape; liquid levels will be marked if bottles are partially full.

- Sample labels will be securely attached to the sample container; each sample container will be placed in a zip-loc baggie (TM), ensuring that labels can be read.

- The bagged sample containers will be placed in a cooler lined with two inches of vermiculite or equivalent absorbent packing material; each sample will be surrounded by packing material and all remaining space in the cooler will be filled with additional packing material.

- Chain-of-custody forms will be placed in a manila envelope; the envelope will be placed in a zip-loc baggie (TM) and taped to the inside of the cooler lid.

- The cooler will be closed and sealed shut with strapping tape; if the cooler has a drain port, it will be sealed shut with tape; custody seals will be placed across the closure at the front of the cooler.

- If shipped offsite, the shipper's and consignee's address will be affixed to the top of the cooler; if the samples are liquid, "This End Up" labels will be placed appropriately.

Samples for organic analyses will be shipped within twenty-four hours of collection if sent to an offsite laboratory. Samples for inorganic analyses will be shipped within forty-eight hours of collection if sent to an offsite laboratory.

7.2.4. Radiological Samples

Environmental samples for radiological analysis should be low-hazard and if shipped offsite will be shipped according to the procedures for low-hazard samples. Samples collected during soil sampling will be screened for radioactivity. Should radioactivity levels exceed DOT criteria for classification as radioactive (specific activity greater than 0.002 microcuries per gram), they will be labeled and shipped according to DOT regulations if sent offsite.

Table 7.1. Required Sample Containers and Preservation for High-Hazard Samples[1]

Testing	Containers	Preservation
Organics in Water and Liquids (High Concentration)		
All Organics Analysis	One 8-oz wide-mouth glass jar with Teflon-lined cap; filled 3/4 full	None required
Inorganics in Water and Liquids (High Concentration)		
All Inorganics Analysis	One 8-oz wide-mouth glass jar; filled 3/4 full	None required
Fluoride	One 500-ml polyethylene bottle filled to shoulder	None required
Organics in Soil and Sediment (High Concentration)		
All Organics Analysis	One 8-oz wide-mouth glass jar with Teflon-lined lid; filled 3/4 full	None required
Inorganics in Soil and Sediment (High Concentration)		
All Inorganics Analysis	One 8-oz wide-mouth glass jar; filled 3/4 full	None required
Fluoride	One 500-ml polyethylene bottle filled to shoulder	None required

[1] All high-hazard sample bottles must be shipped in paint cans as hazardous.

Table 7.2. Required Sample Containers and Preservation[1] for Medium and Low Hazard Samples

Testing	Containers	Preservation
Organics in Water and Liquids (Medium Concentration)[2]		
Extractables (acid, base/ neutral, pesticides/PCB)	Four 32-oz wide-mouth glass jars with Teflon-lined caps; filled to neck	None required
Volatiles	Two 40-ml VOA vials with Teflon-lined caps; completely filled--no air bubbles	None required
Inorganics in Water and Liquids (Medium Concentration)[3]		
Metals	One 16-oz wide-mouth glass amber bottle; filled to shoulder	1:1 HNO_3 to pH<2
Cyanide	One 16-oz wide-mouth glass amber bottle; filled to shoulder	6N NaOH to pH>12
Total Suspended Solids, Total Dissolved Solids	One 500-ml high density polyethylene bottle; filled to shoulder	None required
Minerals		
Acidity	One 500-ml high-density polyethylene bottle; filled to shoulder	Cool 4°C
Alkalinity		Cool 4°C
Chlorine		Room temperature
Fluoride		Room temperaure
Sulfate		Cool 4°C
Nutrients		
Ammonia	One 1-liter polyethylene bottle filled to shoulder	1 ml 1:1 H_2SO_4 to pH<2; cool 4°C
COD		
TKN		
NO_3-NO_2		
TOC		
Total Phosphorous		

Table 7.2. (Continued)

Testing	Containers	Preservation
Organics in Soil and Sediment (Medium Concentration)		
Extractables (acid, base/ neutral, pesticides/PCB)	One 8-oz, wide-mouth glass jar with Teflon-lined lid; filled about 3/4 full	None Required
Volatiles	Two 120-ml glass vials with Teflon-lined lid; filled as completely as possible	None Required
Inorganics in Soil and Sediment (Medium Concentration)		
Metals and Cyanide	One 8-oz, wide-mouth glass jar; filled about 3/4 full	None Required
Organics in Water and Liquids (Low Concentration)		
Extractables (acid, base/ neutral, pesticides/PCB)	Two 1/2-gal. glass amber bottles with Teflon-lined caps; filled to neck	Iced to $4^{o}C$
Volatiles	Two 40-ml VOA vials with Teflon-lined caps; completely filled--no air bubbles	Iced to $4^{o}C$
Inorganics in Water and Liquid (Low Concentration)[3]		
Metals	One 1-liter high-density polyethylene bottle; filled to shoulder	1:1 HNO_3 to pH<2
Cyanide	One 1-liter high-density polyethylene bottle; filled to shoulder	6N NaOH to pH>12
Total Suspended Solids, Total Dissolved Solids	One 500-ml high-density polyethylene bottle; filled to shoulder	None Required

Table 7.2. (Continued)

Testing	Containers	Preservation
Minerals		
Acidity	One 500-ml high-density polyethylene bottle; filled to shoulder	Cool $4^{o}C$
Alkalinity		Cool $4^{o}C$
Chloride		Room temperature
Fluoride		Room temperature
Sulfate		Cool $4^{o}C$
Nutrients		
Ammonia	One 1-liter polyethylene bottle filled to the shoulder	1 ml 1:1 H_2SO_4 to pH<2; cool $4^{o}C$
COD		
TKN		
NO_3-NO_2		
TOC		
Total Phosphorous		
Organics in Soil and Sediment (Low Concentration)		
Extractables (acid, base/ neutral, pesticides/PCB)	One 8-oz, wide-mouth glass jar with Teflon-lined lid; filled about 3/4 full	Iced to $4^{o}C$
Volatiles	One 8-oz glass vial with Teflon-lined lid; fill as completely as possible	Iced to $4^{o}C$
Inorganics in Soil and Sediment (Low Concentration)		
Metals and Cyanide	One 8-oz, wide-mouth glass jar; filled about 3/4 full	Iced to $4^{o}C$ (optional)

[1]All medium-hazard sample bottles must be shipped in paint cans marked as hazardous.

[2]Water samples collected for duplicate analysis must be collected at double the volume specified for organics and inorganics. In addition, one volatile trip blank (distilled-deionized water poured directly into two 40-ml vials) should be supplied per shipment.

[3]If sample preservative is required, pH will be monitored to assure proper adjustment.

8. SAMPLE DOCUMENTATION AND TRACKING

8.1. FIELD RECORDS

Field observations and other pertinent information pertaining to sample collection will be recorded in bound field notebooks using black ink. Data will be recorded on field data records contained in Appendix B of the Technical Data Management Plan and entered into the data base as described in the Technical Data Management Plan.

Notebooks shall be assigned to field personnel. Each notebook will be identified by a Document Control Number. The cover of the notebook will contain the following information: organization, book number, project name, start date, and end date.

8.2. CHAIN-OF-CUSTODY PROCEDURES

All samples will be collected and handled in accordance with the chain-of-custody procedures listed below:

- Samples will be kept in the possession or sight of at least one sampling team member at all times, unless transferred to a secure, locked area.

- A sample ID tag, including predesignated location ID and sample ID will be affixed in the field.

- Prior to relinquishing samples for packaging and shipment, one member of the sampling team will fill out a chain-of-custody record (Figure 8.1) for all team members to sign.

- If samples are stored temporarily prior to shipment, they will be kept cool and placed in a secured storage area. Coolers will be sealed and custody seals affixed just prior to shipment.

- If custody is transferred to the Shipping and Receiving Department at Rocky Flats Plant, the recipient will sign the chain-of-custody form.

- Shipping receipt for shipment by courier (above) should be retained and kept with one copy of the chain-of-custody form.

Custody Transfer Record/Lab Work Request

Received By _____ Client _____ RFW Contact _____
Date _____ Client Contact _____ Date Due _____
Assigned to _____ Phone _____ Project Number _____

SAMPLE IDENTIFICATION **ANALYSES REQUESTED**

Sample No.	Client ID No.	Description	Matrix	Date Collected	Container/Preservative								

Matrix:
S- Soil **DS-** Drum Solids
W- Water **DL-** Drum Liquids
O- Oil **X-** Other

Special Instructions:

Items/Reason	Relinquished By	Received By	Date	Time	Items/Reason	Relinquished By	Received By	Date	Time

RFW 21-21 001/A-3/86

Figure 8.1. Chain-of-Custody.

9. REFERENCES

DOE 1986b: "Comprehensive Environmental Assessment and Response Program Phase 1: Draft Installation Assessment Rocky Flats Plant," US Department of Energy unnumbered draft report, April 1986.

DOE 1986f: "Resource Conservation and Recovery Act Part B - Operating Permit Application for USDOE Rocky Flats Plant, Hazardous and Radioactive Mixed Wastes," US Department of Energy unnumbered report, November 1986.

Hurr 1976: R.T. Hurr, "Hydrology of a Nuclear-Processing Plant Site, Rocky Flats, Jefferson County, Colorado," US Geological Survey Open-File report 76-268, 1976.

RI 1986a: "Annual Environmental Monitoring Report: January-December 1985," Rockwell International Rocky Flats Plant, Golden, Colorado report RFP-ENV-85, April 1986.

RI 1986b: "Rocky Flats Plant Radioecology and Airborne Pathway Summary Report," Rockwell International, Rocky Flats Plant, Golden, Colorado unnumbered report, December 1986.

RI 1986c: "Geological and Hydrological Data Summary, Rocky Flats Plant," Rockwell International, Rocky Flats Plant, Golden, Colorado unnumbered report, December 1986.

APPENDIX A

1. DRILLING AND SAMPLING

1.1. PURPOSE

To provide procedures for borehole drilling and sampling.

1.2. DEFINITIONS

- Monitor Wells: Two-inch wells designed for monitoring water levels and groundwater quality.
- Alluvial Wells: Monitor wells completed in surficial materials (Rocky Flats Alluvium, colluvium, or valley fill alluvium).
- Bedrock Wells: Monitor wells completed in saturated sandstone of the Arapahoe or Laramie Formations.
- Piezometers: Two-inch wells completed in claystone of the Arapahoe or Laramie Formations for monitoring water levels.
- Surface Casing: Casing set and grouted through surficial materials in bedrock wells to prevent interconnection of shallow and deep flow systems.

1.3. RESPONSIBILITY

The Rockwell International CEARP Manager is responsible for the drilling and sampling program.

The Subcontractor Site Manager is responsible for direct supervision of drilling and sampling. The Subcontractor Site Manager will report daily to the Rockwell International CEARP Manager on drilling and sampling progress including any problems encountered implementing the field program.

The Field Team Leader is responsible for supervision of drilling, verification of drilled depths, and approval of the Driller's daily logs. The Field Team Leader is also responsible for sample collection, handling, and field screening.

The Driller is responsible for operating and maintaining the rig and auxiliary equipment, for keeping a clean and safe working environment, and for assisting the Field Team Leader with sampling.

1.4. EQUIPMENT AND MATERIALS

- Drilling rig with auger, rotary tricone, and diamond coring systems
- Water truck
- Rod trailer
- Maintenance and access vehicles
- Miscellaneous drilling equipment
- Volatile organic-free water
- Electric well sounder
- Glass jars and lids
- Labels
- Core boxes
- Plastic wrap
- Pipe wrenches
- Rock hammer
- Pocket knife
- Hand lens
- Tape measure divided in tenths of a foot
- Dropper bottle of hydrochloric acid
- Protractor
- Marking pens and pencils
- Field notebook
- Log of boring form

1.5. PROCEDURES

1.5.1. Alluvial Wells

(1) Alluvial wells will be drilled with hollow stem augers where practical. Boulders in the Rocky Flats Alluvium may prohibit the use of hollow stem augers, in which case alternative drilling methods such as tricone rotary will be used. Sampling through surficial materials will be performed by continuous sampling through the hollow stem augers (with split tube inner barrel) or by split spoon, depending on the materials.

(2) Alluvial wells will be drilled approximately one to three feet into bedrock. They will be terminated after confirming the presence and lithology of bedrock.

(3) The hole diameter will be a minimum of four inches. The use of hollow stem augers eliminates the need for drilling fluids; however, some volatile organic-free water may be used if hole stability is a problem. In no event will mud or foaming agents be used.

1.5.2. Bedrock Wells

(1) Bedrock wells will be augered and rotary drilled through surficial materials and weathered bedrock as described above.

(2) Upon penetration of unweathered bedrock, steel surface casing will be set and neat cement grout will be placed in the annulus through a tremie pipe or by pushing a plug of cement through the surface casing. The surface casing will be approximately 6 in. in diameter.

(3) Grout will be neat Type I or Type II Portland cement, mixed with volatile organic-free water at a mix ratio of 6 to 9 gal. of water per 94-lb bag of cement. Grout will be allowed to set at least twenty-four hours before drilling resumes.

(4) The hole will proceed through bedrock by rotary coring (size NX or larger), using bentonite mud, volatile organic-free water, air mist (air and volatile organic-free water), or filtered air.

(5) Drilling will progress into bedrock until at least 3 ft of saturated sandstone within a 10-ft interval of bedrock is encountered, or until the well is approximately 100 ft deep. Wells may be drilled deeper than 100 ft to fully penetrate a sandstone.

(6) After drilling through sufficient sandstone thickness (as defined above), the hole will be cleaned and stabilized for packer testing.

(7) Geophysical logging may be performed in some holes after packer testing.

(8) After packer testing and geophysical logging are completed, the hole will be reamed, if necessary, to a minimum of 4 in. for well installation.

1.5.3. Sampling and Logging

(1) The Driller will provide either continuous samples from a split tube sampler, split-spoon samples, rotary cuttings, or NX core, depending on the drilling method.

(2) As drilling progresses, the Field Team Leader will confirm sample depths with the Driller, describe the samples, and field screen the sample for organic or radioactive contamination. Descriptions and screening results will be recorded in the field notebook and on a log of boring form. The Field Team Leader will also note the depth at which groundwater is encountered.

(3) Sample descriptions will include the following items as appropriate:

- Borehole designation
- Time and date
- Interval footage and recovered footage
- Name of unit and/or brief rock name
- Characteristic structures of the unit
- Fossils
- Lithologic description
- Nature of contacts
- Water content
- Organic and radioactive field screening results.

(4) Auger and rotary cuttings will be bottled in glass jars and labeled. Intervals designated for chemical analyses will be placed in jars and stored on ice in coolers. These samples will be delivered to the onsite laboratory, if an onsite laboratory is used, within 3 hours of collection.

(5) Core continuous split tube samples, and split-spoon samples will be wrapped with clear plastic to prevent rapid drying and cracking and placed in NX or NC size core boxes as appropriate. Wooden blocks will be inserted in the boxes at the beginning and end of runs to mark footages and will indicate lost core zones. Core boxes will be labeled and stored.

(6) The Driller will keep a daily log detailing footage drilled, material used, and stand-by time. The Field Team Leader will keep an independent record of drilling activities in the field notebook to verify the daily logs. One copy of the daily logs will be submitted to the Subcontractor Site

2. MATERIALS DESCRIPTION

2.1. PURPOSE

To provide procedures for field descriptions of surficial and bedrock materials.

2.2. RESPONSIBILITY

The Field Team Leader is responsible for describing core and samples following this work procedure.

2.3. EQUIPMENT AND MATERIALS

- Log of boring
- Field notebooks
- Clipboard
- Rulers
- Rock-color chart, Geological Society of America
- Waterproof pens
- Colored pencils
- Protractor
- Hand lens
- Dropper bottle of hydrochloric acid
- Rock hammer
- Grain-size chart/scale

2.4. PROCEDURES

(1) All surficial materials and bedrock samples will be described using the following sequence of parameters:

- Footage
- Sample type
- Percent recovery
- General material type
- Color
- Structural characteristics
- Grain sizes
- Composition of grains
- Degree of sorting
- Grain shapes
- Minor characteristics

- Degree and nature of cementation
- Moisture content

Procedures for describing each of these parameters are presented below.

(a) Footage: Depth of sample interval.

(b) Sample Type: Continuous drive, cuttings, core, or split spoon.

(c) Percent Recovery: Percent of sample recovered from borehole.

(d) General Material Type: Clay, clayey sand, sandy clay, Silt, sand, gravel, sand and gravel, shale, sandstone, or siltstone.

(e) Color: Color of samples will be described by comparing samples with a standard color chart. Either a Munsel soil color chart or USGS standard color chart will be used. Colors will be described from moistened samples. Any color abbreviations shall follow those set by the standard color chart used.

(f) Structural Characteristics: This parameter describes bedding and other primary features of the sample, including: nature of bedding (e.g., massive, tabular, lenticular, laminated, graded, or even); primary features within beds or other structures (e.g., grading, laminations, cross bedding, channeling, distorted flow banding, and inclusions); and characteristic secondary features (e.g., cleavage, prominent weathering effects, and fracturing) (Compton 1962).

(g) Grain Size: Grain sizes will be classified according to the Wentworth scale (Dresser Atlas 1982). The percentage of each grain size will be denoted by the following descriptive terms.

Descriptive Term	Percentage
Trace	1-10%
Some	10-20%
Adjective (sandy, silty, etc.)	20-35%
"And"	35-50%

(h) Composition of Grains: Composition of grains will be described by using the major or dominant grain component first, followed by

minor component percentages or the appropriate descriptive term (Compton 1962).

(i) Degree of Sorting: The degree of sorting is a measure of particle size uniformity. It will be visually estimated in the field using sorting charts (Dresser Atlas 1982).

(j) Grain Shapes (Roundness): Roundness is the degree of a clastic particle abrasion and is reflected in the sharpness of its edges and corners. Grain shapes will be determined visually in the field using grain shape charts (Dresser Atlas 1982).

(k) Minor Characteristics: Minor and/or unusual characteristics of a sample will be noted in the description including weathering.

(l) Degree and Nature of Cementation: The degree of cementation will be recorded as uncemented or unconsolidated, poorly cemented or consolidated, or well cemented, based on visual inspection. The nature of calcium carbonate will be determined based on the reaction of samples to dilute hydrochloric acid. The intensity of the hydrochloric acid reaction will be described as no reaction, weak reaction, or strong reaction.

(m) Moisture Content: A general qualitative description will be used to describe moisture content.

Dry: No discernible moisture present.

Damp: Enough moisture present to darken the color of the sample, but does not feel moist to the touch.

Moist: Sample feels moist to the touch.

Wet: Visible water is present.

(2) Geologic descriptions of core will follow the same procedures as outlined above. Additional records required for core are: the cored (run) interval, the footage of recovered core and percent recovery, and the Rock Quality Designation (RQD) of the cored interval. RQD is the percent of sound core recovered in pieces greater than four inches in length (Deere 1964).

2.5 RECORDS

- Field Notebooks
- Log of Boring

2.6. REFERENCES

Compton, R. R., 1962, *Manual of Field Geology*: John Wiley and Sons, Inc., New York, 378 pp.

Deere, D. U., 1964, Technical Description of Rock Cores for Engineering Purposes: Rock Mechanics and Engineering Geology, Vol. 1, pp. 16-22.

Dresser Atlas, 1982, *Well Logging and Interpretation Techniques*: Dresser Atlas, Inc., 228 pp.

3. FIELD SCREENING FOR TOTAL ORGANIC COMPOUNDS IN SOIL SAMPLES

3.1. PURPOSE

To field screen soil samples for volatile organic compounds.

3.2. RESPONSIBILITY

The Field Team Leader is responsible for field screening of samples following this work procedure.

3.3. EQUIPMENT AND MATERIALS

- Field notebooks
- Log of boring
- Adhesive labels
- Waterproof pen
- Sample bottles (500-ml amber glass) with lids
- Photoionization detector (PID)
- Organic vapor analyzer (OVA)

3.4. PROCEDURES

(1) Approximately 50 to 100 ml of soil will be placed in 500-ml amber glass jars, and an equal amount of deionized water will be added to the jar. The jar will then be shaken and allowed to stand for 30 minutes allowing organic compounds to volatilize.

(2) The sample jars will be labeled with the date, time, borehole number, sample depth, and Field Team Leader's.

(3) Field screening of the samples for total organic vapor concentrations will be conducted using an OVA and a PID. The instruments will be calibrated to the volatile organic compounds of concern at each site (Roffman et al. 1986).

(4) The lid of the sample jar will be opened slightly and the probes of the instruments will be placed inside the jar. Values registered on each instrument will then be recorded in the field notebook. The

date and time of the reading, the borehole number, and the sample depth will also be recorded in the field notebook and log of boring.

3.5. RECORDS

Field notebooks
Logs of borings

3.6. REFERENCES

Roffman, H. K., M. D. Neptune, J. W. Harris, A. Carter, and T. Thomas, Field Screening for Organic Contaminants in Samples from Hazardous Waste Sites, 1986, Abstract from: Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater-Prevention, Detection, and Restoration, Houston, Texas, 8 p.

4. LABELING AND STORAGE OF SAMPLES

4.1. PURPOSE

To provide procedures for labeling and storage of boxed cores and jarred samples.

4.2. DEFINITIONS

- Storage Facility: The location where boxed cores and/or jarred samples will be stored without freezing.

4.3. RESPONSIBILITY

The Field Team Leader is responsible for labeling and storage of all samples.

4.4. EQUIPMENT AND MATERIALS

- Labeling Pens
- Adhesive Labels
- Inventory Sheets
- Field Notebook

4.5. PROCEDURES

(1) Label core boxes and sample jars in the field as samples are collected. All samples will be labeled with

(a) location
(b) borehole designation
(c) date
(d) depth
(e) box or jar number
(f) total number of boxes or jars for the borehole
(g) Field Team Leader initials

Check that all information is correct before leaving the field with samples.

(2) Transport samples to storage facility.

5. DECONTAMINATION OF DRILLING, TESTING, AND SAMPLING EQUIPMENT

5.1. PURPOSE

To provide procedures for equipment decontamination.

5.2. DEFINITIONS

Equipment: Augers, drill pipe, bits, sampling devices, tools, tremie pipe, packers, water pipe, geophysical logging equipment, casing, electric well sounders, pumps, and all other miscellaneous equipment used in drilling, sampling, testing, logging, installing, and developing monitor wells.

Decontamination: Decontamination is the process of cleaning equipment to avoid transport of contamination.

5.3. RESPONSIBILITY

The Field Team Leader is responsible for supervising and approving the decontamination cleaning of equipment.

The Driller is responsible for cleaning all drilling, sampling and well construction equipment and assisting the geophysicist in cleaning geophysical probes and cables.

5.4. EQUIPMENT AND MATERIALS

- Portable Steam Cleaner
- Brushes and Buckets
- Organic-free Water
- Alkaline Detergent

5.5. PROCEDURES

5.5.1. <u>Drilling and Well Installation Equipment</u>

(1) Decontaminate all drilling equipment before starting the first borehole.

(2) Upon termination of a borehole, decontaminate all drilling, packer testing, and geophysical logging equipment as well as stainless steel well casing and screen.

(3) Decontamination will include:

(a) a rinse with the steam cleaner using organic-free water;

(b) scrubbing with brushes using a solution of organic-free water and an alkaline detergent; and

(c) a final rinse with the steam cleaner using organic-free water.

(4) Cover drilling equipment with a clean sheet of plastic after it is decontaminated. Install wet casing and screen in the borehole.

(5) Decontaminate all equipment and tools used in well installation.

(6) Before moving to the next drill site, decontaminate the wireline cable by pulling it off the drum to the appropriate length. Also decontaminate the rig table and mast.

5.5.2. <u>Sampling Equipment</u>

(1) Decontaminate all sampling equipment before collecting the first sample and after each sample collected.

(2) Decontamination will include:

(a) scrubbing with brushes using a solution of organic-free water and an alkaline detergent; and

(b) a rinse with organic-free water (a steam cleaner may be used).

(3) Decontaminate the electric well sounder probe and cable before and after measuring water levels.

(4) Decontaminate pumps and pump line exteriors before and after pumping a monitor well. Decontaminate the internal system of pumps and tubing by pumping at least 1 tubing volume of organic free water through the pump.

6. PACKER TESTING

6.1 PURPOSE

To provide information for executing and analyzing packer tests.

6.2. DEFINITIONS

Packer Tests: Packer tests are performed in cored sections of open boreholes to isolate and test the hydraulic conductivity of selected zones. The selected zone is sealed with packers and water is injected into the formation under constant pressure. The flow rate and water pressure in the test section is then compared to the hydraulic conductivity of the material (DOI 1980).

Packer: A packer is a pneumatically inflatable rubber gland which is used to seal a section of the borehole against leakage so that water pressure can be applied to the test section. Single or paired "straddle" packers will be used to isolate test zones (U.S. DOI 1980).

6.3. RESPONSIBILITY

The Subcontractor Site Manager is responsible for determining the borehole intervals to be tested. The test intervals will be approved by the Rockwell International CEARP Manager prior to the packer tests.

The Field Team-Leader is responsible for supervising packer tests, recording all data, and analyzing data.

The Driller is responsible for performing packer tests.

6.4. EQUIPMENT AND MATERIALS

- Organic-free water supply
- Packer assembly
- Pressure gauge assembly
- Flow metering device
- Nitrogen supply and associated connections
- Watch
- Lithologic log of borehole being tested

- Tape measure divided in tenths of feet
- Packer test data sheets
- Field notebook

6.5. PROCEDURES (DOI 1980)

6.5.1. Test Procedures

(1) Record background information at the top of the packer test data sheet.

(2) Remove the core barrel and other tools from the hole.

(3) Set the packers at the prescribed depth and inflate to at least 70 psi above hydrostatic pressure.

(4) Fill the test section with water and adjust the water pressure so the combined static plus gauge pressure does not exceed approximately one-third of the overburden pressure at the top of the test section. Use an overburden pressure of 1 psi/ft.

(5) Observe any leaks in the packer assembly or the packer seal and reseat the assembly as necessary.

(6) Record the flow rate of water into the hole in gallons per minute at equal intervals until steady readings are achieved (at least 15 minutes).

(7) Repeat the test twice more in the same test interval, first at a combined pressure head of approximately two-thirds the overburden pressure, and then again at a combined pressure head of approximately one-third the overburden pressure. The same data recording and time intervals described above should be used.

6.5.2. Data Analyses Procedures

Data analyses will be performed by the Field Team Leader as the tests are performed to assure reasonable results. Calculations will be verified in the office.

The formula for calculating hydraulic conductivity from packer test data is

$$K = \frac{Q}{2(PI)(L)(H)} \ln \left(\frac{L}{r}\right) ,$$

where

K = Hydraulic conductivity (ft/min),
Q = Injection rate ($feet^3$/min),
L = Length of test section (ft),
H = Differential head of water (ft),
= Distance from the water table to the gage plus gage pressure for test intervals below the water table,
= distance from the center of the test interval to the gage plus gage pressure for test intervals above the water table,
r = Radius of borehole (ft),
ln = Natural logarithm, and
PI = 3.141592.

6.6. RECORDS

- Packer test data sheet
- Field notebook

6.7. REFERENCES

Department of the Interior, Bureau of Reclamation, 1974, *Earth Manual - A Water Resources Technical Publication*, US Government Printing Office, 810 p.

7. GEOPHYSICAL LOGGING

7.1. PURPOSE

To provide procedures for geophysical logging of deep boreholes.

7.2. DEFINITIONS

Geophysical Logging: Logging is a remote sensing technique that uses tools lowered into drill holes to evaluate properties of surrounding media. The logging suite will include spontaneous potential, single-point resistance, 16-in. resistivity, and natural gamma ray.

Geophysicist: The company providing logging equipment and personnel for geophysical logging.

7.3. RESPONSIBILITY

The Subcontractor Site Manager is responsible for selecting the boreholes to be geophysically logged. Borehole selections will be approved by the Rockwell International CEARP Manager prior to logging.

The Field Team Leader is responsible for assisting the Geophysicist as necessary and documenting geophysical logging.

The Geophysicist is responsible for geophysical logging of boreholes.

7.4. EQUIPMENT AND MATERIALS

Appropriate equipment for geophysical logging, data acquisition, and data recording will be provided by the Geophysicist.

7.5. PROCEDURES

(1) Decontaminate the geophysical logging probe and cables.

(2) Record all pertinent well data at the top of the geophysical log or in the field notebook (as determined by the Geophysicist).

(3) Center the probe over the open borehole and mark zero at ground surface.

(4) Lower the probe into the hole. Scales will be adjusted by the Geophysicist at this time.

(5) Note total logging depth when the probe reaches the bottom of the hole.

(6) Pull the probe out of the hole at a constant speed while recording geophysical logs.

(7) The Field Team Leader will record the date and time of the Geophysicist's arrival and departure from the borehole as well as the borehole designation and the logging site. The Field Team Leader will also observe geophysical logging and record any pertinent observations in the field notebook.

(8) Copies of all well logs will be delivered to the Subcontractor Site Manager and the Rockwell International CEARP Manager as soon as they are put in final form by the Geophysicist.

7.6. RECORDS

- Field notebook
- Geophysical logs

8. WELL INSTALLATION

8.1. PURPOSE

To provide procedures for monitor well construction and installation.

8.2. DEFINITIONS

Monitor Well: Two-inch well designed for monitoring water levels and groundwater quality.

Alluvial Well: Monitor well completed in surficial materials (Rocky Flats Alluvium, colluvium, or valley fill alluvium).

Bedrock Well: Monitor well completed in saturated sandstone of the Arapahoe or Laramie Formations.

Piezometers: Two-inch well completed in claystone of the Arapahoe or Laramie Formations for monitoring water levels.

8.3. RESPONSIBILITIES

The Subcontractor Site Manager is responsible for selecting completion intervals and well designs. Completion intervals and well designs will be approved by the Rockwell International CEARP Manager prior to well construction.

The Field Team Leader is responsible for supervision and documentation of well completions.

The Driller will assemble and install all materials.

8.4. EQUIPMENT AND MATERIALS

- Schedule 5 Type 316 stainless steel casing
- Schedule 5 Type 316 stainless steel wire wrap screen
- Type 316 stainless steel centralizers
- Bentonite pellets
- Appropriate filter pack
- Neat Type I or II Portland cement

- Concrete mix
- Organic-free water
- Five-gallon buckets
- Tremie pipe
- Hoses and pump
- Shovel
- Trowel
- Protective surface casing
- Padlock
- 100-ft tape measure divided in tenths of a foot with a weight on the end
- Electric well sounder
- Well construction summary data sheets
- Field notebook

8.5. PROCEDURES

(1) Pull all augers and drill pipe from borehole. If borehole stability is a problem, the wells may be completed inside the hollow stem augers.

(2) Decontaminate drilling equipment and casing.

(3) Measure depth to water and design well construction.

Alluvial Wells. The screened interval in alluvial wells will extend from approximately 1 ft below the top of bedrock to 2 to 5 ft above the water table. A filter pack designed for the grain size of the formation will be placed around the screened interval and will not extend more than 2 ft above the top of the screened interval. A 1-ft-thick bentonite seal will be placed above the filter pack, and the annulus will be tremie grouted with neat Portland Type I or II cement to the surface. Cement may be poured from the surface if the cemented interval is within 5 ft of the surface. A locking steel protective casing will be placed over the well, and a concrete surface pad, approximately 3 ft in diameter, will be poured around the surface casing. The pad will be sloped so as to drain away from the well.

Bedrock Wells. Bedrock monitor wells will be screened across the entire interval of saturated sandstone with a minimum screened interval of 5 ft. Filter pack, bentonite, cement grout, protective casing, and a concrete pad will be placed as described above.

Piezometers. Deep boreholes which do not encounter sufficient sandstone thickness after drilling through 70 ft of claystone with an average hydraulic conductivity of 5×10^{-7} centimeters per second will be completed as piezometers with two-inch, Schedule 80, threaded and flush jointed, polyvinylchloride (PVC) casing. Ten ft of machine slotted casing will be placed at the base of the casing string. The remainder of the well completion will be as discussed above for alluvial monitor wells.

(4) Calculate the amount of filter pack, bentonite, and cement that will be required for well construction.

(5) Weld end cap on the bottom of the well screen with a stainless steel welding rod, and thread the casing string together.

(6) Place centralizer in the center of the screened interval, and determine its location on the casing string to the nearest 1/100th foot.

(7) Measure the length of the screened interval and the blank casing to the nearest 1/100th ft.

(8) Measure total depth of the open borehole. If the bottom of the borehole is below the base of the screen, backfill it with bentonite pellets or tremie cement grout to the base of the screen. If the open borehole is backfilled with grout, allow it to set for 24 hours before well completion. Measure total depth of the open borehole again.

(9) Place casing string in open borehole. Place slip-on cap on top of the casing string. Measure stick up to determine total well depth. Check well design for correct total depth.

(10) Slowly pour filter pack into borehole annulus, making sure it is evenly distributed around the well casing. Gently shake the casing as filter pack is added to avoid bridging of the filter pack. Measure depth to the top of the filter pack after each bag is added. Make more frequent measurements as filter pack approaches the top of the screened interval.

(11) Record the final depth to the top of the filter pack on well construction summary sheet. Record amount of filter pack used in the field notebook.

(12) Pour bentonite pellets into borehole annulus, making sure they are evenly distributed around the well casing.

(13) Measure depth to the top of the bentonite seal and record on well construction summary sheet. Record amount of bentonite used in the field notebook.

(14) If the bentonite pellets are above the water table, add 1 to 2 gal. of organic-free water to the hole. Allow the bentonite to swell for approximately 15 minutes before grouting to the surface.

(15) Mix neat Type I or II Portland cement (as directed by the Subcontractor Site Manager) at a mix ratio of 6 to 9 gal. of water per 94-lb bag of cement.

(16) Place tremie pipe in borehole annulus and attach appropriate hoses and pump.

(17) Pump grout down borehole annulus. Pour grout from the surface if the cemented interval is within 5 ft of the surface. Record amount of cement used in field notebook.

(18) Measure final stick-up of well casing and record on well construction summary sheet.

(19) Set protective surface casing over stainless steel well casing.

(20) Allow grout to set for 24 hr.

(21) Place form for concrete surface pad around well casing.

(22) Mix concrete and pour surface pad around well casing. Slope pad away from the well with a trowel.

(23) Weld well number on protective surface casing.

9. WELL DEVELOPMENT

9.1. PURPOSE

To provide procedures for well development.

9.2. DEFINITIONS

Well Development: Well development is the process by which fines from the formation and/or filter pack are removed from the vicinity of the well bore in order to increase the efficiency of the well (UOP Johnson Division 1975).

9.3. RESPONSIBILITY

The Subcontractor Site Manager is responsible for determining which method of development will be used. Well development methods will be approved by the Rockwell International CEARP Manager prior to well development.

The Field Team Leader is responsible for well development.

The Driller will be responsible for supplying an air compressor with an air filter if the well is developed by the air lift method.

9.4. EQUIPMENT AND MATERIALS

- Electric well sounder
- Tape measure calibrated in tenths of feet
- Stainless steel pump*
- Air compressor*
- Teflon bailer*
- Bailer rope*
- PVC drop pipe*
- Gasoline powered generator*
- One liter beaker
- Watch
- Calculator
- Well development summary sheets
- Field notebook

*NOTE: The use of these materials will depend on the method of well development selected.

9.5. PROCEDURES

The well will be developed by pumping, bailing, or air-lifting. Pumping is the preferred method of well development and will be used wherever possible. Air-lifting is less desirable because the potential exists for oils from the air compressor to enter the wells, but may be necessary to adequately stress the wells. An air filter will be used if air-lifting is necessary. Bailing is not an efficient method of well development because of the low flow rates induced by bailing. Bailing will only be done in the event of pump failure and to remove sediments in the bottom of the casing.

(1) Decontaminate all equipment prior to well development.

(2) Measure the water level in the well.

(3) Record the water level on the water level data sheet. Record the date, time, well, and development methods on the well development summary sheet.

9.5.1. Pumping

Well development by pumping will be accomplished by means of a two-inch stainless steel piston pump. The pump will be lowered to approximately 1 ft above the bottom of the well. The well will then be pumped until ten casing volumes of water have been removed from the well, until the well water is clear, or until 4 h have elapsed. The pump will be raised 2 ft at periodic intervals until the entire screened interval is developed.

9.5.2. Air Lifting

Well development by air lifting will be accomplished by using an air compressor and 1-in. PVC air line. An air filter will be attached to the air line from the air compressor to prevent the introduction of compressor oils or other foreign materials into the well.

The 1-in. PVC air line will be lowered until within approximately 2 ft of the bottom of the well. The air line from the air compressor will then be attached to the top section of PVC pipe. The well will then be developed by the introduction of

compressed air into the well for approximately fifteen minutes, or until a column of water is removed from the well. The well will then be allowed to recover and another column of water discharged to the surface. This process will be repeated until 10 casing volumes of water have been removed from the well, until the produced water is clear, or until 4 h have elapsed. At periodic intervals, the air line will be raised 2 ft until the entire screened interval is developed.

9.5.3. Bailing

Well development by bailing will be accomplished using a Teflon bailer and small diameter polypropylene bailing rope. Water, formation and/or filter pack materials will be removed from the well by bailing until 10 casing volumes of water have been removed from the well, until the well water is clear, or until 4 h have elapsed. The bailing rope will be discarded following well development.

9.6. RECORDS

- Well development summary sheets
- Field notebook

9.7. REFERENCES

Johnson, E. E., Inc., *Groundwater and Wells - A Reference Book for the Water-Well Industry*, 1980, Johnson Division, UOP, Inc., Saint Paul, Minnesota, 440 p.

10. DRAWDOWN RECOVERY TESTS

10.1. PURPOSE

To provide procedures for executing and analyzing drawdown-recovery tests.

10.2. DEFINITIONS

Pumping Well: A monitor well which will be pumped during the drawdown phase of the test.

Observation Well(s): A monitor well(s) or piezometer(s) located in the vicinity of the pumping well in which water levels will be measured for the duration of the drawdown-recovery test.

Drawdown: Drawdown is the lowered water level in either the pumping well or observation well(s) in response to pumping.

Recovery: Recovery is the water level response in either the pumping well or observation well(s) in which the depth to water is decreasing in response to cessation of pumping.

Transmissivity: Transmissivity is the rate at which water is transmitted through a unit width of the full saturated thickness of a subsurface material, under a unit hydraulic gradient (Freeze and Cherry 1979).

Storage Coefficient: The storage coefficient of a confined porous media is the volume of water released from storage, or taken into storage, per unit change in hydraulic head (Freeze and Cherry 1979).

Specific Yield: Specific yield is the volume of water that an unconfined porous medium releases from storage per unit volume of material per unit decline in the water level (Freeze and Cherry 1979).

10.3. RESPONSIBILITY

The Field Team Leader is responsible for supervising drawdown-recovery tests, measuring water levels in the pumping well and observation well(s), and determining flow rates from the pumping well.

10.4 EQUIPMENT AND MATERIALS

- Stainless steel piston pump
- Air compressor to drive pump
- Electric well sounder
- Tape measure calibrated in tenths of feet
- Five gallon bucket
- Watch
- Drawdown-recovery test data sheets
- Field notebook

10.5. PROCEDURES

10.5.1. Test Procedures

(1) Decontaminate all equipment before beginning test.

(2) Measure static water levels in pumping well and observation wells.

(3) Lower 2-in. piston pump to within approximately 1 ft of the bottom of the well.

(4) Measure the static water level again and commence pumping.

(5) Continue pumping at a constant discharge rate for up to 8 h (for tests where observation wells are available) or up to 4 h (for single hole tests), or until the rate of drawdown assumes a near constant rate of 0.25 ft of drawdown in 1 h.

(6) Measure water levels at frequent time intervals with an electric well sounder in the pumping well and nearby observation wells (if available). Water levels shall be measured at 0.5, 1, 1.5, 2.3, 3.5, 10, 20, 30 and 45 minutes, followed by measurements at 1, 1.5, 2, 3, 4, 5, 6, 7, and 9 hours.

(7) Measure pumping rates with a 5-gal. bucket and watch, or with a flow meter.

(8) Record water levels and pumping rates on the drawdown-recovery test data sheets.

(9) Calculate water level equivalent to 90% recovery of the static water level.

(10) Following pumping, measure water levels in the pumped well and the observation well(s) following the schedule in item 6, until they recover to within 90% of the static water level.

(11) Record these data on the drawdown-recovery tests data sheets.

10.5.2. Data Analysis Procedures

Data will be analyzed by the Theis method for confined flow-systems (Jacob 1950). Modifications to the Theis equations will be used to analyze data from unconfined systems and to analyze recovery data as discussed below. If drawdown and/or recovery data are available for a nearby observation well, both transmissivity and the storage coefficient or specific yield will be calculated. If only data from the pumped well is available, transmissivity will be calculated and the storage coefficient will be estimated based on laboratory effective porosity tests.

The Theis equation is of the form

$$s = \frac{114.6\ Q}{T} W(u) ,$$

where

$$u = \frac{1.87 r^2 S}{4Tt} \text{ and}$$

$$W(u) = (-0.5772 - \ln(u) + u - \frac{u^2}{2x2!} + \frac{u^3}{3x3!} ...) ,$$

and where

s = drawdown in feet at an observation well due to pumpage from a given well,
Q = pumpage from the pumping well in gallons per minute,
S = storage coefficient, dimensionless,
T = transmissivity in gallons per day per foot,
r = radian distance in feet from the pumping well to the observation well, and
t = time in days (Freeze and Cherry 1979).

The following limiting assumptions apply to the Theis equation: transmissivity of the porous media is constant in time and space, the porous media is isotropic and homogeneous with respect to transmissivity, the media is infinite in areal extent, there is no leakage from overlying or underlying units, there is only a single pumping well, the pumping rate is constant with time, and wells penetrate the entire thickness of the porous media (Freeze and Cherry 1979).

For unconfined groundwater flow systems, specific yield (Sy) is used in place of storage coefficient (S), and transmissivity is defined as

$$T = K\,b\,,$$

where

K = hydraulic conductivity in gallons per day per foot squared, and

b = the initial saturated thickness.

Jacob (1950) has shown that this approach is acceptable as long as drawdowns are small compared to the saturated thickness.

To calculate transmissivity and storage coefficient (or specific yield) from recovery data, the Theis equations will be used in the form

$$s = \frac{114.6\,Q}{T}\,[W(u_1) - W(u_2)]\,,$$

where

$$u_1 = \frac{r^2 S}{4Tt} \text{ and } u_2 = \frac{r^2 S}{4Tt'}\,,$$

and where

t = time in days since the start of pumping, and
t' = time in days since recovery began (Freeze and Cherry 1979).

10.6. RECORDS

- Aquifer test data sheets
- Field notebook

10.7. REFERENCES

Freeze, R.A. and J.A. Cherry, 1979, *Groundwater.* Prentice Hall, Inc., Englewood Cliffs, New Jersey, 524 pp.

Jacob, C.E., 1950, *Flow of Groundwater: Engineering Hydraulics*, John Wiley and Sons, New York, pp. 321-386.

11. WELL PURGING

11.1. PURPOSE

To provide procedures for well purging.

11.2. DEFINITIONS

Casing Volume: The casing volume is the volume of water standing inside the casing, i.e., the distance between the water level and the bottom of the casing (length of the water column in the well) multiplied by the inner cross-sectional area of the casing.

Well Purging: Purging is the removal of sufficient water from the well so that representative formation waters enter the well and can be sampled. Purging will consist of removing three casing volumes.

11.3. RESPONSIBILITY

The Subcontractor Site Manager is responsible for selecting well purging methods. Well purging methods will be approved by the Rockwell International CEARP Manager prior to purging.

The Field Team Leader is responsible for purging wells prior to sampling.

11.4. EQUIPMENT AND MATERIALS

Wells will be purged using dedicated bladder pumps, dedicated Teflon bailers, or portable sampling pumps. Because of the various purging methods, some or all of the following equipment will be needed.

- Bladder pump
- Oil-less air compressor
- Stainless steel piston pump
- Polypropylene rope
- Large container of known volume
- Deionized water
- Watch
- Calculator

- Pencil
- Field Water Quality Data Sheet
- Field notebook

11.5. PROCEDURES

11.5.1. Calculations

(1) Calculate the casing volume using the formula

Casing volume (gallons) = (TD - WL) * (A),

where

TD	=	total depth of the well from ground surface (ft),
WL	=	depth to water from ground surface (ft),
A	=	cross sectional area of the well (gallons/ft),
	=	0.163 for a 2-in. well,
	=	0.367 for a 3-in. well,
	=	0.652 for a 4-in. well, and
	=	1.468 for a 6-in. well.

Note that total depth and depth to water must be measured from the same datum. The total depth of the casing is usually reported as depth below ground surface and the depth to water is measured from the top of the inner casing. In order to correct the depth to water measurement, subtract the height of casing above ground from the depth to water measured from the top of casing.

(2) Multiply the casing volume by three. This is the volume of water to be purged.

(3) Record calculations in the field notebook and on Field Water Quality Data Sheet.

11.5.2. Purging

Remove three casing volumes of water from the well using the pump, the dedicated Teflon bailer, or the portable sampling pump. Regardless of the methods used to purge the well, record the total volume purged and the time when purging begins and ends.

Dedicated Pump System. The dedicated pump system will consist of an air-actuated bladder pump with downward flow checking valves on the inlet to the inside of the bladder and on the tubing above the outlet from the inside of the bladder. Air is delivered to the outside of the bladder and pressure is maintained long enough that the bladder is compressed and water inside it is forced into the discharge tubing. Water is kept from exiting the bottom of the pump by the lower check valve. The air pressure is vented to surface through the same pressurizing tube (requiring a time dependent on length of tubing, required air pressure, and depth of submergence of the pump). Water forced into the discharge tubing is held by the upper check valve. The cycle is repeated until discharge reaches the surface and purging begins. Because of this pumping mechanism, the discharge is delivered to the surface in cyclic slugs, but the pressurizing air is never in contact with the water.

The upper check valve has a small-diameter bypass so that water in the discharge tubing will drain back into well and not freeze.

(1) Attach compressor to Pump Pressure Inlet on controller (use oil-less compressor to protect pneumatic logic components inside controller).

(2) Connect red air hose between well cap and Pump Supply on controller.

(3) Position Refill and Discharge knobs to center position (12 o'clock) and start compressor. Record the time at the start of pumping in the field notebook.

(4) Set gas pressure level to a pressure sufficient to lift the column of water in the discharge tubing plus 30 psi, but do not exceed 125 psi total.

(5) Adjust Discharge knob so that venting occurs at the end of the slug discharge.

(6) Decrease Refill cycle time until volume discharged in each cycle begins to decrease. If decrease is immediate, lengthen both Refill and Discharge cycle times and repeat steps 5 and 6.

(7) Measure volume produced in a container of known volume (e.g., plastic trash can or plastic bucket).

(8) Continue pumping until the appropriate volume has been purged. Record time at end of pumping as well as the total volume pumped in the field notebook and on the Field Water Quality Data Sheet.

(9) Measure and record water level at the end of pumping.

Bailing

(1) Put on surgical gloves. New cotton gloves may be worn over the surgical gloves if desired.

(2) Place a sheet of plastic over the casing. Cut a hole in the plastic for the casing and spread sheet on ground around the well. The plastic and equipment should be arranged in such a manner to enable the samplers to do all work while standing on the plastic.

(3) Attach new polypropylene rope to bailer inspect the check valve, top bail, knot, and rope. Do not allow bailer or rope to contact anything but clean plastic. If any components are loose or damaged, replace them. Decontaminate equipment if any new parts are used.

(4) Lower bailer into well, fill with water, and hoist to surface, coiling the rope into the hands.

(5) Empty bailer into a container of known volume (e.g., 5-gal. bucket).

(6) Continue bailing until appropriate volume has been purged, as determined by volume in container.

(7) Record volume purged in the field notebook and on Field Water Quality Data Sheet.

Portable Pump

(1) Decontaminate the pump and sufficient tubing by scrubbing with an al-alkaline detergent solution followed by a deionized water rinse. Pump at least one tubing volume of deionized water through the pump.

(2) Place decontaminated pump approximately 1 ft above the bottom of the well.

(3) Place up-hole end of the discharge line in container of known volume (e.g., plastic trash can or 5-gal. bucket).

(4) Connect compressor to pump controller.

(5) Turn on compressor and pump appropriate volume as measured in container.

(6) Record purged volume on the Field Water Quality Sheet.

(7) After collecting the sample, decontaminate pump by scrubbing all tubing that has been pulled off the reel and the pump itself with an alkaline detergent solution and rinsing with deionized water. Pump at least one tubing volume of deionized water through the pump.

11.6. RECORDS

- Field water quality sampling and analysis form
- Field notebook

11.7. REFERENCES

U.S. Environmental Protection Agency, 1986, *Hazardous Waste Groundwater Task Force Protocol for Groundwater Evaluation*, Office of Solid Waste and Emergency Response, Washington, D.C., DIR 9080.0-1.

12. GROUNDWATER SAMPLING

12.1. PURPOSE

To provide procedures for groundwater sample collection.

12.2. RESPONSIBILITIES

The Subcontractor Site Manager is responsible for assigning specific wells to be sampled. The sampling schedule will be approved by the Rockwell International CEARP Manager prior to implementation.

The Field Team Leader is responsible for sampling monitor wells, field water quality measurements, and transportation of samples to the onsite laboratory.

12.3. EQUIPMENT AND MATERIALS

- Sample bottles provided by on-site laboratory
- Thermometer inscribed in degrees Centigrade
- pH meter
- Portable electrical conductivity meter
- Field notebook

12.4. PROCEDURE

(1) Pick up sample bottles, cooler, blue ice packs, sample labels, and chain-of-custody form at the laboratory.

(2) Pre-label bottles before leaving the laboratory. Place sample bottles on ice.

(3) Produce the sample with the same device used to purge the well.

(4) Collect the sample immediately after purging if possible. If the well is essentially dry after pumping, measure the water level in the well on a periodic basis (approximately every three hours). Collect the volatile organic samples within three hours of purging. Collect the rest of the samples as soon as there is sufficient volume in the well to sample as soon as there is sufficient volume in the well to fill the sample bottles (approximately 4

gallons). Attempt to collect an aliquot for field tests and laboratory analysis (in that order) 24 hours after purging even if there is insufficient water in the well to fill all sample bottles.

(5) Produce sufficient sample for performance of four field water quality tests (two 500 milliliter beakers - one for temperature and conductivity and one for pH). Perform one field water quality test before sampling, two during sampling, and one after sampling following procedures in this document.

(6) Rinse each bottle with formation water directly from the pump discharge or bailer. Fill the bottle about one-quarter full, cap the bottles, and rinse both bottle and cap with a swirling motion. Discard rinse water. Immediately fill bottle with sample, cap, complete label, rinse bottle exterior with deionized water, place in plastic bag, and return bottle to cooler. Remove only one bottle from the cooler at a time for filling.

(7) After rinsing the volatile organics vials and caps with sample, fill each vial to overflowing with sample. Carefully place the cap on the vial so that air is not captured, and tighten. Invert the vial and tap lightly. If bubbles are observed, repeat the process.

(8) Record time of sampling on Field Water Quality Sheet and in field notebook. Also note weather conditions and any other observations (e.g., insufficient sample to fill all bottles, bottles broken, etc.).

(9) Complete chain-of-custody form and indicate analyses to be performed in the laboratory.

(10) Deliver samples to the on-site laboratory within 3 hours of collection for filtration and/or preservation of appropriate bottles.

12.5. RECORDS

- Field water quality and analysis sampling form
- Field notebook

13. FIELD MEASUREMENTS

13.1. PURPOSE

To provide procedures for field measurements made at the site of monitor wells and surface water stations.

13.2. DEFINITIONS

Field Measurements: These measurements consist of temperature, pH, conductivity, dissolved oxygen, organic vapors, and qualitative observations of color and odor.

13.3. RESPONSIBILITY

The Field Team Leader is responsible for measurement of field parameters.

13.4. EQUIPMENT AND MATERIALS

The equipment used for field measurements has been selected based on proven durability in field applications; however, field equipment is still rather fragile. Equipment should be kept spotlessly clean at all times and protected from temperature extremes. Conductivity meters and pH meters will be calibrated daily following the manufacturers' instructions. All other instruments will be calibrated weekly. Each instrument will have its own calibration log book, and all calibrations will be documented. The following equipment is normally used:

- Thermometer inscribed in degrees Centigrade
- pH Meter - with calibration buffer solutions
- Portable electrical conductivity meter - with calibration
- Standard solutions
- Photoionization Detector (PID)
- Organic Vapor Analyzer (OVA)
- Deionized water
- Pencil
- Field Water Quality Sheets
- Field notebook
- Calibration notebooks

13.5. PROCEDURE

13.5.1. Temperature Measurement

Immerse the thermometer bulb in a beaker filled with sample. Make the measurement immediately after sampling so that the temperature will not have time to change. Read the thermometer while it is still immersed, to the nearest degree Centigrade, and record the reading in the field notebook and on the Field Water Quality Data Sheet. Rinse the thermometer with deionized water and put it away.

Calibrate the thermometer on a weekly basis against a National Bureau of Standards certified thermometer. Document calibrations in the calibration log book.

13.5.2 pH Measurement (VWR Scientific 1976)

(1) Turn on meter.

(2) Check battery.

(3) Place partially filled 50-milliliter beakers containing pH 4 and pH 7 buffer solutions into a water bath (well water) to maintain the temperature of the buffers as close as possible to the temperature of the well water. The water bath will need to be refilled periodically with water removed from the well.

(4) Remove boot from electrode.

(5) Rinse electrode with deionized water. Be sure any salts are removed.

(6) Immerse bulb in pH 7 buffer.

(7) Adjust using calibration knob to read 7.

(8) Rinse electrode with deionized water.

(9) Immerse bulb in pH 4 buffer.

(10) Adjust using temperature knob to read 4 (this is a span adjustment and not a true temperature correction).

(11) Measure the temperature of the buffers using a thermometer, following the procedures described previously. Be sure to rinse the thermometer with deionized water between solutions.

(12) Collect some sample in a beaker (rinse the beaker with sample).

(13) Rinse the thermometer with deionized water, and measure the temperature of the sample. If the buffer solutions are not at the same temperature as the samples, put fresh formation water in the water bath, allow time for temperature equalization, and repeat the calibration procedure.

(14) Rinse the electrode in deionized water.

(15) Immerse the bulb in the sample.

(16) Read the pH to the nearest tenth of a pH unit. Stir the sample with the electrode to hasten reading stability.

(17) If the pH is greater than 7, re-calibrate using the pH 10 buffer instead of the pH 4. Perform steps 5 through 16 above. If most samples have pH values greater than 7, pH 10 buffer should be routinely substituted for pH 4.

(18) Record the pH reading on the data sheet and in the field notebook. Document calibrations in the calibration log book.

(19) Rinse the electrode with deionized water and replace plastic boot.

(20) Turn off meter.

13.5.3 Conductivity Measurement (YSI 1976b)

(1) With conductivity meter off, check zero position. Adjust if necessary.

(2) Switch to red line and adjust.

(3) Calibrate meter against standard solutions and record calibrations in the calibration log book.

(4) Collect a sample in a beaker (rinse beaker with sample before collecting).

(5) Rinse probe with deionized water.

(6) Immerse probe in the sample.

(7) Switch to temperature. Record the temperature on Field Water Quality Sheet and in field notebook (may be different from earlier temperature measurement).

(8) Switch to conductivity and record both the needle reading and scale knob setting. Do not perform any calculations. Record the two values on the Field Water Quality Sheet and in field notebook.

(9) Turn meter off.

(10) Remove probe from sample and rinse with deionized water.

(11) Rinse beaker with deionized water.

13.5.4. <u>Dissolved Oxygen Measurement (YSI 1976a)</u>

(1) Place meter in intended operating position. Do not move without calibrating.

(2) With meter off, adjust meter to zero using center screw.

(3) Switch meter to zero and adjust to zero with zero knob.

(4) Switch meter to full scale and adjust to "15" on ppm scale using full scale knob.

(5) Attach probe to the meter and wait 15 min to polarize probe.

(6) Perform air calibration:

- Switch to calib O2 position;
- Place the probe in moist air (small calibration bottle with a few drops of water) and allow 10 min for temperature stabilization (can be same as polarization wait); and

- Set meter to local altitude (6,000 ft amsl) using calib knob -- be sure reading is steady;

Calibrate meter against standard solutions (on a weekly basis). Document calibrations in calibration log book.

(7) Place probe in sample and stir by raising and lowering the probe about 1 ft per s. Allow probe to equilibrate to sample temperature and dissolved oxygen.

(8) Turn switch to temp and read temperature from lower scale.

(9) Set O2 solubility factor dial to observed temperature, using the salinity index scale on the dial (salinity determined using SCT meter - each bar on index represents 5,000 ppm chloride concentration).

(10) Turn switch to read O2 and read dissolved oxygen value in ppm directly from the meter.

(11) Turn off meter, rinse probe with deionized water, add a few drops of deionized water to the sponge in the probe holder, and return probe to holder.

13.5.5. <u>Photoionization Detector Measurements (HNU Systems 1975)</u>

(1) Remove plate on the top half of the case by pulling up on the two fasteners. The extension tube and battery charger are located under this plate.

(2) Attach extension tube to the end of the probe.

(3) Check to see if the instrument's function switch is in the "OFF" position.

(4) Install the 12 pin interface connector for the probe into the connector on the instrument box by carefully matching the alignment key of the probe connector to the slots in the box connector. Twist the connector in a clockwise manner until a distinct snap and lock is felt.

(5) Check the battery supply by turning the function switch to the "BATT" position. The meter needle should deflect to the far right or well within

the green zone (NOTE: The battery check indicator will not function unless the probe is attached). If the needle is below or just in the green zone or the red LED light is on, the battery should be recharged.

(6) To zero the instrument, turn the function switch to the "STANDBY" position and rotate the "ZERO" potentiometer until the meter reads zero. This is an electronic zero adjustment. Calibration gases are not needed.

(7) Turn the function switch to the selected scale. There should be a humming sound emanating from the probe. This is the fan which pulls air into the probe. A blue glow should be seen through the end of the probe. Do not stare at this glow, as it is an ultraviolet light source which can damage the eyes. An overall check can also be done by passing a magic marker past the tip of the probe. This should generate a reading or jump of the needle.

(8) Place the function switch in the 0 - 20-ppm range for the most sensitive monitoring.

(9) Before entering a work area, determine the background concentration. This concentration should be used as a reference to readings made in the work area. Under no circumstances should one attempt to adjust the "ZERO" or "SPAN" adjustments while the instrument is being used in the work area (NOTE: When using the 0 - 20 ppm range, background concentrations up to 1.0 ppm are common in clean environments. This reading is generated internally by the instrument and should be referred to as zero ppm).

(10) Take PID readings in the headspace of a well before making water level measurements. Condensation and dust on the lamp can interfere with proper readings. PIDs do not function well during precipitation events or sudden temperature changes which can fog up the lamp.

(11) Record all readings in the field notebook.

13.5.6. Organic Vapor Analyzer Measurements (Foxboro Analytical)

(1) Remove top cover of the instrument.

(2) Move the INSTR switch to ON and allow five minutes for warm up.

(3) Set the audible alarm to a predetermined level by turning the PUMP switch to ON. Adjust the meter pointer to the desired alarm level using the CALIBRATE ALARM (zero) knob. Turn the ALARM LEVEL ADJUST knob on the back of the readout assembly until the audible alarm comes on. Adjust speaker volume with VOLUME knob. The instrument is then preset to activate the alarm when the organic vapor level exceeds that of the setting.

(4) Move the CALIBRATE switch to 10X and adjust the meter reading to zero with the CALIBRATE ADJUST (zero) knob.

(5) Ensure the PUMP switch is ON and observe the SAMPLE FLOW RATE indicator. The flow rate should be approximately 2 units.

(6) Open H2 TANK VALVE one turn and observe the reading on the H2 TANK PRESSURE indicator (approximately 150 psi of pressure is needed for each hour of operation).

(7) Open H2 SUPPLY VALVE one-half to one turn and observe the reading on the H2 SUPPLY PRESSURE indicator.

Caution: Do not leave H2 SUPPLY VALVE open when the pump is not running, as this will allow hydrogen to accumulate in the detector chamber.

(8) Confirm that meter is still reading zero (readjust if required).

(9) Depress the igniter button. There will be a slight "pop" as the hydrogen ignites, and the meter pointer will move upscale of zero. Do not depress igniter button for more than 6 seconds. If burner does not ignite, let instrument run for several minutes and try again.

(10) Move instrument to an area representative of the "lowest ambient background concentration" to be surveyed. Move the CALIBRATE switch to 1X and adjust the meter to read 1 ppm with the CALIBRATE ADJUST (zero) knob.

(11) If the alarm level is to be set above background levels, turn the ALARM LEVEL ADJUST knob on the back of the readout assembly until it activities slightly above background.

(12) Set the CALIBRATE switch to the desired range.

(13) Using one hand operation, survey the areas of interest while observing the meter and/or listening for the audible alarm indication.

(14) Record readings in the field notebook.

13.5.7. Color and Odor

Record any observations regarding the general condition of the samples. Especially note color, turbidity and odor.

13.6. RECORDS

- Field water quality data sheets
- Field notebook

13.7. REFERENCES

Foxboro Analytical Century Systems Portable Organic Vapor Analyzer Instructions and Service Manual.

HNU Systems Inc., 1975, Instruction Manual for Model PI101 Photoionization Analyzer.

VWR Scientific, 1976, Care and Feeding of the Mini and Digital pH Meters, Model 47.

Yellow Springs Instrument Co., 1976a, Instruction Manual, YSI Model 51B Dissolved Oxygen Meter.

Yellow Springs Instrument Co., 1976b, Instructions for YSI Models 33 and 33M S-C-T Meters.

14. WATER LEVEL MEASUREMENTS

14.1. PURPOSE

To provide procedures for measuring water levels in monitor wells and piezometers.

14.2. DEFINITIONS

Electric Water Level Sounder: An electric water level sounder is a device to measure the depth from a reference point (usually top of casing) to the water level in a well. The sounder consists of a two-wire cable on a reel with a double electrode tip. The reel houses a battery and voltmeter (or other device such as a light or buzzer) so that electrical continuity is indicated between the electrodes when submerged. The cable is graduated, indicating the length of cable in the well (Todd 1980).

14.3. RESPONSIBILITY

The Field Team Leader is responsible for water level measurements and accurate recording of data.

14.4. EQUIPMENT AND MATERIALS

- Electric water level sounder
- Deionized water
- Extra batteries
- Tape measure graduated in hundredths of feet
- Watch
- Pencil
- Photoionization Detector (PID)
- Field Water Quality Data Sheet
- Water Level Data Sheet
- Field notebook

14.5. PROCEDURES

(1) Record well location, identification number, date, time, and Field Team Member initials in field notebook and on data sheets.

(2) Check headspace of the well for any organic vapors with a PID. Record reading in field notebook.

(3) Decontaminate electrode on sounder and sufficient length of cable by washing with an alkaline detergent solution and rinsing with deionized water so that only clean cable enters the well.

(4) Turn on sounder, check battery, and lower cable into well until the presence of water is indicated.

(5) Hold wire so thumb and index finger are touching the top of casing when probe just enters the water (alarm will sound). Use the north rim of the inner casing for the depth to water reference point.

(6) Raise cable until alarm stops (i.e., probe is just above water level). Lower cable until alarm sound again. Check to see if thumb and index finger are at the same location as before.

(7) Still holding the cable at the measurement point, pull an arm's length of cable from the well. With other hand, push the zero end of tape measure against thumb, holding the measurement point, and measure distance to the first downhole graduation on the cable. Measure to the nearest 1/100th of a foot.

(8) Record the time, cable and tape measure readings in the field notebook. Transfer readings to the Field Water Quality Data Sheet and the Water Level Data Sheet.

(9) Coil the downhole cable into hands to minimize contamination of the entire sounder.

(10) Decontaminate all of the cable that was downhole plus 5 ft by washing with an alkaline detergent solution and rinsing with deionized water. Decontaminate equipment between wells and at the end of each day.

(11) Wrap sounder in clean plastic after decontaminating.

15. SOIL WATER MONITOR (TENSIOMETER) INSTALLATION

15.1. PURPOSE

To provide procedures for tensiometer installation.

15.2. DEFINITIONS

Tensiometer: A field instrument installed in a borehole to monitor capillary potential, which is then converted to soil moisture. A tensiometer consists of a porous ceramic cup attached to a rigid plastic tube. The cup is inserted into the soil, filled with water, and connected to either a manometer, a vacuum gage, or a pressure transducer (Linsley et al. 1975).

Capillary Potential: The work required to move a unit mass of water from a reference plane to any point in a soil column (Linsley et al. 1975).

Soil Moisture Content: The amount of water contained in the soil, generally expressed as a percentage (Morrison 1982).

$$\% \text{ Moisture Content} = \frac{\text{Mass of Water in Soil}}{\text{Mass of Dry Soil}} \times 100.$$

15.3. RESPONSIBILITIES

The Subcontractor Site Manager is responsible for selecting tensiometer locations and installation designs. All tensiometer locations and designs will be approved by the Rockwell International CEARP Manager prior to installation.

The Field Team Leader is responsible for supervision and documentation of tensiometer installations.

The Driller will assemble and install all materials.

15.4. EQUIPMENT AND MATERIALS

- Tensiometer
- Manometer, Vacuum Gage, or Pressure Transducer
- Teflon tubing
- Protective cover
- #200 silica filter pack
- Bentonite pellets
- Tremie pipe
- Shovel
- 100-ft tape divided into tenths of a foot and weighted on the end
- Field notebook.

15.5. PROCEDURES

(1) Auger borehole to desired depth.

(2) Pull all augers and drill pipe from borehole. If borehole stability is a problem, the tensiometer may be installed through the hollow stem augers.

(3) Decontaminate all drilling equipment, tensiometer, and casing.

(4) Measure total depth of the borehole and design tensiometer installation.

(5) Pour one borehole volume of organic-free water into borehole to saturate the soil that will be in immediate contact with the tensiometer (Morrison 1982).

(6) Tremie a slurry of silica filter pack and organic-free water down the borehole.

(7) Seat the porous cup of the tensiometer in the borehole at the desired depth. Make sure the porous cup is completely imbedded in the slurry (Morrison 1982).

(8) Measure depth to the top of the filter pack and record in the field notebook.

(9) Pour approximately a two-ft thickness of bentonite pellets into borehole annulus, making sure pellets are evenly distributed around the casing.

(10) Measure depth to top of the bentonite seal and record in field notebook.

(11) Add 1 to 2 gal. of organic free water to the borehole.

(12) Measure final stick up of tensiometer installation to determine total depth.

(13) Place protective cover over the tensiometer installation.

15.6. RECORDS

- Field notebook

15.7. REFERENCES

Linsley, R. K., M. A. Kohler, J. L. Paulhus, 1975, *Hydrology for Engineers*, McGraw Hill Book Company.

Morrison, R. D., 1982, Groundwater Monitoring Technology, Timco Publishing, Prarie de Sac, Wisconsin, 318 p.

16. SOIL WATER SAMPLER (LYSIMETER) INSTALLATION

16.1. PURPOSE

To provide procedures for lysimeter installation.

16.2. DEFINITIONS

Lysimeter: A field instrument installed in a borehole used for collecting soil pore water via suction in the unsaturated zone. Lysimeters are capable of retaining accumulated water within the sampling vessel.

16.3. RESPONSIBILITIES

The Subcontractor Site Manager is responsible for selecting lysimeter locations and installation designs. All lysimeter locations and designs will be approved by the Rockwell International CEARP Manager prior to installation.

The Field Team Leader is responsible for supervision and documentation of lysimeter installations.

The Driller will assemble and install all materials.

16.4. EQUIPMENT AND MATERIALS

- Teflon lysimeter attached to 2-in. PVC casing
- 6-5/8 inch PVC casing
- Protective cover
- #200 silica filter pack
- Bentonite pellets
- Tremie pipe
- Shovel
- 100-ft tape divided into tenths of a foot and weighted on the end
- Field notebook.

16.5. PROCEDURES

(1) Auger borehole to desired depth.

(2) Pull augers and drill pipe from borehole. If borehole stability is a problem, the lysimeter may be installed through the hollow stem augers.

(3) Decontaminate all drilling equipment, lysimeter, and casing.

(4) Measure total depth of borehole and design lysimeter installation.

(5) Install approximately 6-5/8 inch PVC casing to within approximately two feet of the bottom of the borehole.

(6) Tremie a slurry of silica filter pack and organic-free water into the bottom two feet of the borehole (Morrison 1982).

(7) Seat the lysimeter into the filter pack slurry. Make sure the lysimeter is completely imbedded in the slurry (Morrison 1982).

(8) Measure the depth to the top of the filter pack. Record in the field notebook.

(9) Pour approximately a two-ft thickness of bentonite pellets into borehole annulus, making sure pellets are evenly distributed around the casing.

(10) Measure depth to top of the bentonite seal and record in field notebook.

(11) Add 1 to 2 gal. of organic-free water to the borehole.

(12) Measure final stick up of the 2-in. PVC casing to determine total depth.

(13) Place protective cover over the lysimeter installation.

16.5. RECORDS

- Field notebook

16.6. REFERENCES

Morrison, R. D., 1982, Groundwater Monitoring Technology, Timco Publishing, Prairie de Sac, Wisconsin, 318 p.

17. SURFACE WATER QUALITY SAMPLING

17.1. PURPOSE

To define procedures for surface water sampling.

17.2. DEFINITIONS

Surface Water: Surface water refers to all flowing and ponded waters on the project site. It includes springs, creeks, and constructed ponds and ditches.

17.3. RESPONSIBILITY

The Subcontractor Site Manager is responsible for developing the sampling schedule. The sampling schedule will be approved by the Rockwell International CEARP Manager prior to implementation.

The Field Team Leader is responsible for surface water sample collection, decontamination of equipment, appropriate documentation, and prompt delivery of samples to the laboratory.

17.4. EQUIPMENT AND MATERIALS

- Narrow mouth glass jar on stainless steel wading rod
- Sample bottles and cooler provided by the laboratory
- Field water quality sampling and analysis form
- Field notebook
- Pencil and waterproof marker

17.5. PROCEDURES

(1) Collect the sample in 1-gal. glass containers attached to a stainless steed wading rod (DOI 1977). At stations where flows are measured, collect the sample immediately upstream of the flow measurement point. In ponds, collect the sample in the center of downstream embankment. If possible, raise and lower the sampling apparatus to collect a depth-integrated sample.

(2) Rinse all bottles provided by the laboratory with sample. Fill the bottles about one-quarter full, tighten cap, and rinse both bottle and cap with a swirling motion. Discard rinse water.

(3) Completely fill all bottles supplied by the laboratory. Carefully fill volatile organic vials to overflowing and cap so that no air is present in the vial. Invert the bottle and tap lightly. If air bubbles are observed, repeat the procedure.

(4) Perform field tests for temperature, pH, conductivity, and dissolved oxygen.

(5) Record observations on sample color, turbidity, and odor, as well as climatic and other conditions that might affect the sample.

(6) Label all bottles and place bottles in a cooler containing ice.

(7) Deliver samples to laboratory within three hours of collection.

17.6. RECORDS

- Field water quality sampling and analysis form
- Field notebook

17.7. REFERENCES

U.S. Department of the Interior, 1977, National Handbook of Recommended Methods for Water-Data Acquisition, revised August 1984.

18. STREAM FLOW MEASUREMENT

18.1. PURPOSE

To present procedures for measuring flow rates of ditches, creeks, and springs.

18.2. DEFINITIONS

Stream: Any natural or artificial flow.

Flume: Open channel flow measuring device in which depth of flow is measured to compute flow volume. The Parshall flume is commonly used and is specially configured so as to be self-cleaning. The Cutthroat flume, in contrast to the Parshall, has a flat bottom that allows relatively easy temporary installation in existing channels.

18.3. RESPONSIBILITY

The Subcontractor Site Manager is responsible for selecting flow measurement locations. Locations will be approved by the Rockwell International CEARP Manager prior to flow measurements.

The Field Team Leader is responsible for measuring flow rates immediately before collecting surface water quality samples.

18.4. EQUIPMENT AND MATERIALS

- Portable Cutthroat flume
- Carpenter's level
- Tools for assembling flume
- Shovel and sandbags
- Twenty foot tape measure graduated in 0.1 feet
- Twelve foot steel tape measure graduated in 0.1 feet
- Cork
- One foot of PVC pipe
- Five-gallon bucket
- One-liter beaker
- Stopwatch
- Pencils
- Field water quality sampling and analysis form
- Field book

18.5. PROCEDURES

Procedures are described below for measuring surface flows by four methods. Existing Parshall and portable Cutthroat flumes are the preferred methods of measurement. Procedures are also presented for the velocity - cross sectional area method and for the bucket and stopwatch method, although these methods are to be used only when the Subcontractor Site Manager determines that the preferred methods are infeasible.

18.5.1. Existing Parshall Flumes (Leupold and Stevens 1978)

(1) Remove any material that may have been deposited in the flume. Check that flume is level using carpenter's level. Inspect strip chart on recorder to be sure that it is operating. Report any deterioration of the station immediately to the Subcontractor Site Manager.

(2) Read the depth of flow on the upstream permanent scale and the downstream permanent scale, if submerged, and record.

(3) Measure and record throat width.

(4) Record time and data of data collection.

18.5.2. Portable Cutthroat Flume

(1) Estimate flow rate and select appropriate throat width for Cutthroat flume.

(2) Assemble flume with nuts on outside of flow cross section.

(3) Place the flume in the stream bed at the surface water station and level using the carpenter's level. The actual location of the station should be established in the field during the initial measurement event using the following criteria.

- Channel cross section is small enough that flow can be easily channeled through the flume.

- Sufficient sediments are available for use in diverting the flow.

- There is sufficient gradient that free-flowing downstream conditions can be achieved.

(4) Use sandbags and local sediments to divert the flow through the flume.

(5) Check that there are no backwater effects downstream of the flume. Read the depth of flow from the attached scale and record.

(6) Record the throat width.

(7) Record the time and date of the measurements.

18.5.3. <u>Velocity - Cross Sectional Area Method (DOI 1977)</u>

(1) Mark off a convenient length (10 to 20 feet) along the bank where the width and depth of flow remain relatively constant. Record the marked-off length.

(2) Measure and record the width and depth of flow at both the upstream and downstream ends of the marked-off length.

(3) Measure and record the time required for a cork to pass through the length.

(4) Record the time and date of measurement.

18.5.4. <u>Bucket and Stopwatch Method (DOI 1977)</u>

(1) Dam the flow using local sediments so that all of the flow goes through the one-foot length of PVC pipe. Make sure the pipe is high enough off the ground that the flow will enter the selected vessel.

(2) Place either the 5-gal bucket or the 1-L beaker under the pipe so that all of the flow is collected. Use the 5-gal bucket for flows in excess of 1 gal per min unless there is insufficient topographic relief to direct the flow into the bucket.

(3) Measure the time required to fill the vessel.

(4) Record the time and date of the measurement, the time required to fill the vessel, and the volume of the vessel.

18.6. RECORDS

- Field notebook
- Field water quality and sampling and analysis form

18.7. REFERENCES

Leupold and Stevens, Inc., 1978, Stevens Water Resource Data.

U.S. Department of the Interior, 1977, National handbook of Recommended Methods for Water-Data Acquisition, revised August 1984.

19. SEDIMENT SAMPLING

19.1. PURPOSE

To establish uniform methods for collection of stream and pond sediments.

19.2. DEFINITIONS

BMH-53 Bed-Material Sampler: A hand-held, piston-type bed-material sampler (Guy and Norman 1982).

Coliwasa: The composite liquid waste sampler (Coliwasa) is a device to sample free-flowing liquids and slurries. It is equipped with an end closure which can be opened and closed while the tube is submerged in the material to be sampled (DOI 1977).

19.3. RESPONSIBILITY

The Subcontractor Site Manager will select locations for sediment sampling. Locations will be approved by the Rockwell International CEARP Manager prior to sampling.

The Field Team Leader is responsible for collecting sediment samples.

19.4. EQUIPMENT AND MATERIALS

- BMH-53 bed-material sampler
- Teflon Coliwasa sampler (approximately two-inch)
- Polycarbonate tubes (approximately two-inch)
- Boat or raft
- Field notebook
- Tape measure
- Sample containers supplied by on-site laboratory
- Waterproof pens
- Pencils
- Hip Boots

19.5. PROCEDURES

Procedures are presented below for sampling stream and ditch sediments (bed materials) and for sampling pond sediments.

19.5.1. Stream and Ditch Sediments

(1) Determine number of samples to be collected at each sampling station based on width of stream or ditch.

If width is less than 5 ft, collect one sample from the center of the channel.

If width is greater than or equal to 5 ft, but less than 10 ft, collect two samples from the third points along an imaginary line perpendicular to the direction of flow.

If width is greater than or equal to 10 ft, but less than 20 ft, collect three samples at the quarter points along the imaginary perpendicular line.

If width is greater than or equal to 20 ft, collect samples every 5 ft along the imaginary perpendicular line.

(2) Wade to sampling point and push the BMH-53 bed-material sampler into the sediment about 1 ft (decontaminate sampler before use and between sampling points).

(3) Place sample in containers.

(4) If sample volume is not sufficient to fill the containers, continue to sample in an area approximately 1 ft sq until sufficient sample is collected.

(5) Seal sample containers and label.

(6) Record time of sample collection.

(7) Place sample in cooler with ice.

(8) Repeat process at additional sampling sites as required.

(9) Deliver samples to onsite laboratory, if an onsite laboratory is used, within three hours of sample collection.

19.5.2. Pond Sediments

(1) Clean all equipment.

(2) Ponds will be divided into sections and representative samples will be collected from each section.

(3) Access sampling point using boat or raft.

(4) Collect sample with a Coliwasa.

- Open sampler by placing stopper rod handle in the T-position and pushing rod down until handle sits against locking block.
- Slowly lower sampler into fluid.
- When the sampler hits bottom, push sampler tube into sediments.
- Lock the stopper by turning the T-handle upright so that one end rests on lock block.
- Withdraw Coliwasa from sediment and fluid.

(5) If the sediment is too consolidated to be sampled with the Coliwasa, use a BMH-53 Bed-Material Sampler;

(6) Place sample in containers.

(7) If sample volume is insufficient to fill containers, repeat sampling process in vicinity of sampling location until sufficient volume is collected.

(8) Label sample containers and record time of sample collection.

(9) Place samples in cooler with ice.

(10) Decontaminate equipment and move to next sampling point.

(11) Deliver samples to the onsite laboratory, if an onsite laboratory is used, within three hours of collection.

19.6. RECORDS

- Field notebook

19.7. REFERENCES

Guy, H.P. and V. W. Norman, 1982, Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter C2, Field Methods for Measurement of Fluvial Sediment, Book 3, Applications of Hydraulics.

U.S. Department of the Interior, 1977, National Handbook of Recommended Methods for Water-Data Aquisision, revised August 1984.

20. SOIL MOISTURE CONTENT

20.1. PURPOSE

To describe the laboratory procedure to determine moisture content of soil samples.

20.2. DEFINITIONS

Water Content (%): The water content is defined as the ratio, expressed as a percentage of the weight of water in a soil to the weight of solid particles (Army Corps of Engineers 1970).

$$W = \frac{Ww}{Ws} \times 100\%$$

20.3. RESPONSIBILITIES

The Subcontractor Site Manager is responsible for sample selection. These selections will be approved by the Rockwell International CEARP Manager prior to laboratory testing.

Laboratory staff will perform water content analyses.

The Field Team Leader will be responsible for sealing collected samples to retain native water content until delivery to the laboratory.

20.4. EQUIPMENT

- An oven of forced draft type, controlled to maintain a uniform temperature of 110 $\pm 5^{o}C$
- Balances sensitive to .01 g
- Evaporating dishes

20.5. PROCEDURE

(1) Sample size depends on grain size, gravels requiring up to 1000 g. Most site samples are anticipated to be 90% finer than no. 4 sieve, for which 100 - 200 g is an adequate sample.

(2) Laboratory staff will accurately measure the tare weight of an evaporating dish.

(3) The sample container will be unsealed and a portion accurately weighed in the evaporating dish.

(4) The dish and sample will be transferred to the oven and dried to constant weight. Clayey soils may require 16 h of drying.

(5) The dish and sample will be carefully reweighed.

(6) Computation: The water weight (Ww) is the loss through drying of the sample and the dish, the soil weight (Ws) is the dried sample and dish weight minus the tare, and water content is given by $W = (Ww/Ws) \times 100\%$.

20.6. RECORDS

Laboratory staff will record water content on data forms.

20.7. REFERENCE

U.S. Army Corps of Engineers, 1970, Engineering Manual EM 1110-2-1906.

21. GRAIN SIZE ANALYSIS

21.1. PURPOSE

To describe laboratory procedures for sieve and hydrometer analyses of grain size distribution.

21.2. DEFINITIONS

Grain-size Analysis: This determines the proportion of material of various grain sizes in a sample. The grain-size distribution of coarse-grained soils is determined directly by sieve analysis, while that of fine-grained (passing 200 sieve) soils is determined indirectly by hydrometer analysis. For broadly graded materials with fine and coarse fractions, sieve and hydrometer analyses are performed separately and the analyses combined (Army Corps of Engineers 1970).

21.3. RESPONSIBILITY

The Subcontractor Site Manager is responsible for sample selection. These selections will be approved by the Rockwell International CEARP Manager prior to laboratory analysis.

Laboratory staff will perform grain size distribution analyses.

The Field Team Leader will be responsible for the collection and representativeness of the sample.

21.4. EQUIPMENT

- US Standard series, number and sizes depending on sample
- Sieve shaker
- Weighing scale accurate to .01 g
- Oven
- Hydrometer, calibrated
- Sedimentation cylinders
- Clay dispersant
- Agitators
- Thermometer
- Stopwatch

21.5 PROCEDURE

(1) The dry weight of the sample will be determined by weighing the sample and measuring its moisture content.

(2) The sample will be split into coarse and fine fractions by washing on a no. 200 sieve.

(3) Sieve analysis (U.S. Army Corps of Engineers 1970).

- Oven-dry and weigh the coarse (plus 200) fraction of the sample.
- Shake the coarse sample in the sieve rest for approximately 10 minutes.
- Measured weights of sediments retained on each sieve screen.
- Convert cumulative weight retained to 40% finer than each sieve size, for the total sample weight (coarse and fine fractions combined).

(4) Hydrometer analysis (U.S. Army Corps of Engineers 1970):

- Determine the specific gravity of the fine fraction.
- Soak the fine sample with a chemical dispersant to de-flocculate clays.
- Agitate the sample in a sedimentation cylinder.
- Use the hydrometer at timed intervals to measure the density of the fluid at a fixed depth in the sedimentation cylinder.
- Compute particle diameter corresponding to measurement times from nomographs based on Stokes' Law and material specific gravity.
- Calculate percent finer than a particular particle diameter, that is material that has not yet passed the measuring point, from temperature corrected, fluid suspension density.
- Correct percent finer values to percentages of the total sample, combining coarse and fine fractions.

(5) Plot combined sieve and hydrometer analysis on a gradation curve form.

21.6. RECORDS

- Sieve analysis form
- Hydrometer analysis form
- Gradation curve form

22. GEOPHYSICAL PROCEDURES

22.1. PURPOSE

To provide procedures for geophysical methods for source delineation.

22.2. DEFINITIONS

Geophysical Survey: The exploration of an area in which geophysical properties and relationships are mapped by one or more geophysical methods.

Geophysical Methods: The use of one or more of the following geophysical techniques: magnetometrey, electromagnetic induction, electrical resistivity (vertical electrical soundings), and metal detection.

Geophysicist: The company providing geophysical equipment and personnel to conduct a geophysical survey.

22.3. RESPONSIBILITY

The areas to be geophysically surveyed will be selected on a site-specific basis and delineated in the site-specific monitoring plans as appropriate.

The Subcontractor Site Manager is responsible for providing the survey grid to the Geophysicist. The survey grid will be approved by the Rockwell International CEARP Manager prior to survey implementation. If grid modifications are needed during the survey to better locate sources, they will also be approved by the Rockwell International CEARP Manager prior to implementation.

The Geophysicist is responsible for conducting the geophysical survey, survey documentation, and data interpretation.

The Field Team Leader is responsible for assisting the Geophysicist as necessary.

22.4. EQUIPMENT AND MATERIALS

Appropriate equipment for the geophysical survey, data acquisition, and data recording will be provided by the Geophysicist.

22.5. PROCEDURES

The following quality assurance procedures apply to all of the geophysical instruments and their use during the geophysical survey.

22.5.1. General

(1) General data transmittals will be documented on standard Chain-of-Custody data forms. These forms will be maintained onsite.

(2) All geophysical instrumentation will be operated in accordance with operating instructions as supplied by the manufacturer. Copies of the manufacturer's operating instruction and updated calibration records will accompany the instruments. Each instrument will have its own calibration log book.

(3) Battery voltage levels for all instruments will be monitored each day throughout the survey. Battery packs will be fully charged or replaced when voltage levels fall below the geophysical equipment specifications. Battery and charger checks will be documented in calibration log books.

22.5.2. Magnetometers

(1) The magnetometer will be operated in accordance with operating instructions as supplied by the manufacturer. Operating instructions for the EG&G Geometrics Portable Proton Magnetometer/Gradiometer (Model G-856AG) are presented in Appendix B.

(2) Maintain calibration records from the magnetometer manufacturer. The magnetometer will be calibrated annually by the manufacturer and the date of most recent calibration will be tagged and affixed to the instrument.

(3) Perform quarterly calibration checks using a magnetometer tester for the proton magnetometer. Quarterly calibrations will be documented in the calibration log book.

(4) A swing sensor test will be conducted with the proton magnetometer prior to initiating site operations. For inclinations of the earth's magnetic field greater than 45°, four readings with the sensor oriented 90° to the other readings shall be taken. This will be repeated three times. Variations greater than ± 0.2 gammas will not be observed. Any directional sensitivity of the probe will be corrected by washing the sensor with detergent and water.

NOTE: At Rocky Flats Plant, the earth's magnetic field is dipping approximately 70° North.

(5) Obtain a daily background reading in the immediate vicinity of the survey site. This reading will be outside the influence of manmade magnetic fields (e.g., power lines and pipelines). The Geophysicist will confirm that background readings are reasonable with respect to the total magnetic field for the site's latitude and longitude. This daily background reading should repeat to within reasonable diurnal variations in the earth's magnetic field. Generally, acceptable repeat readings are within 50 to 100 gammas.

NOTE: The total magnetic field intensity for Rocky Flats Plant is approximately 55 to 60 kilogammas.

(6) Sequential readings will be taken before and after magnetic surveying operations. These readings (within 10 seconds of each other) will be taken at any location onsite, preferably at the location of the daily background readings. The readings will be distant from manmade magnetic fields and recorded in the field notebook. Two or three sequential readings will be sufficient. In the absence of magnetic storms (sudden variations in the earth's magnetic field), the drift in the readings should be less than 0.1 to a few tenths of a gamma. Drift during magnetic storms may approach 1

gamma. Records of the daily sequential readings will be recorded in the field notebook.

(7) Base station readings will be taken so that the effects of diurnal variations in the earth's magnetic field can be removed from the data. In addition, magnetic storms can be detected if the base station sampling frequency is high enough. During a magnetic storm, operations will be suspended and resumed when the storm has passed. A permanent base station may be set up onsite where continuous readings are automatically recorded every ten to fifteen minutes, or a base station may be occupied every 45 to 60 minutes during the survey.

(8) Use of automatic magnetometers requires recording the magnetometer readings for the first and last station of each traverse in the field notebook. Data recorded in the field notebook will be compared at the end of the day with data from the automatic recording device. Data recorded in the field notebook should be within ±1 gamma of the values derived from the recording device. If the differences exceed ±1 gamma, then the traverse will be suspect and the data considered unusable. Data will be transferred daily onto hard copies from the recording device.

(9) Where the magnetic survey traverses cross at grid nodes, data from the two traverses will be compared. The data should be ±10% of one another. If the differences exceed ±10%, three consecutive readings will be taken at the grid point node. The three readings will be averaged and compared to the two measurements in question. If either measurement exceeds ±10%, then that survey traverse will be suspect and the data considered unusable.

22.5.3. Electromagnetic Induction

(1) The EM systems will be operated in accordance with operating instructions as supplied by the manufacturer. Operating instructions for the Geonics, Ltd., Terrain Conductivity Meters (Models EM 34-3 and EM 31) are presented in Appendix B.

(2) Maintain calibration records from Geonics, Ltd. The EM system will be calibrated annually by the manufacturer and the date of the most recent calibration will be tagged and affixed to the instrument.

(3) Perform quarterly calibration checks at a designated point on a nearby bedrock outcrop. Quarterly readings should be repeatable to ±5%. The electromagnetic indication meter will be returned to the manufacturer for calibration if quarterly calibration readings are not within ±5% of the manufacturing calibration. Quarterly calibrations will be documented in the calibration log book.

(4) Prior to conducting a survey, a location will be selected for daily calibration checks. If possible, this location should be the same as for the quarterly calibration checks. Calibration checks will be made before and after conducting daily survey operations. Readings shall repeat to ±5%. All calibrations will be documented in the calibration log book.

NOTE: All calibration checks should be made in the absence of power lines, buried utilities, etc. They should also be made on a relatively flat surface outside of topographic lows.

(5) Instrument stability will be checked when there is local or distant thunderstorm activity. Electromagnetic radiation from thunderstorms can generate noise in the EM system. Operations will be postponed during disturbances from distant thunderstorms and resumed when these effects have ceased.

(6) The Geophysicist will confirm that field conductivity readings are reasonable with respect to existing site conditions.

(7) Use of an automatic data recorder requires recording the conductivity readings for the first and last station of each traverse in the field notebook. Data recorded in the field notebook will be compared with data from the automatic recording device at the end of each day. Data recorded in the field notebook should be ±5% of the values derived from the recording device. If the differences exceed ±5%, then the transverse

will be suspect and the data considered unusable. Data will be transferred daily onto hard copies from the recording device.

(8) Where the conductivity survey traverses cross at grid nodes, the data from the two traverses will be compared. The data should be ±10% of one another for the same instrument (EM 34-3 or EM 31) and ±20% for different instruments (EM 34-3 or EM 31). If the differences exceed these ranges, then three consecutive readings with the respective instruments will be taken at the grid node. The three readings will be averaged and compared to the measurements in question. If either measurement exceeds their error range, then that survey traverse will be suspect and the data considered unusable.

22.5.4. Vertical Electrical Soundings (VES)

(1) The VES system will be operated in accordance with operating instructions as supplied by the manufacturer. Operating instructions for the Bison BOSS System (Model 2365) are presented in Appendix B.

(2) Maintain calibration records from Bison Instruments, Inc. The VES system will be calibrated annually by the manufacturer and the date of the most recent calibration will be tagged and affixed to the instrument.

(3) Perform quarterly calibration checks at a designated location. The location should be clear of power lines, buried utilities, etc. The location should also be on a relatively flat homogeneous surface. The quarterly readings should repeat to ±5%. If the differences exceed +5%, the instrument will be returned to the manufacturer for calibration. Quarterly calibrations will be documented in the calibration log book.

(4) All VES data will be checked for accuracy prior to completion of the sounding. The technique outlined in the manufacturer's operating instructions (Appendix B) will be followed. If the cross-checks exceed ±5%, a minimum of three sets of readings will be conducted after a thorough check of the setup. The average of the three sets of readings will be used

for the data analysis. Should the cross-checks exceed ±5% on a regular basis, the instrument will be returned to the manufacturer for calibration.

22.5.5. Metal Detector

(1) The metal detector will be operated in accordance with operating instructions as supplied by the manufacturer. Operating instructions for the White's Treasure master 600 Cache Locator (TM 600 S2) are presented in Appendix B.

(2) The metal detector will be operated in the ground reject mode as outlined in the operating instructions. The ground reject mode balances out ground mineralization for better detection of ferrous and nonferrous metals in the ground.

(3) Prior to conducting a survey, a location will be selected for daily nulling procedures. The daily nulling location should be free of power lines, buried utilities, and groups of large metal objects. The nulling procedures will be made before and after conducting daily survey operations. The settings of the null adjustments will be recorded in the calibration log book.

(4) Adjustment of the sensitivity control will be made onsite as required.

22.6. RECORDS

The Geophysicist will be responsible for documentation and transmittal of all data. All data will be recorded in bound field notebooks with numbered pages, and a calibration log book will be maintained for each instrument. Standard chain-of-custody forms will accompany all data transmittals.

The field notebook will contain actual survey data and will document items such as the date, time, site location, names of the field team members, weather conditions, and other information. The field notebook will contain information which will recreate the day's events in a clear and concise manner. The Geophysicist will sign the field notebook each day.

23. SOIL GAS SURVEYS

23.1. PURPOSE

To perform soil gas surveys for source and groundwater plume delineation.

23.2. RESPONSIBILITY

Soil gas sampling locations will be selected on a site-specific basis.

The Subcontractor Site Manager is responsible for providing the survey control grid. The survey grid will be approved by the Rockwell International CEARP Manager prior to survey implementation. If grid modifications are needed during the survey to delineate groundwater plumes, they will also be approved by the Rockwell International CEARP Manager.

The Soil Gas Surveyor is responsible for conducting the soil gas survey and documenting the survey.

23.3. EQUIPMENT AND MATERIALS

- Hollow stainless steel rod with Teflon-coated drive tip
- Water seal pneumatic pump
- Plastic delivery tube
- Hypodermic needle
- Field Gas Chromatograph
- Field notebooks

23.4. PROCEDURES

(1) Record the time and location of the sample collection in the field notebook.

(2) Insert a freshly decontaminated hollow stainless steel rod 3 to 5 ft into the soil at the grid node.

(3) Pump soil gas through the rod via a water sealed pneumatic pump to remove a fixed sample of soil gas. The sample will be removed through a delivery tube utilizing a standard laboratory hypodermic needle.

(4) Pump soil gas for approximately ten minutes to allow for stabilization.

(5) Extract approximately 5 cubic centimeters of soil gas for analysis.

(6) Inject the soil gas sample directly into the field gas chromatograph.

(7) Record results in field notebook.

(8) Proceed to the next sampling location and repeat procedure.

23.5. RECORDS

- Field Notebook
- Chromatographs

GEONICS LIMITED

Leaders in Electromagnetics

NOTE TO EM31 AND EM34 USERS:

One of the most common problems with the instrument is the contamination of battery contacts. To clean these contacts use fine sand paper (#400 or higher) and wipe several times over the contacts.

Ensure that the spring action of the battery holders is maintained. Bend holder sides slightly if necessary.

July 1985.

GEONICS LIMITED
1745 Meyerside Dr. Unit 8 Mississauga, Ontario Canada L5T 1C5

Tel. (416) 676-9580
Telex 06-968688
Cables: Geonics

OPERATING MANUAL

for

EM31-D

NON-CONTACTING

TERRAIN CONDUCTIVITY METER

Revised June 1984.

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EM31-D SPECIFICATIONS

Measured Quantities	(1)	Apparent conductivity of the ground in millimhos per meter
	(2)	Inphase component of the induced magnetic field
Primary Field Source		Self-contained dipole transmitter
Sensor		Self-contained dipole receiver
Intercoil Spacing		3.66 meters
Operating Frequency		9.8 kHz
Power Supply		8 disposable alkaline 'C' cells (approx. 20 hrs life continuous use)
Conductivity Ranges		3, 10, 30, 100, 300, 1000 mmhos/meter
Measurement Precision		± 2% of full scale
Measurement Accuracy		± 5% at 20 millimhos per meter
Noise Level		<0.1 millimhos per meter
Operator Controls		•Mode Switch •Conductivity Range Switch •Phasing Potentiometer •Coarse Inphase Compensation •Fine Inphase Compensation
Analog Output		Connector on EM31-D for dual channel analog recording of ground conductivity and inphase component
Dimensions		Boom : 4.0 meters extended 1.4 meters stored Console : 24 x 20 x 18 cm Shipping Crate: 155 x 42 x 28 cm
Weight		Instrument Weight: 9 kgm Shipping Weight: 23 kgm

1. INTRODUCTION

Measurement of ground resistivity is one of the oldest geophysical techniques. Table 1, taken directly from Heiland*, lists typical values of resistivity for a variety of geological materials (pages 4-7). The values given are in ohm-centimeters and must be divided by one hundred to give ohm-meters.

It will be observed that in most cases the actual resistivity itself is not diagnostic and a knowledge of the way in which the resistivity varies laterally and with depth is of great importance, since this permits us to "see" features as a result of their shape rather than their actual resistivity values. There is thus a requirement for instrumentation which permits the rapid and accurate measurement of terrain resistivity. Since the EM31 does not require electrical contact with the ground it fulfills this objective.

The basic principle of operation of the EM31 is simple. With reference to Fig. 1 a transmitter coil located at one end of the instrument induces circular eddy current loops in the earth. Under certain conditions fulfilled in the design of the EM31 the magnitude of any one of these current loops is directly proportional to the terrain conductivity in the vicinity of that loop. Each one of the current loops generates a magnetic field which is proportional to the value of the current flowing within that loop. A part of the magnetic field from each loop is intercepted by the receiver coil and results

* Heiland, C.A. Geophysical Exploration. Hafner Publishing Co., New York 1968

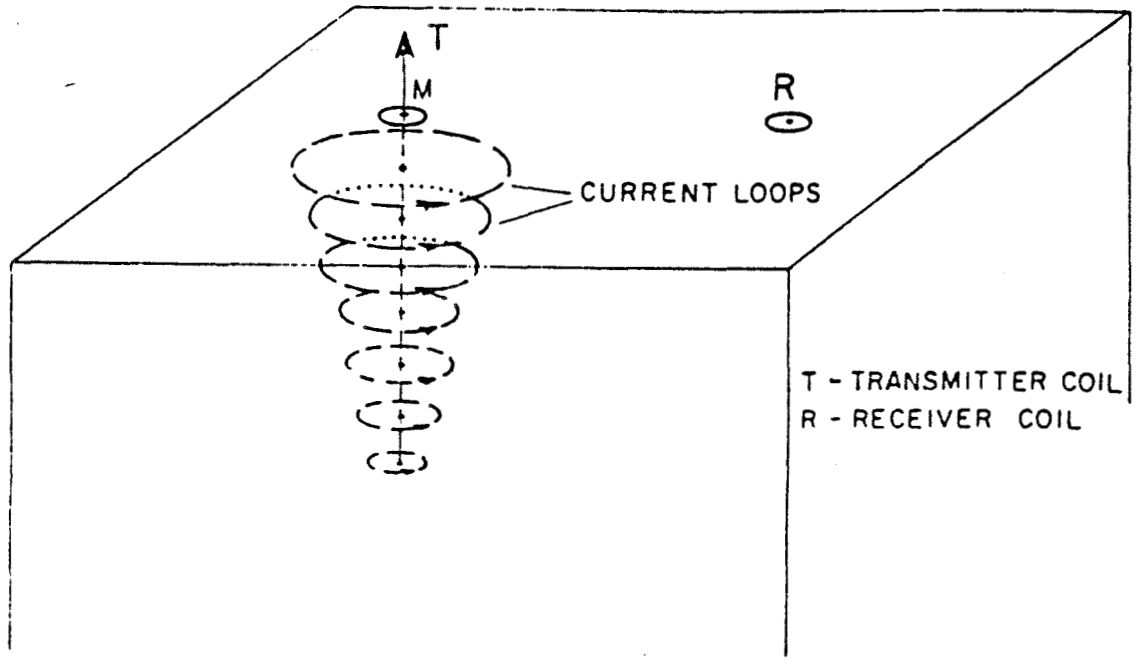


Fig. 1 INDUCED CURRENT FLOW IN GROUND

1. INTRODUCTION (cont'd)

in an output voltage which is therefore also linearly related to the terrain conductivity.

This instrument is calibrated to read the correct conductivity when the earth is uniform. In the event that the earth is layered, with each layer of different conductivity, the instrument will read an intermediate value as discussed in more detail in Section 5.2.

The unit of conductivity used is the millimho per meter. To obtain resistivity in ohm-meters the instrument reading is divided into 1000 - i.e., a reading of four millimhos per meter divided into 1000 gives two hundred and fifty ohm-meters.

Theoretical calculations show, as will be quickly evident to the operator, that the reading obtained is essentially independent of the orientation of the instrument with respect to the earth. There is, however, a small dependence on the height above the ground; lifting the instrument from the surface of a uniform earth to the normal operating height of about one meter results in a reduction in the reading of 12%. The calibration has been adjusted at the factory so that the instrument reads correctly over a uniform half-space when worn as shown in the data sheet. If the earth is layered, raising the instrument from the surface of the earth to the normal operating position can result in a reading which stays constant or even increases slightly with height. In general, readings made with the instrument at hip height will be sufficiently accurate, but for maximum accuracy the instrument can be laid on the ground as discussed in Section 5.2.

There are two components of the induced magnetic field measured by the EM31. The first is the quadrature-phase component which gives the ground conductivity measurement as described. The second is the inphase component used primarly in the EM31 for calibration purposes. The inphase component however is significantly more sensitive to large metallic objects and hence very useful when looking for buried metal drums. Although this component has been available in the standard EM31 by operating in the compensation mode (Section 2.2), both components are now available in the EM31-D from an analog output connector when coupled to a dual channel recorder.

TABLE 1A

RESISTIVITIES OF IGNEOUS & METAMORPHIC ROCKS

Rock	Locality	Investigator	Dir.	Freq.	Resistivity in ohm-cm							
					Intermediate Conductors							
					10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9
Specimens												
Diabase	Idaho	Sundberg	3				3.1					
Granite	Bavaria	Hunkel	3							1		
Devonian slate	Harz	Ebert					2					
" "	"	"						6.5				
Porphyry, schistose	S. Australia	Edge & Laby		100			3					
Serpentine		Eve & Keys					3–2					
Diorite	Bavaria	Hunkel	3					1				
Gabbro	Mineville	Lee & Boyer		D.C.					1.0	—	1.4	
Garnet gneiss	Bavaria	Hunkel	3						2			
Hornblende gneiss	Mineville	Lee		D.C.						1–6		
Gray biotite gneiss	"	Lee & Boyer		D.C.						4		
Syenite	Bavaria	Hunkel	3							1		
In Situ												
Graphitic schist	Normandy	Schlumberger		16	1–	1						
Schists	Missouri	Poldini			2–	6						
Hard calc. schist	Belgian Congo	Geoffroy & Charrin				2–	1.1					
Mica schist (hard packed)	Washington, D. C.	Gish & Rooney		16			1.3					
Quartz porphyry (slightly altered)	Newfoundland	Kihlstedt				3.4						
Keweenawan lavas	Michigan	Hotchkiss, *et. al.*		10–15		1.2	—	4.4				
Greenstone	"	Rooney		16			1.1					
Porous trap-rock	"	"		16		1.6						
Pre-Cambrian	Sweden	Sundberg					3–6					
Granite	Washington, D. C.	Gish & Rooney		16			5					
Slightly altered syenite	Ontario	Kihlstedt		200			2.4					
							3.7					
Massive vein quartz	"	"		200				2				
Diabase	Michigan	Rooney		16		4.5						
Serpentine	Ontario	Kihlstedt		200		2.1						
						5.3						

TABLE 1B

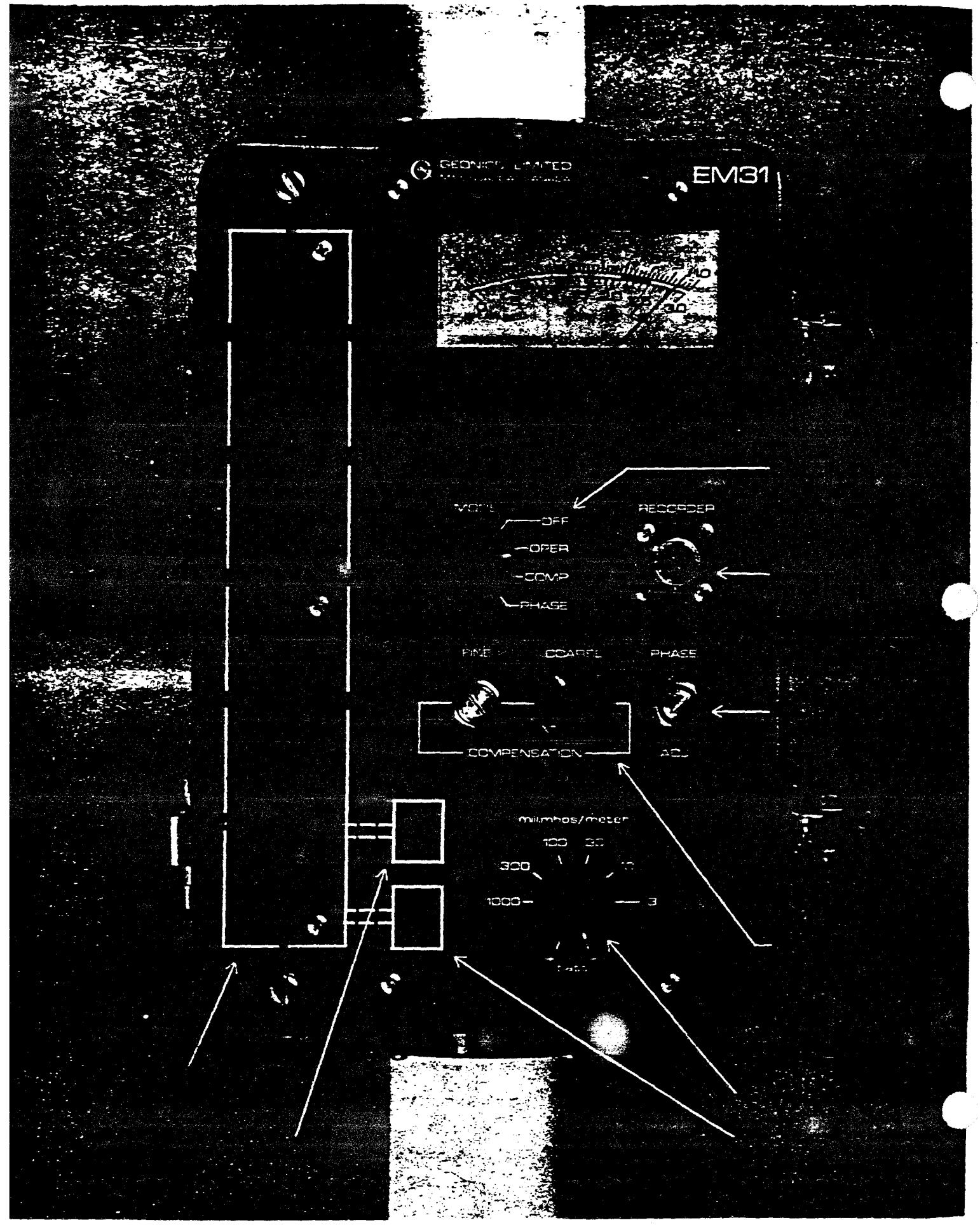
RESISTIVITIES OF CONSOLIDATED SEDIMENTS[14]

Rock	Locality	Investigator	Dir.	Freq.	n°	Resistivity in ohm-cm 10^3	10^4	10^5	10^6	10^7	10^8
Shales and Slates											
Chattanooga shale (Dev.)	Cent. & south Illinois	Hubbert		50			2		1.4		
Shale & glacial drift	"	"		50			5				
Nonesuch shale	Houghton Co., Mich.	Hotchkiss, *et. al.*		10-15				1.8			
Shale	W. Hancock, Mich.	Rooney		60					2		
Slate		Lee, Joyce, & Boyer		0				6.4			
Clay (wet)	Jugoslavia	Loehnberg & Stern		D.C.			2.1				
Grinneld argillite	N½ sec. 23, T32N R20W, Flathead Co., Montana	Erdmann	dip 32°	16							
					10			1.7			
			∥ to stratification		20		9.6				
					20			1.1			
					30			1.0			
			⊥ to strike		10		8.7				
					20		7.4				
					40			1.1			
Grinneld argillite	" (Water's Edge)	"	dip 32°	16				1.3			
			∥ to strike		15			1.4			
					30			8.0			
								8.2			
					10			7.7			
Argillite (Missoula group); pre-Cambrian, thin-bedded, platy argillite; resembles Grinneld	Sec. 27, T 32N R20W, Flathead Co., Montana	"	dip 31°	16							
					10			1.4			
					20			1.6			
			⊥ to strike		30			1.5			
					40			1.4			
					50			1.5			
									1.1		
Conglomerates											
Great conglomerate outcrop	Eagle Harbor, Mich.	Hotchkiss, *et. al.*		10-15							
Calumet & Hecla conglomerates	Michigan	Rooney		60					2	1.3	
Sandstone											
Eastern sandstone	Michigan	Hotchkiss, *et al.*		10-15			3.5	1.2			
Eastern sandstone	"	Rooney		16			4.3				
Muschelkalk ss. (Triassic)	Lorraine	Schlumberger		16			7				
Sandstone (Tertiary Oligocene); soft, friable; extremely fine grained ss.; pale green to yellowish and buff; contains thin beds of lignite	Coal Creek Road, Flathead Co., Montana	Erdmann	dip = almost 0	16	10		8.8				
							9.8				
					20		6.2				
							6.7				
					30		4.8				

TABLE 1B cont'd

RESISTIVITIES OF CONSOLIDATED SEDIMENTS

Rock	Locality	Investigator	Dir.	Freq.	e°	Resistivity in ohm-cm					
						10^0	10^1	10^2	10^3	10^4	10^5
Armorican ss. compact Siliceous-Ordovician	Normandy	Schlumberger						1			
Ferruginous sandstone (Jurassic)	Switzerland	Koenigsberger						4			
Limestone											
Muschelkalk ls. (Triassic)	Lorraine	Schlumberger		16		6					
Limestone with lenses of hematite	Algeria	"					1.2–4				
Muschelkalk oolitic ls. (Triassic)	Lorraine	"		16			1.8				
Limestone	Mississippian (Missouri)	Poldini					3–4				
Siyeh ls., hard homogeneous, dark bluish-gray, siliceous magnesium ls.; pre-Camb.	SW cor. sec. 5 T29N R18W Flathead Co., Montana	Erdmann	dip 54°	16			6.8	–1.4			
			∥ to strike		20			1.5			
					30			1.4			
			⊥ to strike		10		3.6				
					20		5.4				
							7.9				
					30		6.6				
							6.9				
					50		6.1				
							8.1				


GEONICS LIMITED
EM31
OFF
OPER
COMP
PHASE
RECORDER
FINE
COARSE
PHASE
COMPENSATION
ADJ
millimhos/meter
100
300
1000
3

2. OPERATING INSTRUCTIONS

The EM31 can be used both to measure the electrical conductivity of the ground and to detect buried metal objects. Section 2.1 describes the procedure for measuring ground conductivity and section 2.2 for buried metal detection.

2.1 Ground Conductivity Measurements

2.1.1 Initial Set-up Procedure

a) Using the identifying labels on the tubes select the transmitter coil tube, align it with respect to the main tube, insert it and fix it with the clamp.

b) Check the battery condition, plus and minus, by setting the Mode switch (MODE SELECTOR SWITCH) to the OPER position and the Range switch to the +B and -B positions respectively. If the needle reads inside the BATT mark on the meter, batteries are in good condition, otherwise replace the batteries with a fresh set of C size alkaline batteries.

c) Check the zero reading by setting the Mode switch to the OPER position and the Range switch to the least sensitive position 1,000 mmhos/meter (this minimizes any external noise interference while checking the zero position). If a zero adjustment is required adjust the DC ZERO CONTROL located under the front panel to obtain a zero reading. To do this the battery pack must be removed to gain access to the controls.

d) Align and connect the receiver coil tube to the main frame tube. The instrument is now ready to proceed with the functional checks.

2.1.2 Equipment Functional Checks

The Range switch should be set at 30 millimhos/meter position for all the following tests. (If the reading is off scale, i.e., greater than 30 millimhos/meter, see note.)

a) Set the Mode switch to the COMP position and adjust the meter reading to zero using the COARSE and FINE COMPENSATION controls.

b) To check the phasing of the instrument set the Mode switch to the PHASE position. Note the meter reading and rotate the COARSE control one step clockwise. If the meter reading remained the same, the phasing is already correct; return the COARSE control to its original position (one step counter clockwise) and no further adjustment is necessary.

If there was a difference in the meter readings taken before and after the COARSE control was rotated one step clockwise then a phase adjustment is required. With the COARSE control in its original position adjust the PHASE potentiometer about 1/4 turn clockwise and note the new meter reading. Rotate the COARSE control one step clockwise, take a reading, and return the COARSE control to its original position. If the <u>difference</u> in meter readings has decreased, repeat the procedure using a further clockwise adjustment, until rotating the COARSE control the one step clockwise produces no change in the meter reading.

If, on the other hand, the difference in meter readings was increased, the PHASE potentiometer should be rotated in a counter clockwise direction instead and the procedure described above repeated until there is no change in the meter readings. Always remember to set the COARSE control back to its original position. This can be confirmed by setting the Mode switch in the COMP position and checking that the meter reads zero. If it does not read zero, repeat steps (a) and (b).

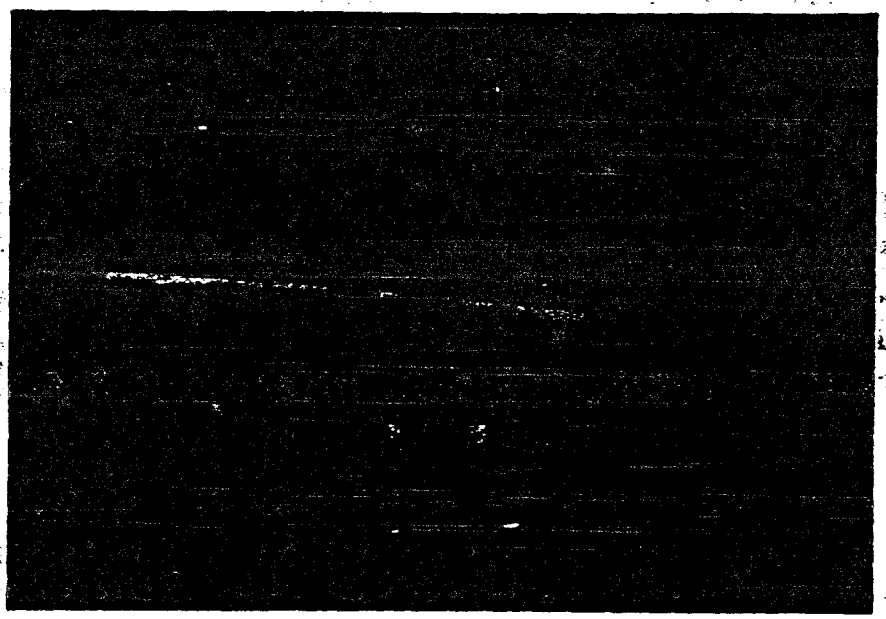
c) To check the sensitivity of the instrument, set the Mode switch to the COMP position and rotate the COARSE control clockwise one step. The meter should read between 75% and 85% (22 to 26 millimhos/meter) of full scale deflection (inside black mark). It is unlikely that the sensitivity of the instrument will vary, however it may be useful to record the actual meter reading for comparison at a later date.

Return the COARSE switch to its original position and the EM31 is now ready to make ground conductivity measurements.

NOTE: When conducting the functional tests over ground of higher conductivity than 30 millimhos/meter, the Range switch should be set at the appropriate level. At whatever level the Range switch is in, the reading taken in (c) should still be between 22 and 26 millimhos/meter.

2.1.3 Operating Procedure

a) Wearing the instrument with the shoulder strap adjusted so that the instrument rests comfortably on the hip as shown, switch the Mode switch to the OPER position and rotate the Range switch so that the meter reads in the upper two thirds of the scale. The full scale deflection is now indicated by the Range switch and the instrument is reading the terrain conductivity directly in millimhos per meter.



b) The EM31 can be operated continuously while moving from one measurement station to the next however, the instrument has a time constant of about one second for which the operator should adjust his walking speed to obtain greatest accuracy.

Alternatively, to extend battery life the instrument can be switched on at each measurement station when not using a recorder. The operator will notice that the type of integrator used results in a slight initial overshoot of the needle at turn on. This is normal, and that at least two seconds should be allowed after turn on before the measurement is taken.

2.2 Buried Metal Detection

2.2.1 Set-up and Operating Procedure

The inphase component of the magnetic field is significantly more sensitive to large metallic objects than the quadrature-phase component used for ground conductivity measurements.

a) The inphase component is readily measured with the EM31 by simply taking the reading with the Mode switch in the COMP position rather than in the OPER position.

It is recommended that the 30 mmho/m range be used since it usually gives adequate sensitivity, however more or less sensitive positions of the Range switch may also be used.

b) To carry out a survey measuring the inphase component set the Mode switch to the COMP position and adjust the COARSE and FINE compensation controls so that a meter deflection of about 20% of full scale deflection is obtained. (The procedure of adjusting to 20% of the full scale deflection rather than to zero is only a convenience to allow for negative readings on the meter and under certain conditions a possible change in the reference level. For example, a sudden jar to the instrument can result in a small positive or negative change in the inphase reference level).

The survey is then carried out exactly as if the conductivity were being measured.

c) This lack of a true zero reference should not cause any serious problems since when using the inphase component one is usually only looking for buried metallic objects.

These will be easily recognizable by relatively localized meter deflections occuring either singly or in a series of responses depending on the number of buried objects, their spacing and depth of burial.

Notes (1): The 20% offset should only be used when the inphase component only is being measured continuously. If both conductivity (quadrature phase) and inphase measurements are being made at each station the procedure described in 2.1.2 (a) should be used so that accurate ground conductivity measurements are obtained. If negative inphase measurements are obtained one should check the inphase reference level and/or the area for buried metallic objects or utilities.

(2) Similarly when the dual channel recorder is being used there should be no zero offset as described in 2.2.1 (b) and the meter reading set to zero using the COARSE and FINE controls as described in 2.1.2 (a).

A zero offset for negative inphase readings can however be allowed for on the recorder by setting the zero position of the pen at some arbitrary positive value when calibrating the recorder.

3. INSTRUMENT CALIBRATION

Prior to shipping, the instrument is calibrated in the factory to read properly. If necessary, calibration procedures are easily carried out as described below. IMPORTANT The most critical adjustment is the QF (quadrature fine) potentiometer which has been precisely adjusted at the factory.

4. SURVEY TECHNIQUE

Surveying with the EM31 is straightforward. As pointed out in a previous section, measurements may be made either continuously or on a station-by-station basis. In either case it is always recommended, as for any other geophysical survey, that survey lines and measurement stations be carefully laid out, and the survey performed in a systematic fashion with the resulting data accurately plotted for each measurement station. The most common survey error is to have the survey lines too short, in which case they do not extend sufficiently far off the supposedly anomalous region to permit the operator to establish the background values of terrain conductivity.

The EM31 yields good spatial resolution and measurement stations should be ten meters apart if the maximum resolution is to be employed. In many cases this spacing will be smaller than necessary, and twenty or perhaps forty meters will be adequate. The decision as to the correct spacing will be based on a knowledge of the lateral dimensions of the anticipated resistivity anomaly. To ensure the correct spacing it is useful, at the start of the survey, to continuously observe the conductivity values that are encountered as the operator moves down the survey line.

The resolution in conductivity of the EM31 is also high, with changes of 5% being quickly perceived. This instrument is capable of giving an extremely precise survey with information on small variations in the terrain conductivity.

4. SURVEY TECHNIQUE (cont'd)

It was seen in Section 1 that current flow within the earth consists of a series of concentric circles, assuming that the conductivity is laterally uniform. Therefore in the case of a uniform half-space, rotation of the instrument in a horizontal plane about the transmitter coil as a pivot will produce no change in the meter reading. Conversely, any change in the reading as this procedure is carried out is an indication of lateral inhomogeneities in conductivity. It is simpler and usually sufficiently accurate for the operator to rotate the instrument through 90° using himself as pivot at each measurement station. Thus if the lines are in a north-south direction the operator would normally walk along the line with the instrument pointing in a north-south direction; at each measurement station he can also take a reading with the instrument pointing east-west to check that this is essentially the same as the north-south reading. In the event that this reading is significantly different it may be worthwhile for the operator to then rotate the instrument to the points where the conductivity reading is both a maximum and a minimum, and to record both values. The average value can then be used for the data reduction.

The EM31 is somewhat sensitive to underground conductors such as large pipes, etc. These are usually easily recognized by the large meter fluctuations which occur within a short distance, as shown in Fig. 2. In an actual survey, since the negative-going peak is often off-scale, it is not possible to use it to locate the pipe; finding the point half way between the two positive-

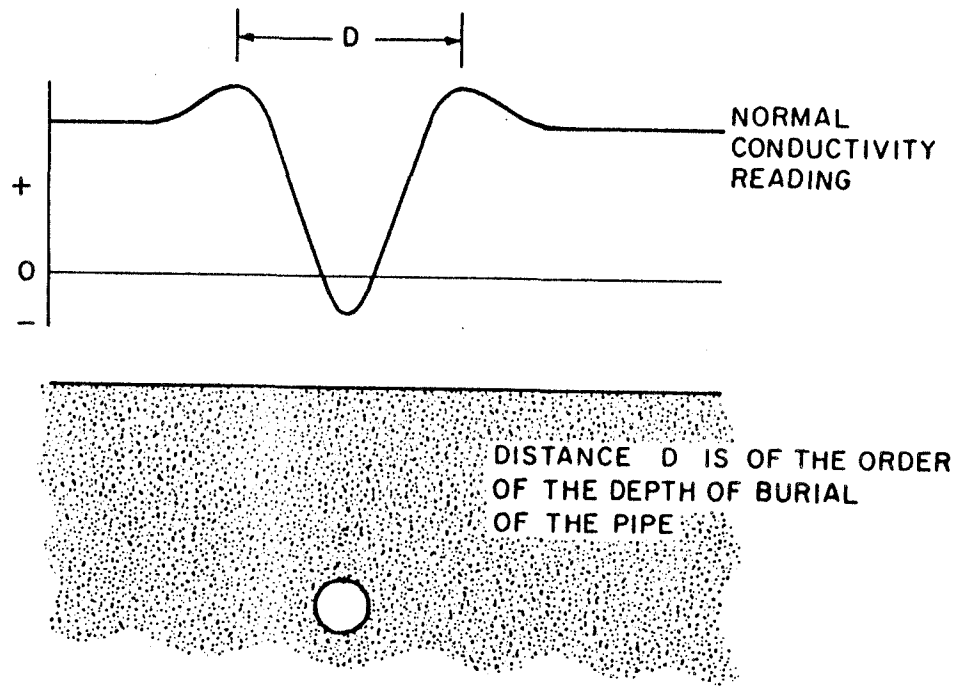


Fig. 2 TYPICAL RESPONSE OVER A PIPE

4. SURVEY TECHNIQUE (cont'd)

going peaks approximately performs the same task. It is then possible to accurately determine the location and strike direction (azimuth) of the conductor axis as follows: the approximate location is determined as above, and a traverse is then made over the conductor with the EM31 pointing in the approximate direction of the conductor axis. The meter reading will now be a positive maximum when the instrument is both directly over the conductor and pointing accurately along the conductor axis.

The instrument is relatively unaffected by fences, overhead power lines, and other nearby metallic objects. In order to determine whether the reading is influenced by such structures the operator should rotate the instrument to check for changes in reading, becoming suspicious if a maximum or minimum occurs when the instrument points either perpendicular or parallel to the structure. Before recording the measurement the operator should move away from the structure until no evidence of lateral inhomogeneity is seen when the instrument is rotated.

It should be remembered that the EM31 is an electromagnetic tool and care should be taken near obvious conductors until the operator has satisfied himself as to their possible affect. In every case this is determined by rotating the instrument and determining whether there is a maximum and minimum which appears to be realted to the structure. If a structure is giving such an effect it is not advisable to take the average value of the two readings as an indicator of the terrain conductivity.

4. SURVEY TECHNIQUE (cont'd)

In general the conductivity readings obtained with the EM31 will vary smoothly from one region to another. In some cases however, as for example where a well defined vertical contact separates a poor conductor from a very good conductor, edge effects may be seen in which the readings vary rapidly with position and are no longer a good indicator of the terrain conductivity. Edge effects may also occur where a very good conductor (a few ohm-meters or less) has dimensions of the order of the inter-coil spacing, and again the indicated readings may not accurately reflect the true terrain conductivity. In any circumstance where the apparent conductivity varies significantly in a distance which is short compared with the intercoil spacing the possible presence of edge effects or local subsurface conductors must be considered.

Finally, particularly during mid-summer afternoons, electrical static (electromagnetic radiation from local or distant thunderstorms) may cause the meter readings to become noisy. This is usually evidenced by sudden flicks of the meter needle, however in very severe cases the meter may simply wander about an average reading. Should this occur it is recommended that measurements cease until the "spherics" are over, usually later in the afternoon. Similarly, noisy readings may also be noted when making measurements near large power lines.

5. DATA INTERPRETATION

5.1 Uniform Halfspace

The EM31 has been designed to operate over a range of resistivities from a few ohm-meters to thousands of ohm-meters. For smaller resistivities the instrumental response departs from linearity as shown in Fig. 3, where it will be seen that up to one hundred millimhos per meter the indicated conductivity (σ_a) closely approximates the true conductivity. A departure from linearity is evident for true conductivity greater than one hundred millimhos per meter and beyond one thousand millimhos per meter the instrument response decreases with increasing conductivity. As stated in the introduction, it is generally more informative to observe the spatial variations of terrain conductivity rather than the absolute value of conductivity itself. Fig. 3 shows that as long as the terrain conductivity does not fall below five hundred millimhos per meter (2 ohm-meters) the instrument will be adequately sensitive to small changes in conductivity although it does not read the actual value of conductivity accurately. If necessary, Fig. 3 can be used to correct values of indicated conductivity to actual conductivity.

It should be noted that the graph refers to the worst case viz that of the uniform halfspace. If only a portion of the subsurface ground beneath the instrument is of high conductivity as in the case of horizontal layering, the influence of the high conductivity layers will be proportionately reduced and the indicated conductivity will accurately read the "apparent conductivity" as defined in the following section.

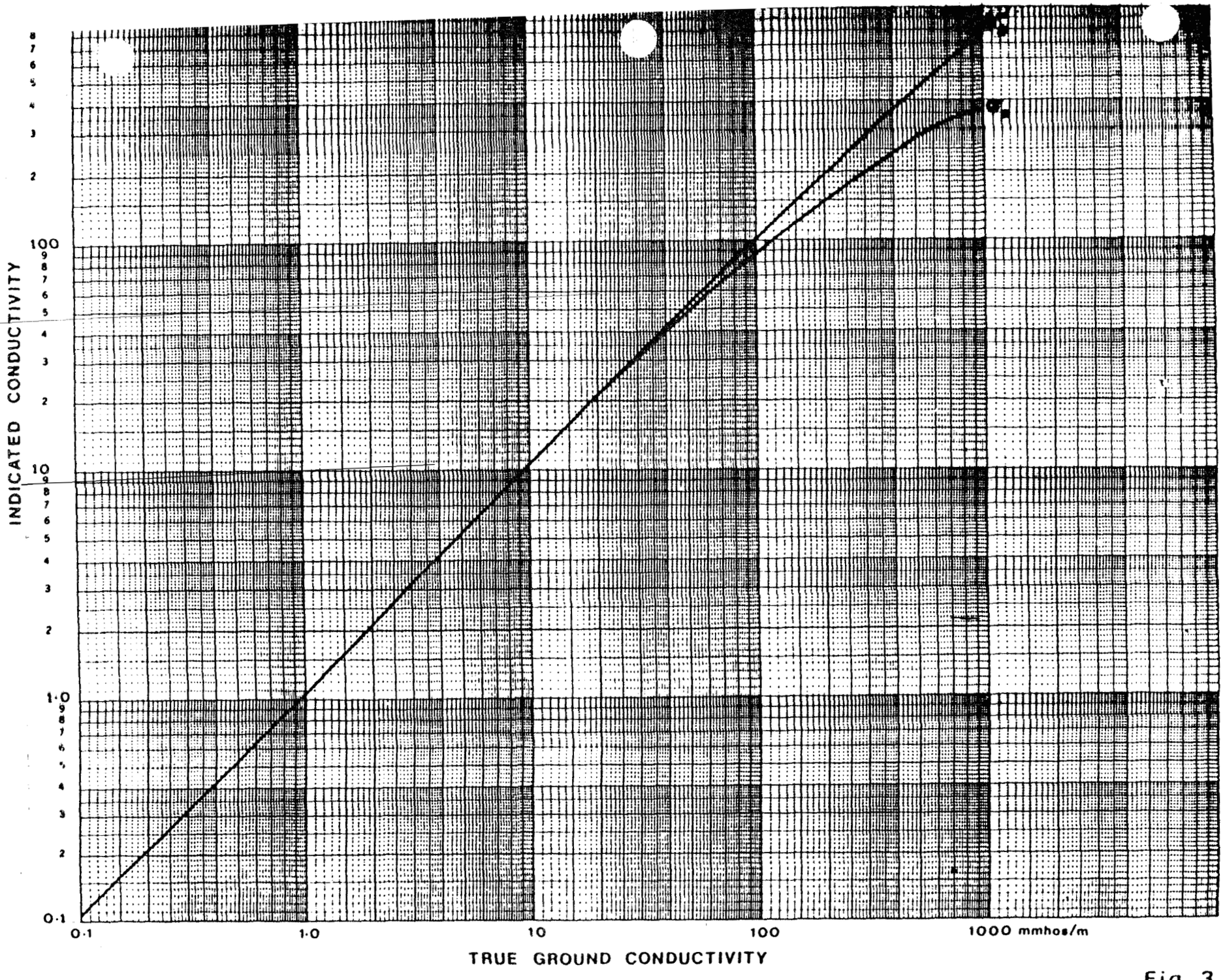

INDICATED CONDUCTIVITY
TRUE GROUND CONDUCTIVITY
0·1
1·0
10
100
1000 mmhos/m

Fig. 3

5.2 Multi-Layered Earth

A geophysical model that is of particular importance is the horizontally layered earth, and the EM31 allows a very simple interpretive technique for this model. In order to utilize the model the terrain layering must be well defined and constant over a lateral distance of at least five meters in any direction from the instrument. This condition is often satisfied and this fact is responsible for the usefulness of the technique described herein.

Fig. 4 is a plot of "R(Z)", a function which describes the cumulative relative contribution of all of the material below a depth Z to the instrument reading. Thus if we multiply this function by one hundred (so as to yield percent) all of the ground below a depth of two meters yields 59% of the response, the ground below three meters yields 47%, the ground below six meters yields 29%, etc., assuming that the conductivity itself does not vary with depth.

The algebraic expression given on the figure illustrates the technique which is used to calculate the "apparent conductivity" that will be measured by the instrument for any number of layers, for any values of conductivity and for any thicknesses. Consider for example Fig. 5, which illustrates in cross section a buried river valley cut into shale and subsequently infilled with glacial till. We wish to calculate the instrument response as such a structure is traversed. This is a two layer problem and the expression for the apparent conductivity reduces to:

$$\frac{\sigma_a}{\sigma_1} = 1.000 - R(Z_1) + k_2 R(Z_1) \qquad (1)$$

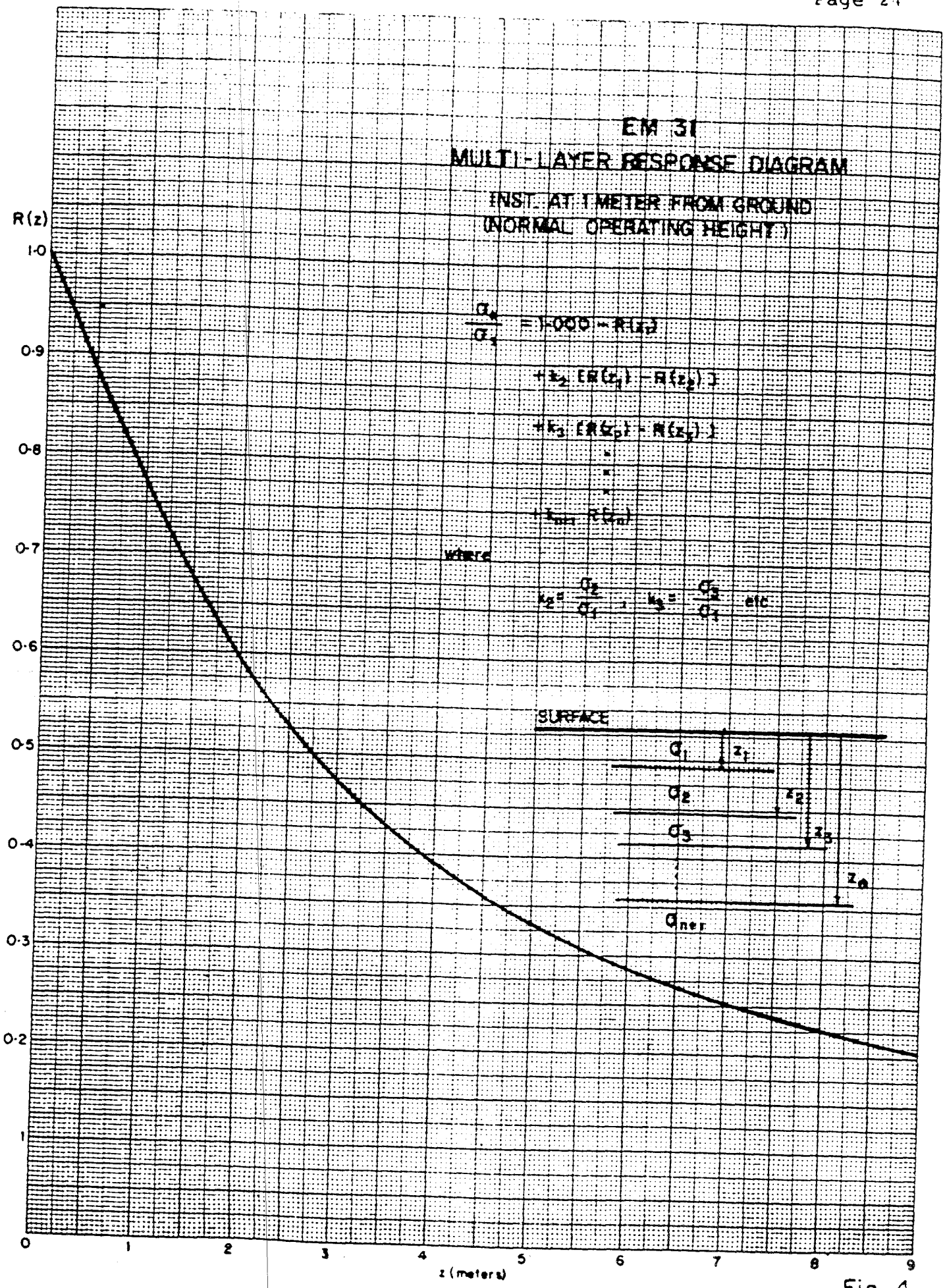

EM 31
MULTI-LAYER RESPONSE DIAGRAM
INST. AT 1 METER FROM GROUND
(NORMAL OPERATING HEIGHT)
R(z)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
1
0
1
2
3
4
5
6
7
8
9
z (meters)
$\frac{\sigma_a}{\sigma_1} = 1.000 - R(z_1)$
$+ k_2 [R(z_1) - R(z_2)]$
$+ k_3 [R(z_2) - R(z_3)]$
$+ k_{n+1} R(z_n)$
where
$k_2 = \frac{\sigma_2}{\sigma_1}$, $k_3 = \frac{\sigma_3}{\sigma_1}$ etc.
SURFACE
σ_1
z_1
σ_2
z_2
σ_3
z_3
z_n
σ_{nex}

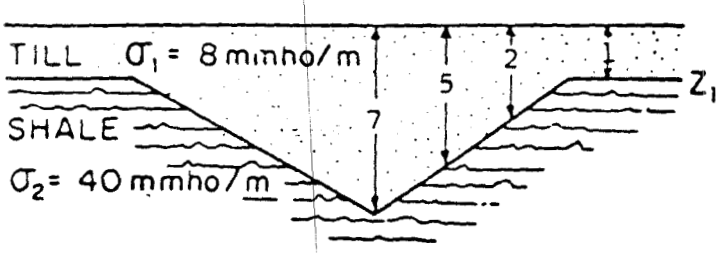
Fig. 4

5.2 Multi-Layered Earth (cont'd)

The table accompanying the figure shows the calculations which yield the value of apparent conductivity at various thicknesses of the upper layer. Thus as we traverse such a structure we would find that the apparent conductivity fell from 32.6 millimhos per meter at a large distance from the buried river valley to 16.0 millimhos per meter at the center of the valley.

Fig. 6 illustrates a second situation where now the objective is to locate bedrock highs within muskeg. This is again a two layer case and the table illustrates the calculations to determine the apparent conductivity. For this configuration, i.e. a conductor on top of an insulator and k_2 a small quantity, the measured apparent conductivity becomes relatively independent of the actual value of the conductivity of the lower layer. For $k_2 << 1$, the apparent conductivity simply becomes a function of the thickness of the upper conductive layer.

Finally a third example is given in Fig. 7. In this case we wish to traverse a thickening gravel deposit; the maximum thickness is such that the instrument still responds to material below the deposit. This is an example of the situation of an insulator sandwiched between two conductors and is inevitably the most difficult geometry for electromagnetic systems to detect, as evidenced by the tabulated values of apparent conductivity. Even at a thickness of five meters (station D) there is still significant response from the till beneath the deposit and this response tends to keep the apparent conductivities high.

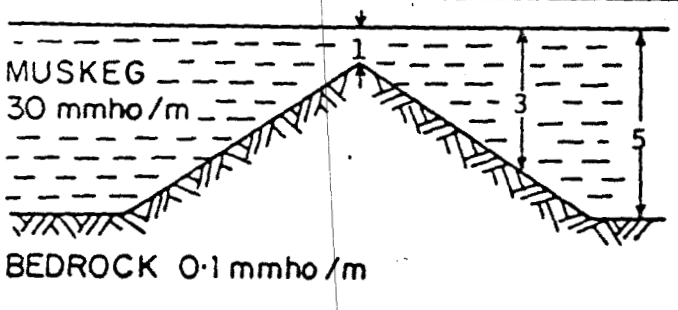


$$\frac{\sigma_a}{\sigma_1} = 1{\cdot}000 - R(Z_1) + k_2 R(Z_1) \qquad (1)$$

$$k_2 = \frac{\sigma_2}{\sigma_1} = \frac{40}{8} = 5$$

z_1 = 1m, σ_a = 8(1.00 - 0.77 + (5 x 0.77)) = 32.6 mmho/m
z_1 = 2m, σ_a = 8(1.00 - 0.59 + (5 x 0.59)) = 26.9 "
z_1 = 5m, σ_a = 8(1.00 - 0.33 + (5 x 0.33)) = 18.6 "
z_1 = 7m, σ_a = 8(1.00 - 0.25 + (5 x 0.25)) = 16.0 "

Fig. 5 CROSS SECTION BURIED RIVER VALLEY

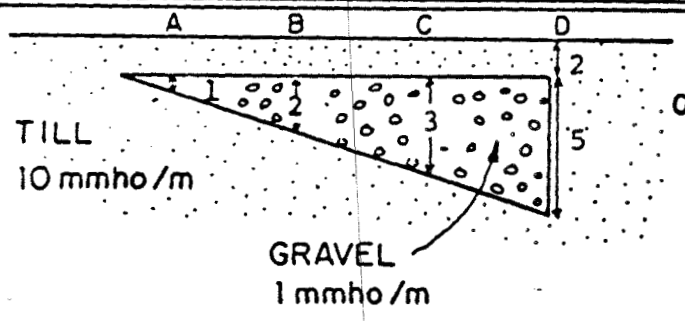


$$\frac{\sigma_a}{\sigma_1} = 1{\cdot}000 - R(Z_1) + k_2 R(Z_1)$$

$$k_2 = \frac{0{\cdot}1}{30} = 0{\cdot}0033$$

z_1 = 5m, σ_a = 30(1.00 - 0.33) = 20.1 mmho/m
z_1 = 3m, σ_a = 30(1.00 - 0.47) = 15.9 "
z_1 = 1m, σ_a = 30(1.00 - 0.77) = 6.9 "

Fig. 6 CROSS SECTION BEDROCK HIGH



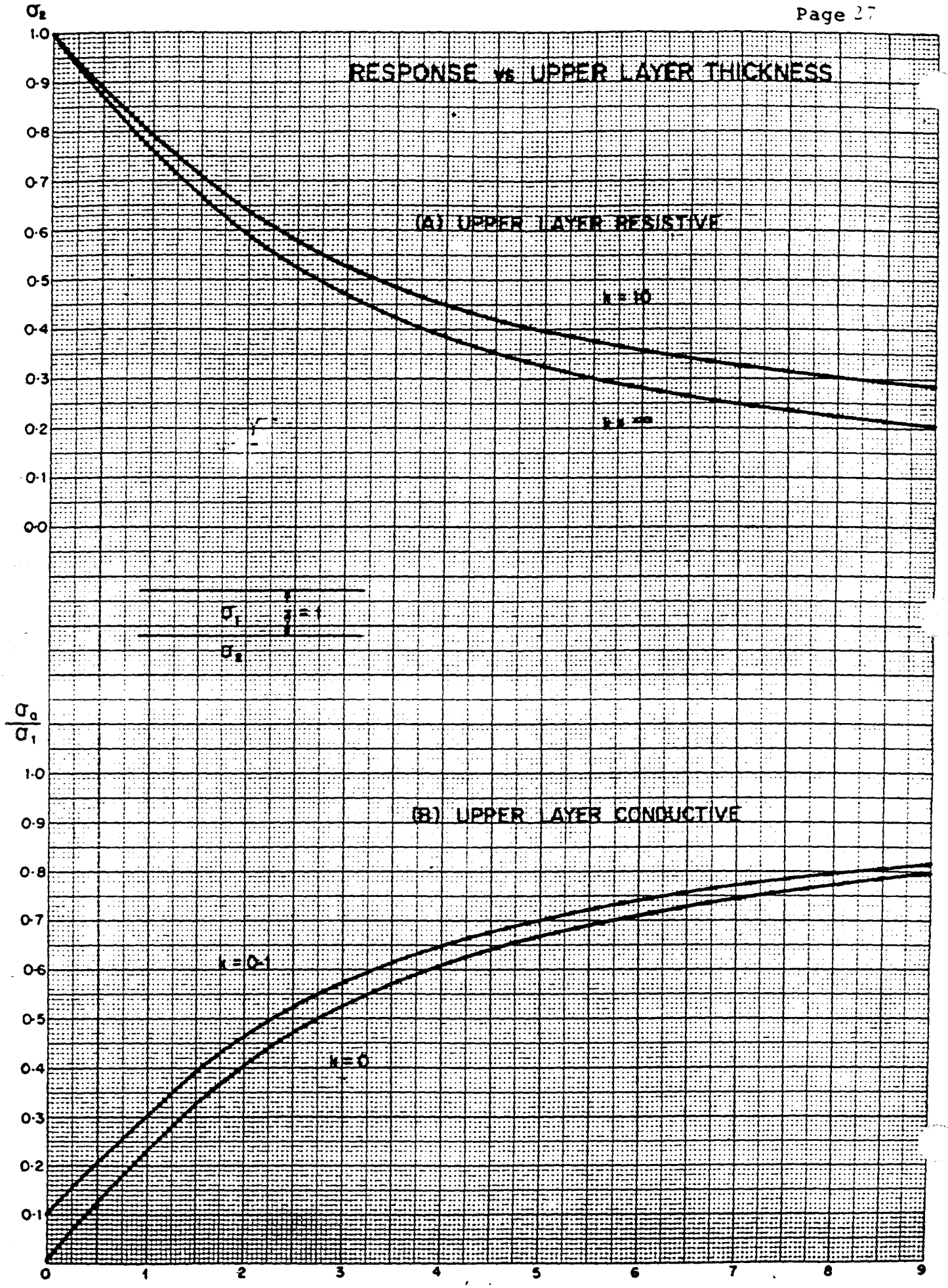
$$\sigma_a = \sigma_1 [1{\cdot}000 - R(Z_1) + k_2 R(Z_1) - k_2 R(Z_2) + k_3 R(Z_2)]$$

$$k_2 = \frac{\sigma_2}{\sigma_1} = \frac{1}{10} = 0{\cdot}10$$

$$k_3 = \frac{\sigma_3}{\sigma_1} = 1{\cdot}00$$

(A) σ_a=10 (1.00-0.59+(0.10x0.59)-(0.10x0.47)+(1.00x0.47)) = 8.9 mmho/m
(B) σ_a=10 (1.00-0.59+(0.10x0.59)-(0.10x0.39)+(1.00x0.39)) = 8.2 "
(C) σ_a=10 (1.00-0.59+(0.10x0.59)-(0.10x0.33)+(1.00x0.33)) = 7.7 "
(D) σ_a=10 (1.00-0.59+(0.10x0.59)-(0.10x0.25)+(1.00x0.25)) = 6.9 "

Fig. 7 CROSS SECTION GRAVEL DEPOSIT



461510
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

5.2 Multi-Layered Earth (cont'd)

The three examples show how to calculate the response of the EM31 over a variety of geological environments. Since the instrument operates at a fixed intercoil spacing it is not possible to completely "sound" or evaluate differing conductivity layers with depth. Section 5.3 will show how to further resolve the two-layer case, however it is always useful to be able to calculate the apparent conductivity which would arise from a given multi-layer model to see whether that model fits the measured data.

Fig. 8 shows the apparent conductivity over the two limiting cases of a two layer geometry where the conductivity contrast is very large. In Fig. 8A the upper layer is assumed to be very resistive and the figure shows the apparent conductivity with respect to the lower layer conductivity (assumed known) as a function of the depth below the surface of the lower layer, for values of k of ten and infinity. Thus for large k the figure permits the operator to quickly convert the measured values of apparent conductivity to depth, and to estimate the error if the conductivity contrast is not infinite.

Fig. 8B performs the same task for small values of conductivity contrast. It should be noted that Fig. 8B plots the apparent conductivity with respect to the upper layer conductivity.

It is stated in the data sheet that the effective depth of penetration of the EM31 is approximately six meters. Justification for this claim is shown in Fig. 8 where it is seen that for either a resistive ($k = \infty$) or conductive ($k = 0$) upper layer the apparent conductivity is still

5.2 Multi-Layered Earth (cont'd)

satisfactorily sensitive to changes in the upper layer thickness at six meters. The limitation in resolving further changes in thickness is imposed by probable variations in the conductivity of either layer.

5.3 Geometrical Sounding of Two Layered Earth

It is possible with the EM31 to determine whether the conductivity increases or decreases with depth by laying the instrument on the ground, noting the reading, and then placing the instrument on its side so that the meter face is vertical and again noting the instrument reading. The reason for this is that when the instrument is on its side the new transmitter and receiver coil orientation with respect to the earth causes the effective depth of penetration of the instrument to be essentially halved. It should be noted that in this configuration the current flow does not exhibit the circular symmetry shown in Fig. 1. Thus let σ_a be the apparent conductivity indicated by the instrument on the ground in its normal operating position and let σ_a' be the apparent conductivity indicated when the instrument is lying on its side. If σ_a is greater than σ_a' we know that the conductivity is increasing with depth and vice versa. The ability of the EM31 to indicate whether the conductivity is increasing or decreasing with depth is often of considerable diagnostic value.

It will be observed from the above that it is now possible to obtain two measured quantities at each measurement station. In the event that the earth consists only of two layers, there are three unknown quantities i.e.

5.3 Geometrical Sounding of Two Layered Earth (cont'd)

the conductivity of the upper and lower layer and the thickness of the upper layer. If one of these is known it is possible, using the technique described above, to determine the other two. More importantly, when there is a large conductivity contrast so that the conductivity of either the upper or lower layer can be ignored with respect to the other layer then it is possible to completely resolve the two layered earth. An example of the importance of this can be seen in Fig. 8 which gives the instrumental response as a function of upper layer thickness for either a resistive or conductive upper layer. In order to use these graphs it is necessary to know the conductivity of the lower or upper layer respectively, since both graphs are normalized with respect to these quantities. An inaccurate knowledge of σ_2 in the case of a resistive upper layer or σ_1 in the case of a conductive upper layer can result in a substantial error in the calculated thickness of the upper layer. Any technique which allows us to determine the conductivity of the more conductive layer is of considerable importance since by definition the EM31 is most useful when one layer presents a significant conductivity contrast with respect to the other.

Fig. 9 shows a multi-layer response diagram R(Z), completely analogous to Fig. 4 but with the instrument now laying on the ground. Fig. 10, which presents the function R'(Z) as a function of depth is the same function as Fig. 9 but now with the instrument rotated on its side so that the meter face is vertical. It will be noted from Fig. 9 that with the instrument on the ground in its normal operating configuration the total contribution from

5.3 Geometrical Sounding of Two Layered Earth (cont'd)

all ground in excess of a depth of five meters is 34% whereas Fig. 10 shows that with the instrument lying on its side the ground in excess of five meters causes a total contribution of only 17.5% of the total response. This is the justification for stating earlier that the instrument has effectively one half the depth penetration when lying on its side. Fig. 9 also contains a plot of the ratio R'/R and Fig. 10 a plot of the ratio (1-R')/(1-R), both as a function of depth.

Case 1. σ_1 and σ_2 comparable and σ_1 known. It is shown in Appendix 1 that for this case

$$\frac{R'(Z)}{R(Z)} = \frac{\frac{\sigma_a'}{\sigma_1} - 1}{\frac{\sigma_a}{\sigma_1} - 1}, \qquad \sigma_2 = \frac{\sigma_a - \sigma_1 + R\sigma_1}{R} = \frac{\sigma_a' - \sigma_1 + R'\sigma_1}{R'}$$

thus given σ_a', σ_a, and σ_1, R'/R is calculated; Fig. 9 then gives the thickness of the upper layer as a function of R'/R; with this thickness Fig. 9 or 10 is used to determine R or R' and the second equation given above is used to determine σ_2 thus fully resolving the two layer case.

Case 2. σ_1 and σ_2 comparable and σ_2 known. In this case Appendix 1 shows that

$$\frac{1 - R'(Z)}{1 - R(Z)} = \frac{\frac{\sigma_a'}{\sigma_2} - 1}{\frac{\sigma_a}{\sigma_2} - 1}, \qquad \sigma_1 = \frac{\sigma_a - \sigma_2 R}{1 - R} = \frac{\sigma_a' - \sigma_2 R'}{1 - R'}$$

5.3 Geometrical Sounding of Two Layered Earth (cont'd)

Knowing σ_a', σ_a, and σ_2, $(1-R')/(1-R)$ is calculated, Fig. 10 gives the thickness and given the thickness Fig. 9 or 10 gives R or R' so that the second equation given above is used to calculate σ_1.

Case 3. Upper layer resistive. σ_1 much less than σ_2. In this case Appendix 1 shows that

$$\frac{R'(Z)}{R(Z)} = \frac{\sigma_a'}{\sigma_a}, \qquad \sigma_2 = \frac{\sigma_a}{R} = \frac{\sigma_a'}{R'}$$

and the same proceedure as for Case 1 above is used to determine the thickness of the upper layer and the conductivity of the lower layer.

Case 4. Upper layer conductive. σ_1 much greater than σ_2. Again Appendix 1 shows that

$$\frac{1 - R'(Z)}{1 - R(Z)} = \frac{\sigma_a'}{\sigma_a}, \qquad \sigma_1 = \frac{\sigma_a}{1 - R} = \frac{\sigma_a'}{1-R'}.$$

and the calculations for Case 2 yield the thickness and the conductivity of the upper layer.

To illustrate the above let it be assumed that the upper layer is known to be 10 millimhos per meter and the EM31 indicates 3.8 millimhos per meter when laying on the ground in its normal configuration and 6.5 millimhos per meter when lying on its side. Fig. 3, which also gives the correction factor to use when the instrument is lying on its side, shows that no correction is necessary.

5.3 Geometrical Sounding of Two-Layered Earth (cont'd)

Since the instrument has been calibrated to be operated at one meter above the ground both of these numbers must be multiplied by .88 since the instrument is being used on the ground. This results in $\sigma_a = 3.3$ millimhos per meter and $\sigma_a' = 5.7$ millimhos per meter. Then

$$\frac{R'(Z)}{R(Z)} = \frac{\frac{\sigma_a'}{\sigma_1} - 1}{\frac{\sigma_a}{\sigma_1} - 1} = \frac{\frac{5.7}{10} - 1}{\frac{3.3}{10} - 1} = 0.64$$

whereupon Fig. 9 shows that the thickness of the upper layer is 1.25 meters and R(Z) = 0.825 whereupon

$$\sigma_2 = \frac{\sigma_a - \sigma_1 + R\sigma_1}{R} = \frac{3.3 - 10 + 0.825 \times 10}{0.825} = 1.9$$

The technique for the other cases described above is exactly the same.

The calculations described above assume that the earth is known to be two-layered. It is possible to determine whether this is true by measuring the apparent conductivity with the EM31 elevated to various heights above the ground and comparing the results with a family of curves given in Appendix II. If the measured variation of apparent conductivity with height matches one of the curves, one can immediately calculate the conductivity of both layers and the thickness of the upper layer, as described therein.

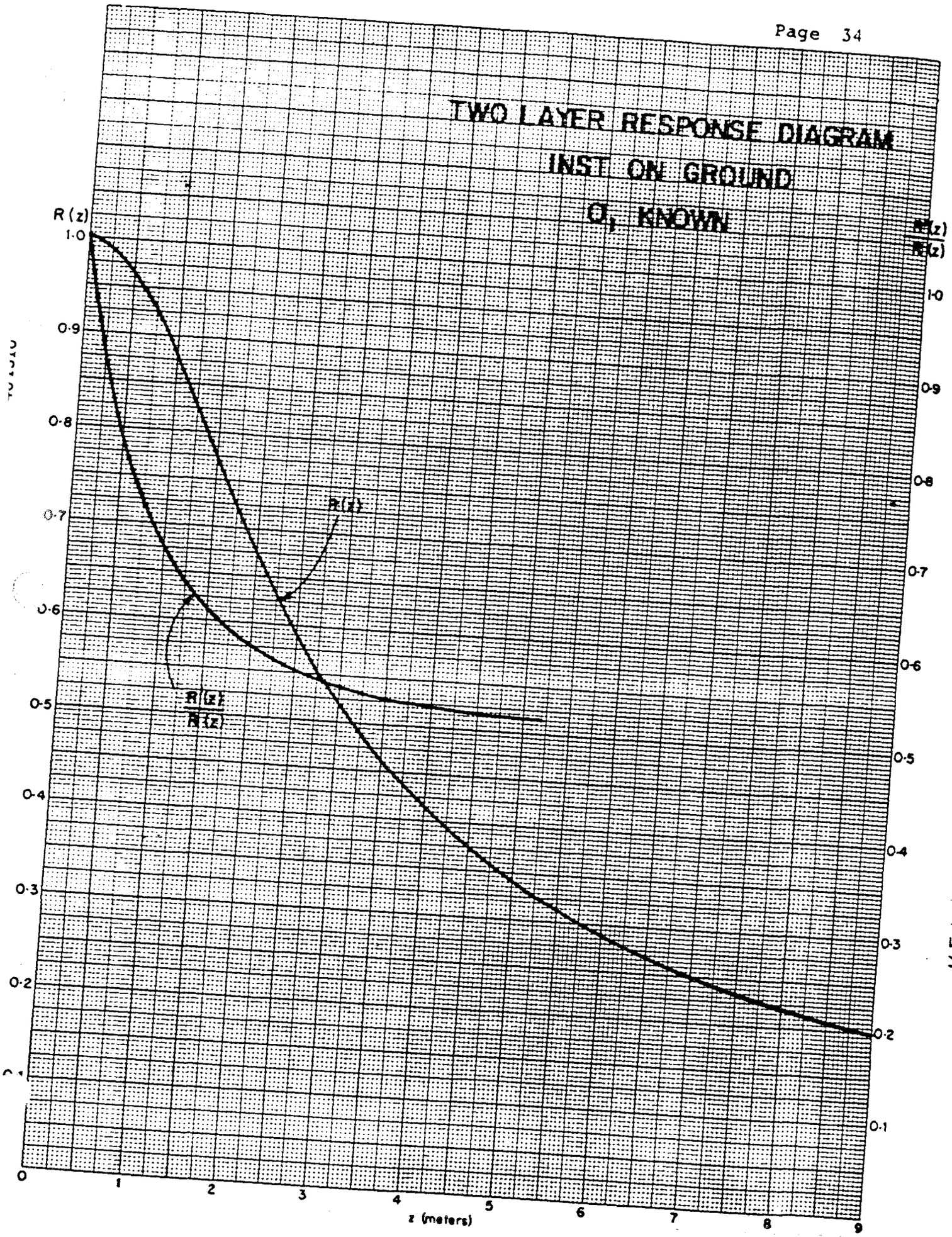

TWO LAYER RESPONSE DIAGRAM
INST ON GROUND
σ_1 KNOWN
R(z)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
1
2
3
4
5
6
7
8
9
z (meters)
R(z)
R'(z)/R(z)

Fig. 9

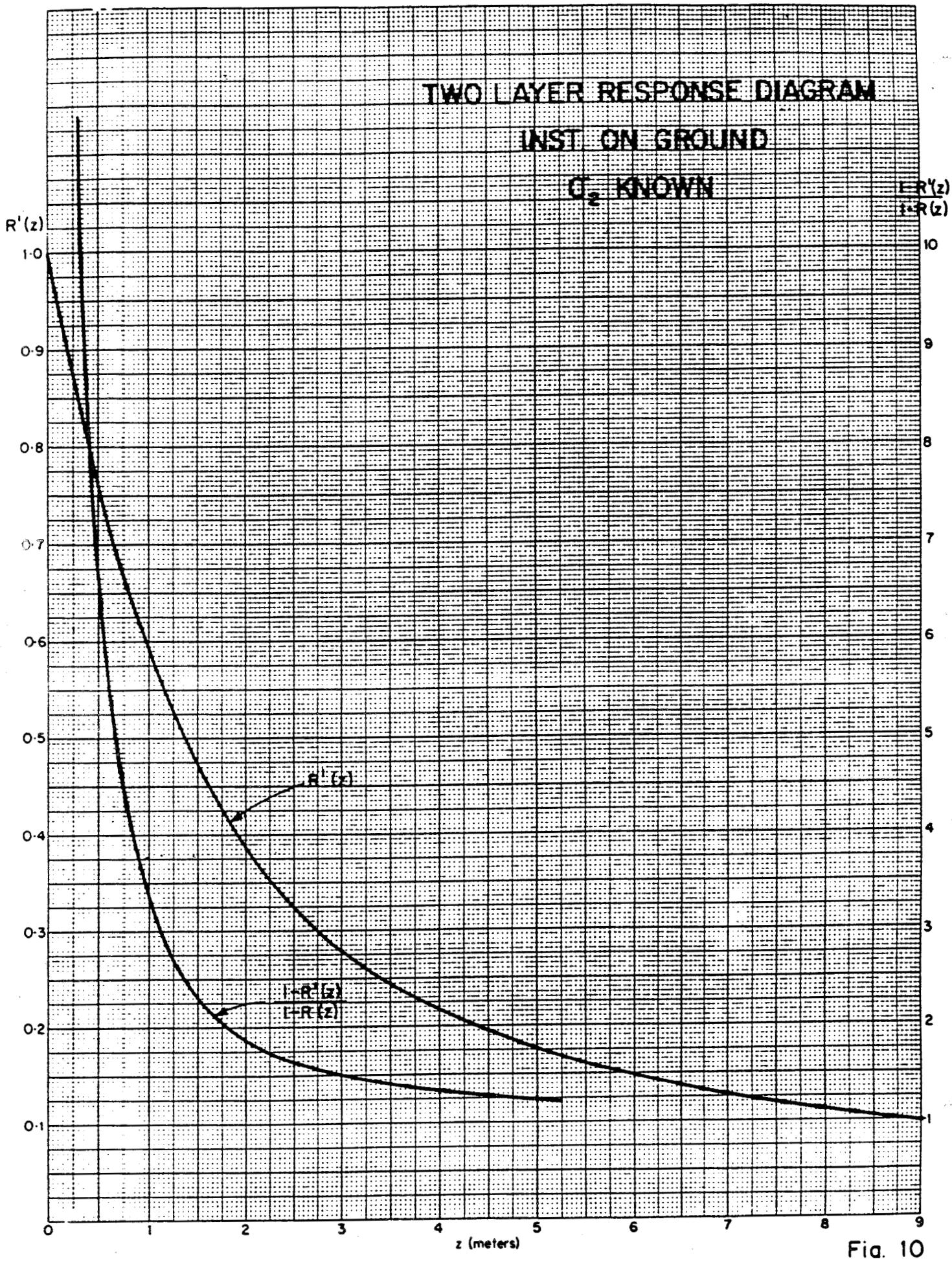

TWO LAYER RESPONSE DIAGRAM
INST. ON GROUND
σ_2 KNOWN
R'(z)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
$\frac{1-R^2(z)}{1+R(z)}$
10
9
8
7
6
5
4
3
2
1
R'(z)
$\frac{1-R^2(z)}{1-R(z)}$
0
1
2
3
4
5
6
7
8
9
z (meters)

Fig. 10

6. CASE HISTORIES: ELECTROMAGNETIC NON-CONTACTING GROUND RESISTIVITY MAPPING

6.1 Introduction

This short note gives some illustrative examples of surveys that have been carried out using electromagnetic techniques to measure terrain resistivity. The instruments employed were the Geonics Limited EM31 and a prototype version of the Geonics Limited EM34. Both instruments were calibrated to read terrain conductivity in millimhos per meter directly; however in some of the case histories illustrated in this note the measurements have been converted to resistivity in ohm-meters.

Two features which often limit the usefulness of conventional ground resistivity surveys are their high cost and in some regions (granular material, frozen ground) difficulties associated with generating sufficient current in the ground. The use of inductive electromagnetic techniques avoids both problems since ground probes are not required. This allows measurement over any type of terrain and greatly reduces the time to perform a survey.

Basically the technique consists of energizing a small coil at an audio frequency and measuring the resultant total magnetic field from this coil and the ground with another coil a fixed distance away. Theoretical studies show that, if the intercoil spacing is maintained at a small fraction of the electrical skin depth in the ground, all of the information about the

6.1 Introduction (cont'd)

ground conductivity is in the quadrature-phase response. Furthermore, the quadrature-phase response is essentially linearly related to ground conductivity, thus permitting an instrument design in which the output is calibrated to read conductivity (or resistivity) directly. Also under these conditions, the effective depth penetration of the system is determined by the intercoil spacing and is independent of skin depth and thus of ground conductivity. This feature greatly simplifies interpretation of survey results. In order to vary the depth to which the resistivity is sensed one simply varies the intercoil spacing in analogy with conventional resistivity surveys. Conversely each survey carried out at a fixed intercoil spacing is essentially analogous to a survey carried out with conventional resistivity equipment at a fixed interprobe spacing.

The Geonics EM31 is a one-man portable instrument designed for engineering geophysical applications down to depths of the order of six meters. The intercoil spacing is fixed at twelve feet (3.66 meters). The effective penetration referred to above is an average value; in those regions where a conductive medium is to be located beneath a resistive layer the penetration depth is substantially larger.

The prototype EM34 is operated at two intercoil spacings vis 50 and 100 feet, resulting in effective depth penetrations of the order of 75 and 150 feet (25 to 50 meters) depending on the intercoil spacing employed for the particular survey. Operation of the EM34 requires two men; however measurements are still taken virtually as fast as the team walks.

6.1 Introduction (cont'd)

Most of the case histories in the technical note have been taken with the EM31; however in some cases data from EM34 surveys are presented in order to further elucidate the features of inductive electromagnetic terrain resistivity mapping.

6.2 Example A: Heart Lake, Ontario (EM31)
Measurement Interval: 100 feet over till,
10 feet over sand/gravel

This survey line compares the results obtained with conventional resistivity equipment (Wenner array with "a" spacings of 1 foot and 20 feet) and the Geonics EM31. It is seen that over the till, where the resistivity is slowly varying, the agreement between the two techniques is excellent. In the region shown as "sand and interbedded gravel" there was a good deal of concretion which caused the resistivity to vary greatly over short distances and which accounts for the discrepancy between the two techniques. Over the till the EM31 was read continuously however the data was recorded, with one exception, at every 100 feet. The exception occurred at station 7+50 where it was noted that a local resistivity high occurred; this was of course not observed on the Wenner array since measurements were taken only at every 100 feet.

6.3 Example B: Sunnybrook Park (EM31, EM34)
Measurement Interval: 100 feet

This case history shows measurements made with both the EM31 and the EM34 and illustrates the effective depth penetration of the two systems. The second sheet shows

6.3 Example B: (cont'd)

the results of expanding Wenner spreads at station 4+00 and 12+00. At station 4+00 we would expect the EM31 to read approximately 40 ohm-meters and the EM34 50 to 60 ohm-meters, which is the case. At station 12+00 the resistivity increases with depth and thus the EM31 should read a relatively low value and the EM34 a higher value which increases with intercoil spacing. This is indeed the case.

6.4 Example C: Cavendish Test Site (EM31)
Measurement Interval: 50 feet

This survey, which was carried out over line C to establish the overburden resistivity shows that with the exception of the swamp area the overburden is extremely resistive. The value of resistivity obtained over the swamp is in good agreement with that from other measurements. The example also illustrates the performance of the instrument over zones A & B, both of which are small highly conductive mineralized zones and cause the instrument to read off scale.

6.5 Example D: Lake Scugog (EM31)
Measurement Interval: 50 feet

This survey illustrates the extremely high resolution achievable with the EM31 or the EM34 systems since neither technique requires electrical contact with the ground. Resolution in conductivity of the order of 3% or 4% is easily achieved and completely repeatable as long as the terrain remains unchanged. The example also illustrates the speed with which a survey can be carried out. In this particular case 1.9 line miles of survey

6.5 Example D: (cont'd)

was performed in seventy minutes with a station interval of 50 feet. Furthermore since the measurements were actually taken continuously any unusual activity in the resistivity between stations would have been recorded.

6.6 Example E: Cooksville/Mississauga, Ontario (EM31)
Measurement Interval: 25 feet

This example illustrates a survey carried out with the EM31 to search for a buried river channel. The channel, which is filled with glacial till, has been cut into the Dundas shale which, as seen from the example, has a resistivity of the order of 25 to 30 ohm-meters. The total time to plot out the profiles shown in the figure was approximately 2½ hours, with a measurement interval of 25 feet. A shortcoming of the technique is seen on line 5, where a region was encountered which was so conductive that it was not possible to take readings.

The second sheet illustrates the application of the two layer curves to interpret the survey results in terms of depth.

6.7 Example F: Discontinuous Permafrost (EM31)
Measurement Interval: Variable

These two examples were taken in Northern Canada and compare the results obtained with the EM31 with a medium frequency version of the Radiohm (Geonics EM16R) technique operating at 250 kHz. The data interval is fairly coarse, nevertheless there is good agreement between the two techniques, which is particularly interesting in view of the fact that the current distribution in the ground

6.7 Example F: (cont'd)

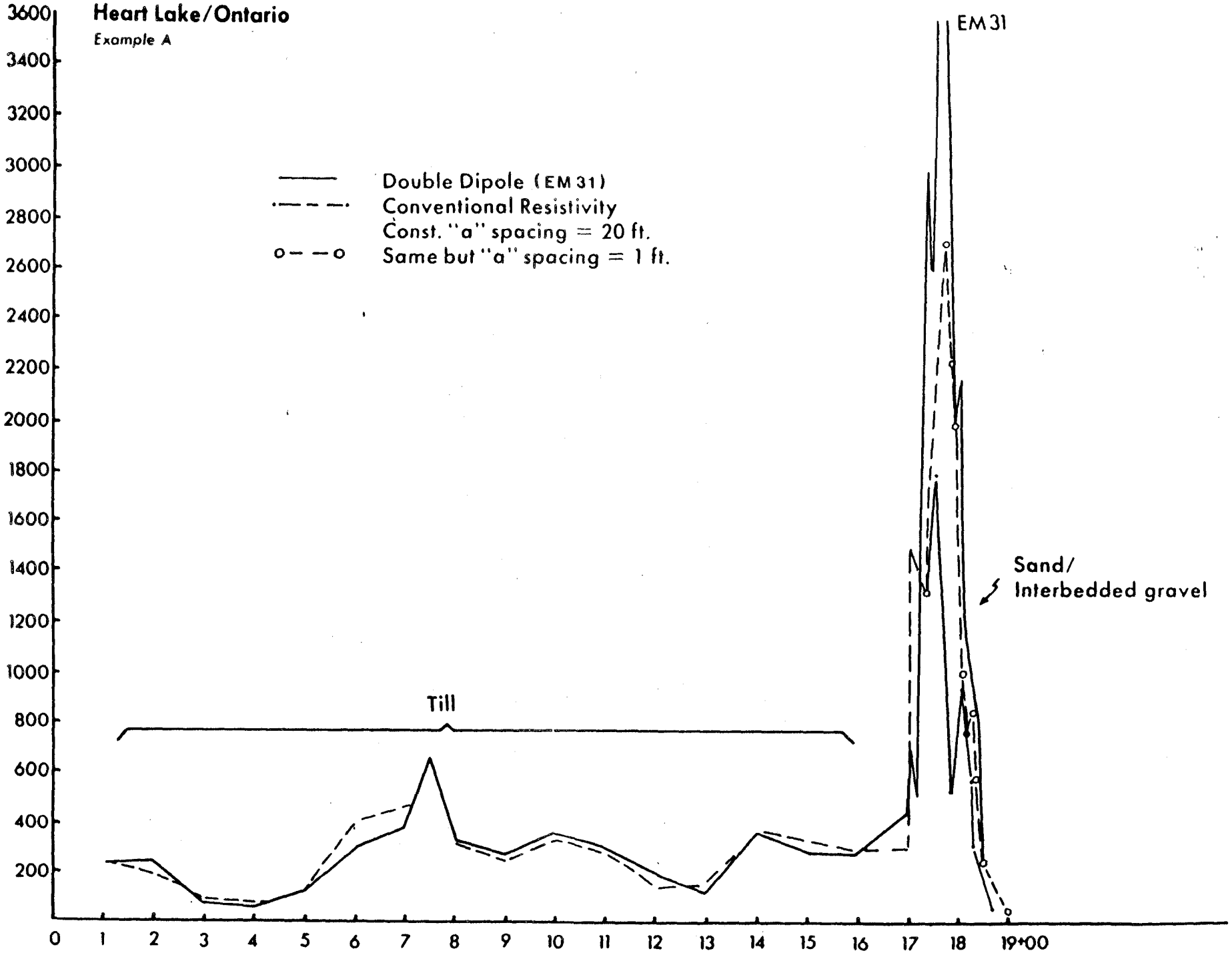
is totally different for the two systems. Furthermore the EM31 operates at a frequency of approximately 40 kHz whereas the MF Radiohm operates at 250 kHz.

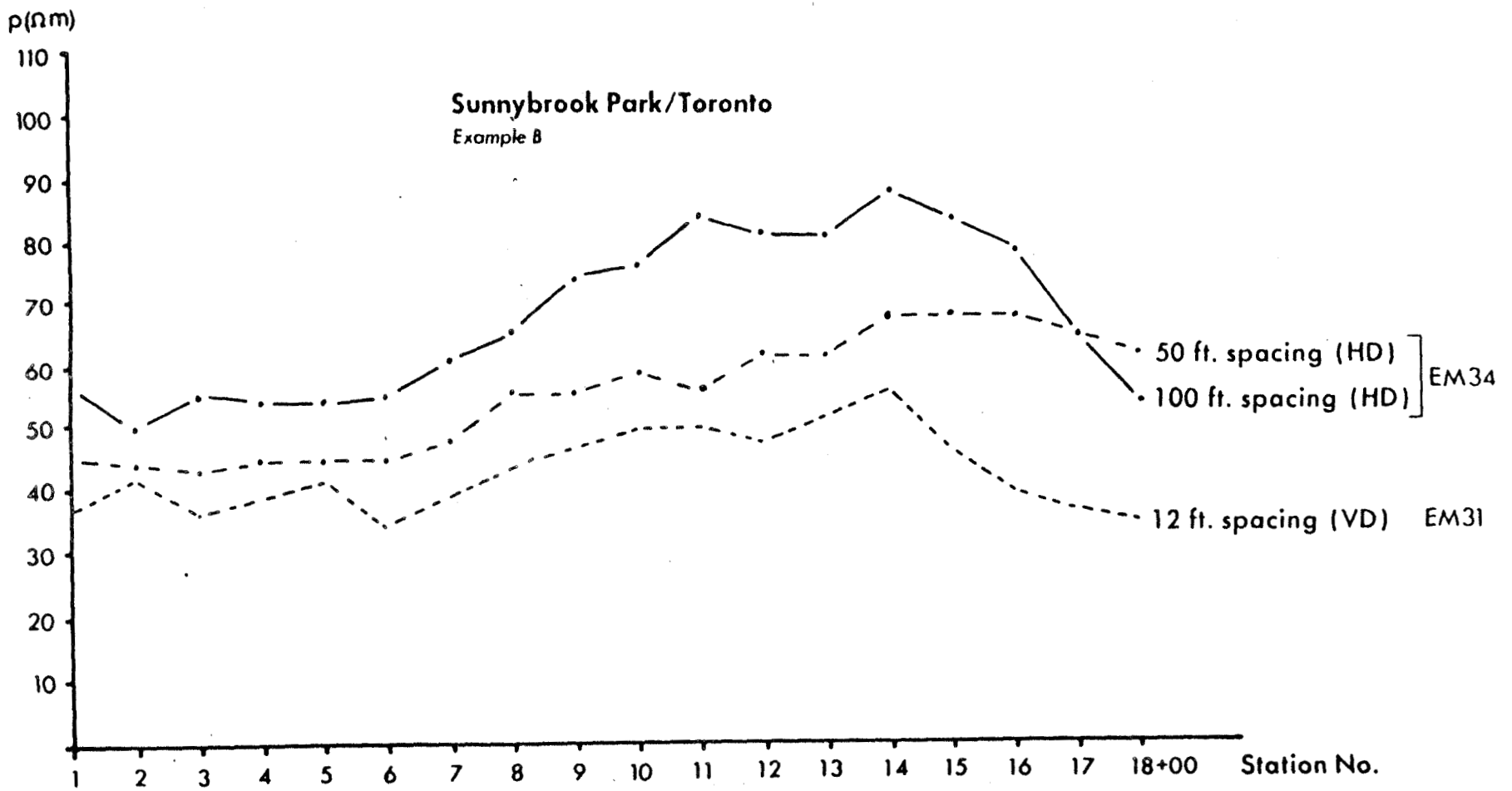
6.8 Example G: Pre-glacial River Valley (EM31, EM34)
Measurement Interval: 100 feet

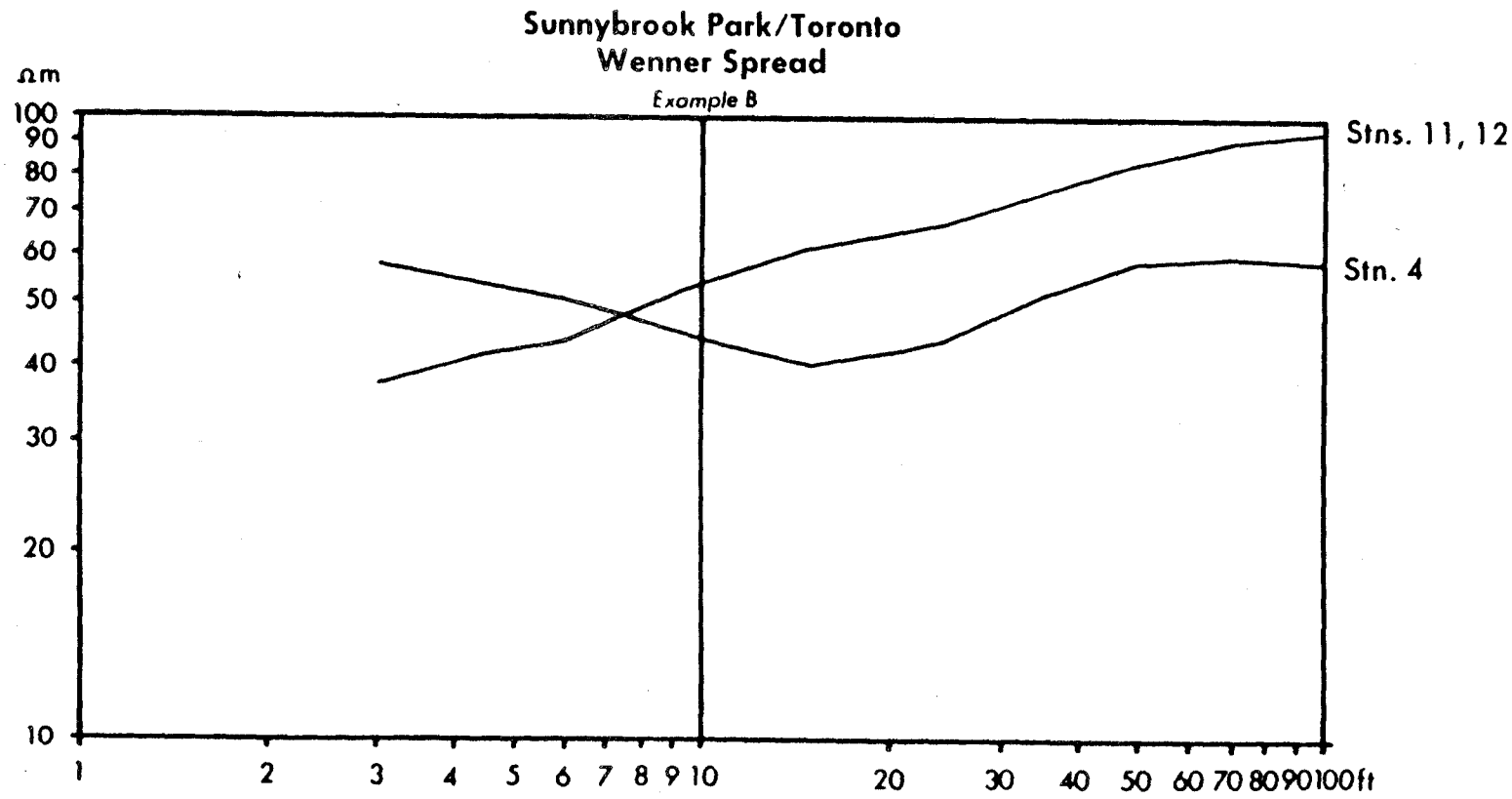
This survey was performed to outline a pre-glacial river valley whose existance had been suggested from water-well data. The survey was performed with the EM34 at a station interval of 100 feet and with intercoil spacing of both 50 and 100 feet. At either spacing the time required to complete the 8400 foot survey line was 1½ hours. The same line was subsequently surveyed with the EM31.

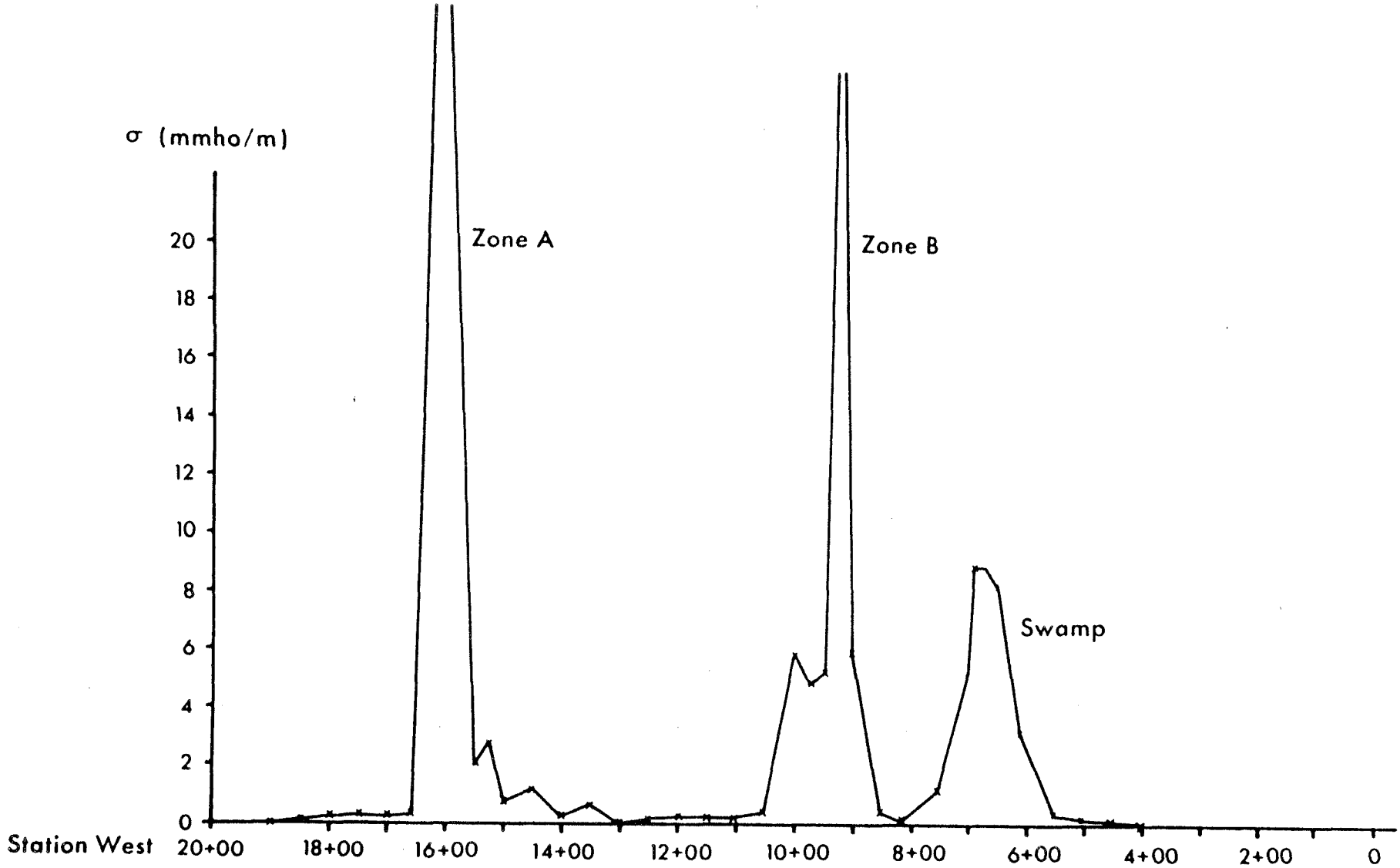
Typical bedrock conductivity in the area is approximately 32 millimhos per meter, whereas an average value for the conductivity of the infilling glacial till is of the order of 8 to 12 millimhos per meter. Thus the EM34 at either intercoil spacing yields approximately 30 to 34 millimhos per meter at the valley edges where the overburden is thin and 12 to 14 millimhos per meter at the valley center. The EM31 yields values of 14 to 18 millimhos per meter at the valley edges (slightly affected by the presence of bedrock) and approximately 10 millimhos per meter at the valley center. The interpreted depth of the valley, based on the model shown in the figure, is approximately 120 feet which is in reasonable agreement with the water-well data value of 150 feet, bearing in mind that the three sets of data show that a two layer model is an over simplification.

The conductivity high which occurs between station 32 and 38 results from a very large pile of waste furnace ash lying on the surface.


Heart Lake/Ontario
Example A
EM 31
Double Dipole (EM 31)
Conventional Resistivity
Const. "a" spacing = 20 ft.
Same but "a" spacing = 1 ft.
Till
Sand/
Interbedded gravel
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19+00


ρ(Ωm)
110
100
90
80
70
60
50
40
30
20
10
Sunnybrook Park/Toronto
Example B
50 ft. spacing (HD)
100 ft. spacing (HD)
EM34
12 ft. spacing (VD)
EM31
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18+00
Station No.


Sunnybrook Park/Toronto
Wenner Spread
Example B
Ωm
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
ft
Stns. 11, 12
Stn. 4

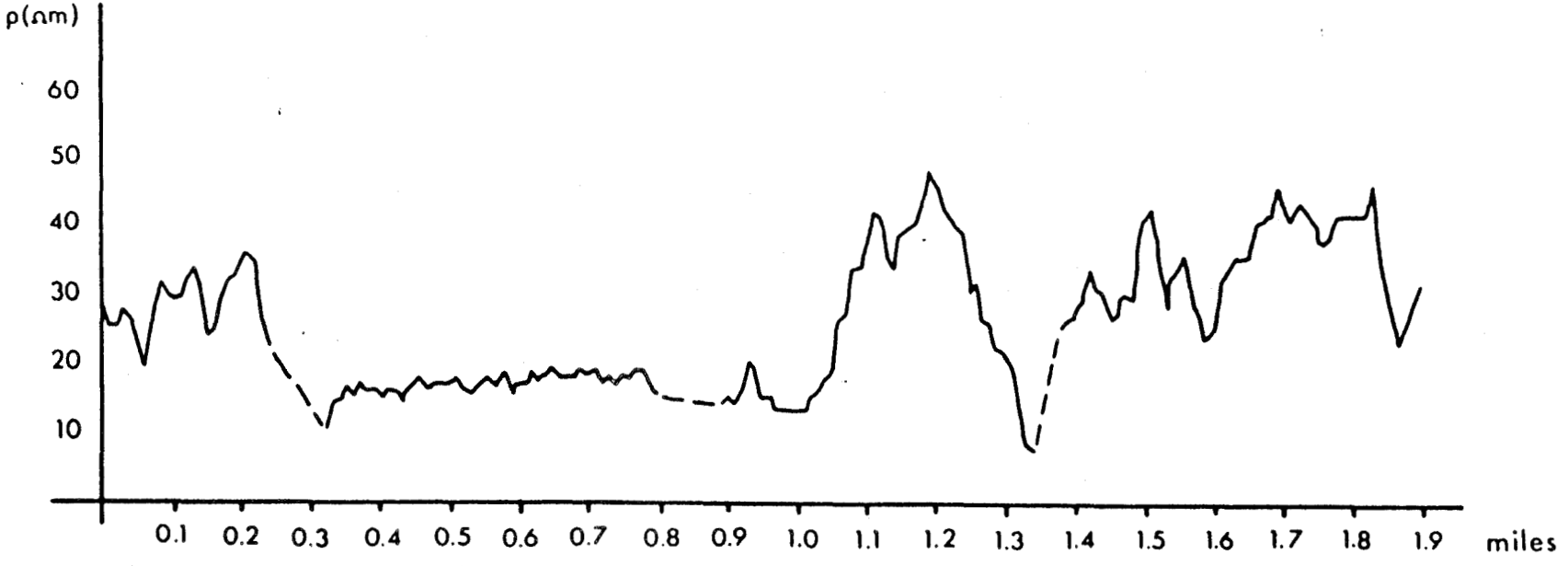


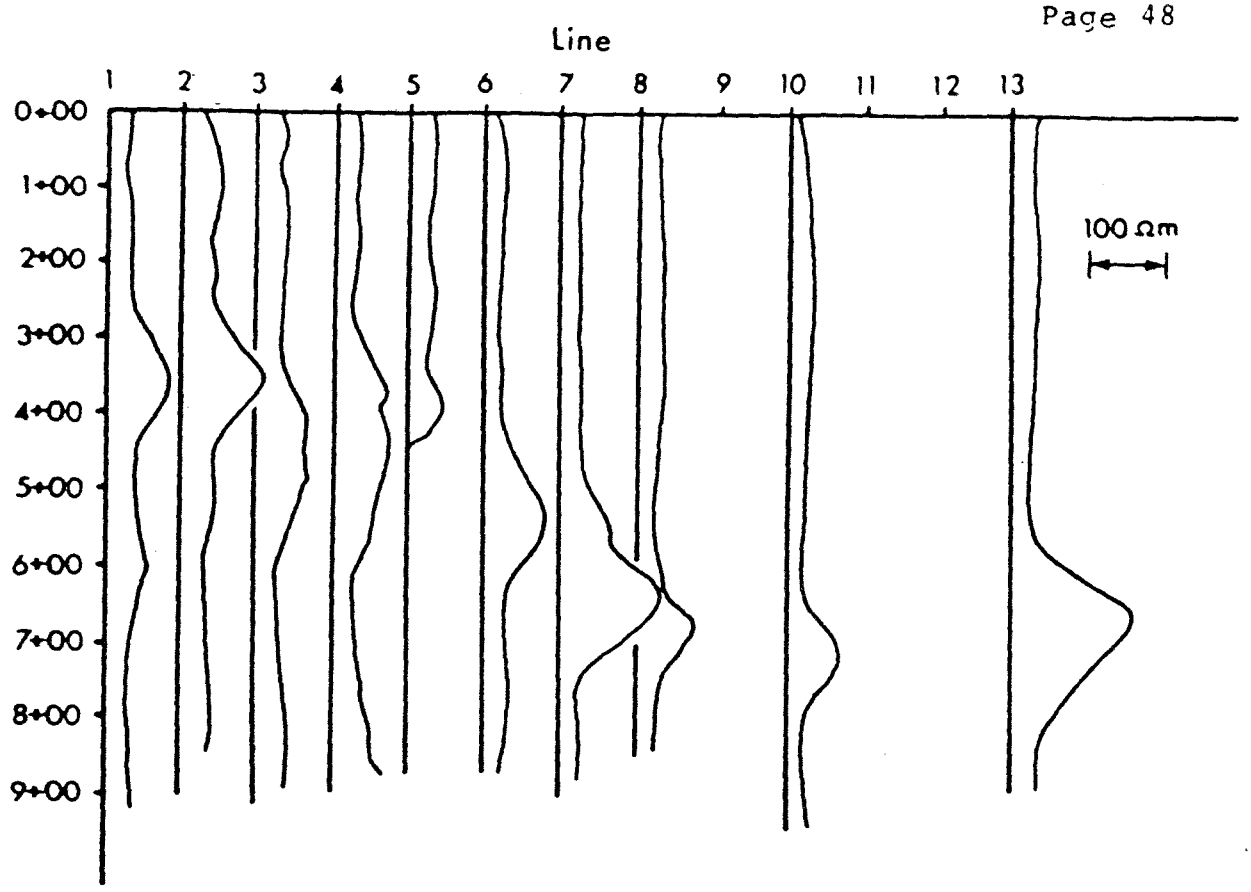
Cavendish Test Range — Line C

Example C

Lake Scugog/East Causeway *Example D*

Note (1) Station interval = 0.01 mile
(2) Survey duration =70 minutes
(3) Total no. of stations = 190
(4) 2.7 stations per minute

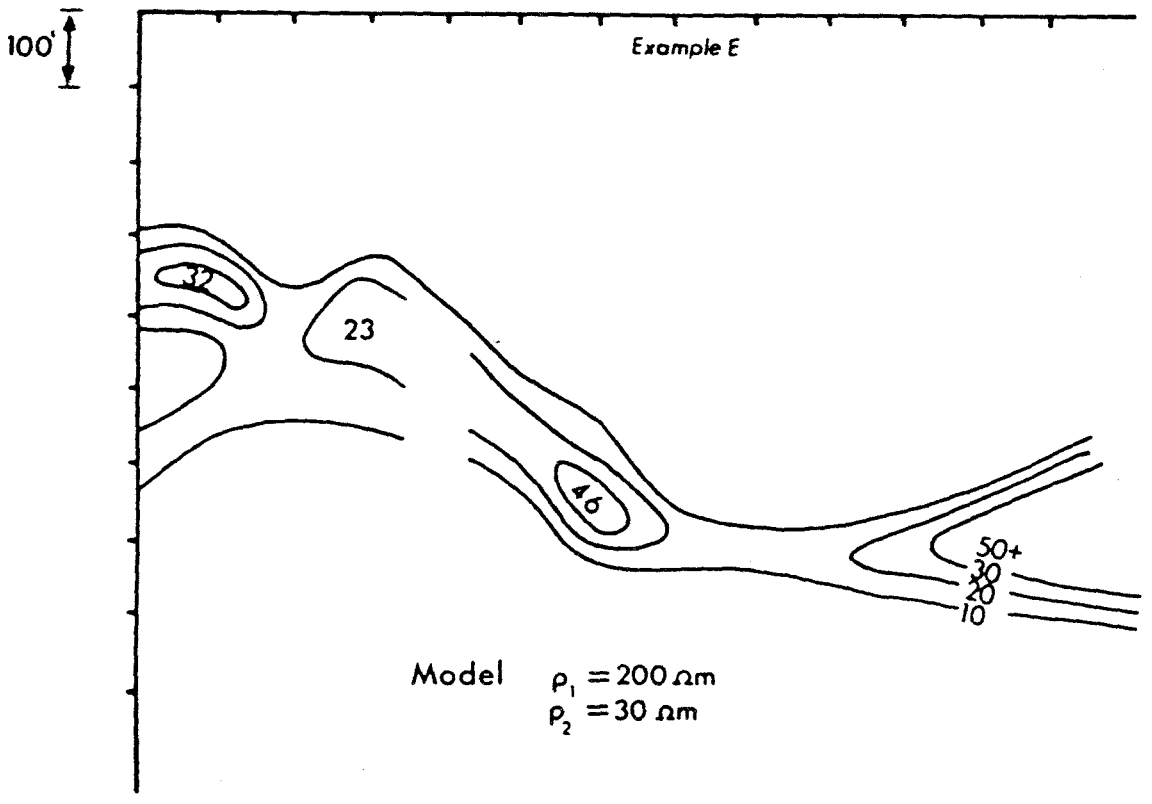


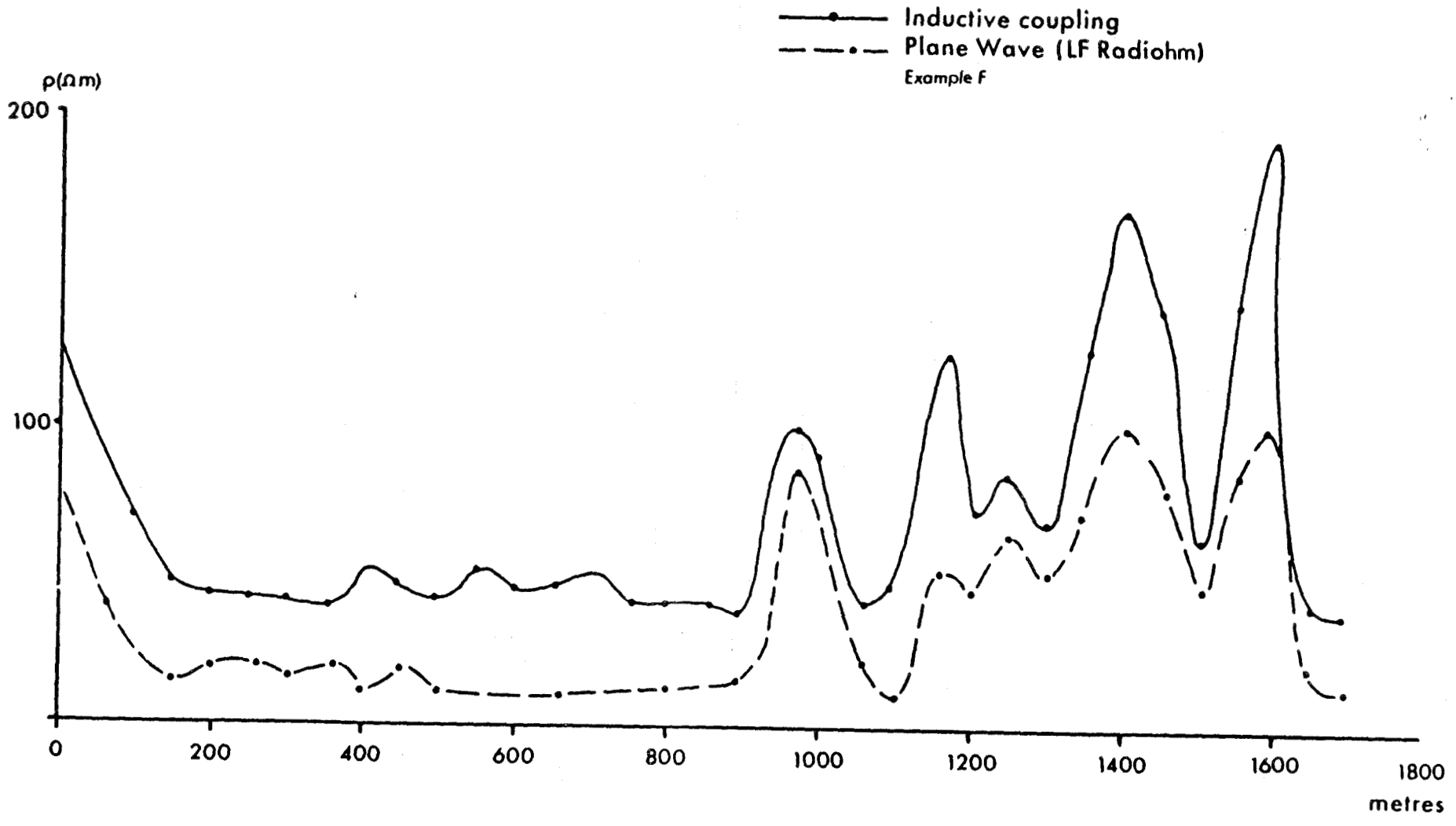


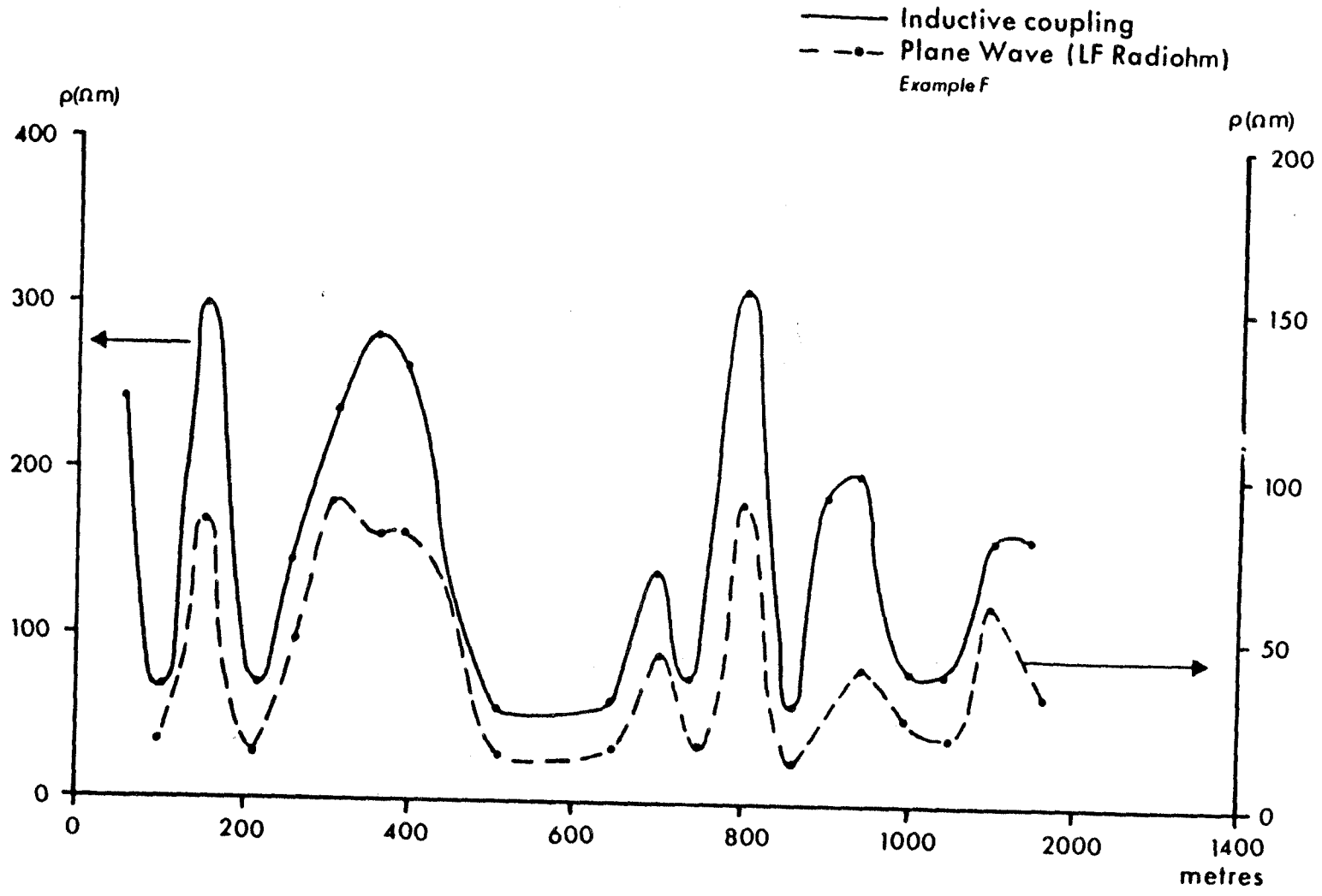
Cooksville/Ontario

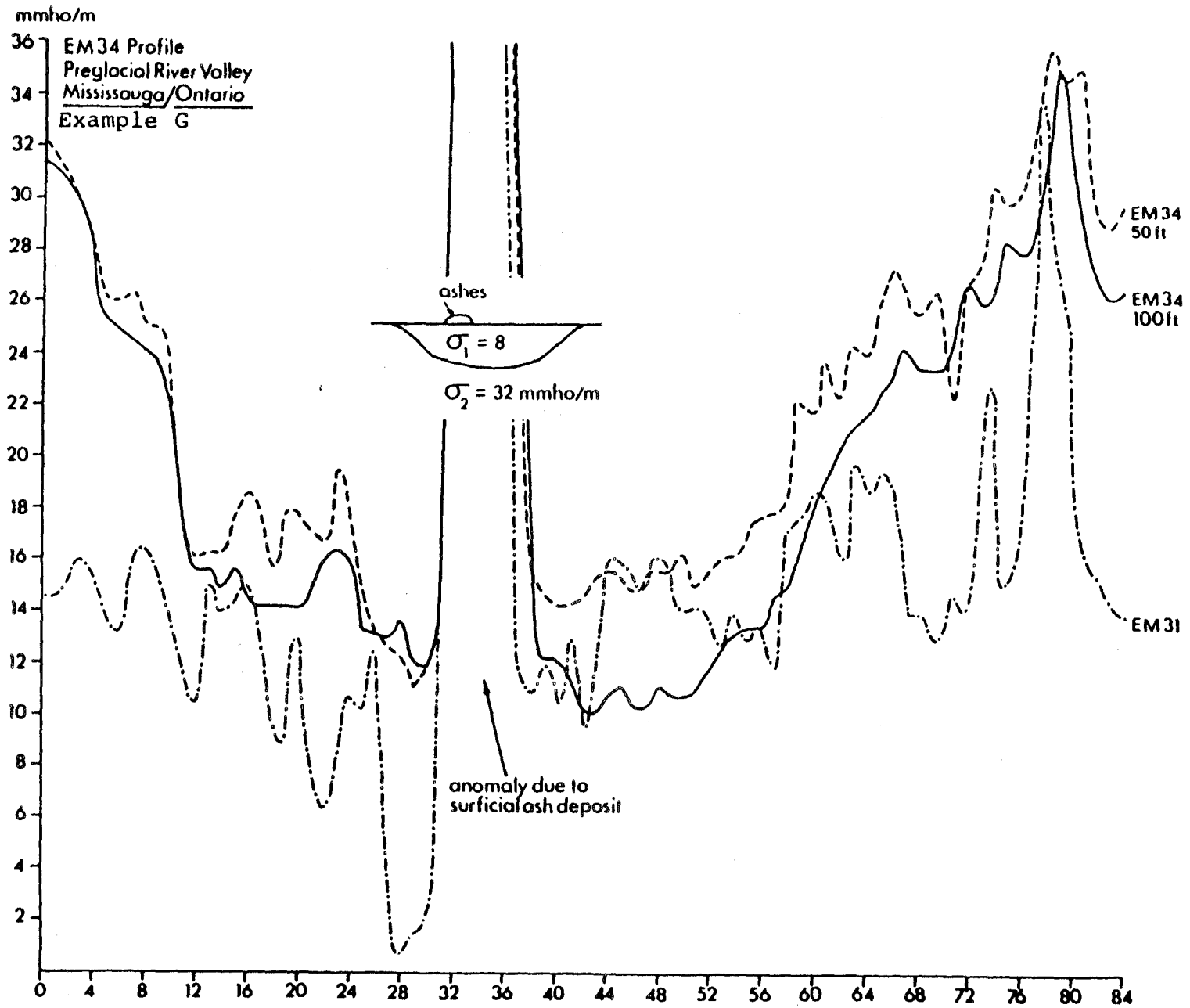
Example E

Contoured Depth




Inductive coupling
Plane Wave (LF Radiohm)
Example F
ρ(Ωm)
200
100
0
200
400
600
800
1000
1200
1400
1600
1800
metres


Inductive coupling
Plane Wave (LF Radiohm)
Example F
ρ(Ωm)
400
300
200
100
0
ρ(Ωm)
200
150
100
50
0
0
200
400
600
800
1000
2000
1400
metres


mmho/m
EM34 Profile
Preglacial River Valley
Mississauga/Ontario
Example G
ashes
$\sigma_1 = 8$
$\sigma_2 = 32$ mmho/m
anomaly due to
surficial ash deposit
EM34
50 ft
EM34
100 ft
EM31
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84

APPENDIX I - Formulae for Geometrical Sounding of Two-Layered Earth

In the case of a two-layered earth the apparent conductivity is given by:

$$\frac{\sigma_a}{\sigma_1} = 1 - R + kR = R(k - 1) + 1 \qquad (1)$$

with the instrument on the ground in its normal operating position, and

$$\frac{\sigma_a'}{\sigma_1} = 1 - R' + kR' = R'(k - 1) + 1 \qquad (2)$$

with the instrument on the ground on its side.
Case 1. Therefore

$$\frac{R'}{R} = \frac{\frac{\sigma_a'}{\sigma_1} - 1}{\frac{\sigma_a}{\sigma_1} - 1} \qquad (3)$$

and from the first and/or second equations, with $k = \sigma_2 / \sigma_1$

$$\sigma_2 = \frac{\sigma_a - \sigma_1 + R\sigma_1}{R} = \frac{\sigma_a' - \sigma_1 + R'\sigma_1}{R'} \qquad (4)$$

Case 2. When the conductivity of the lower layer is known, from equations (1) and (2)

$$\sigma_a' = \sigma_1 - R'\sigma_1 + R'\sigma_2 \qquad (5)$$

APPENDIX I - Cont'd

Case 2. (cont'd)

$$\sigma_a = \sigma_1 - R\sigma_1 + R\sigma_2 \tag{6}$$

$$\sigma_a' - \sigma_2 = \sigma_1 - R'\sigma_1 + R'\sigma_2 - \sigma_2 \tag{7}$$

$$= (1 - R')(\sigma_1 - \sigma_2) \tag{8}$$

$$\sigma_a - \sigma_2 = (1 - R)(\sigma_1 - \sigma_2) \tag{9}$$

$$\frac{1 - R'}{1 - R} = \frac{\frac{\sigma_a'}{\sigma_2} - 1}{\frac{\sigma_a}{\sigma_2} - 1} \tag{10}$$

$$\sigma_1 = \frac{\sigma_a - \sigma_2 R}{1 - R} = \frac{\sigma_a' - \sigma_2 R'}{1 - R'} \tag{11}$$

Case 3. When the upper layer is resistive and σ_2 is much greater then σ_1, from equations (5) and (6)

$$\sigma_a \simeq \sigma_2 R \tag{12}$$

$$\sigma_a' \simeq \sigma_2 R' \tag{13}$$

$$\frac{\sigma_a'}{\sigma_2} = \frac{R'}{R} \tag{14}$$

and

$$\sigma_2 = \frac{\sigma_a}{R} = \frac{\sigma_a'}{R'} \tag{15}$$

APPENDIX II - Determination of Two-Layered Earth Geometry by Varying Instrument Height

The electrical conductivity of the earth often exhibits horizontal layering and it is possible with the EM31 to determine how closely this layering can be approximated by a two-layered earth geometry.

Suppose measurements made with the instrument on the ground have yielded different values of apparent conductivity when the instrument meter is (a) face-up (i.e. the instrument is in normal position), and (b) vertical (i.e. the instrument is lying on its side). As discussed in Section 5.3 had the value of apparent conductivity been the same in both positions we would know that the earth was homogeneous, but the fact that the values are different for the two positions shows that the electrical conductivity varies with depth. We would now like to know whether the earth is two-layered.

To determine this we make measurements of the apparent conductivity with the instrument at various heights above the ground, as measured by the distance between the ground and the nearest point of the white tube. It is suggested that measurements be made at increments at least as small as one-half meter, for an example at 0, 0.5, 1, and 1.5 meters. Measurements made at smaller increments will yield greater accuracy, as will measurements made up to 2 meters height if possible. Measurements should be made both with the instrument in its normal position (meter face upright, i.e. vertical dipoles,) and with the instrument on its side (meter face vertical, horizontal dipoles) since it will be seen from the curves that the fall-off with height for these two configurations is quite different and that this difference is therefore of considerable diagnostic value in determining the two-layered earth characteristic. It is important to make the measurements of height and apparent conductivity as accurately as possible.

APPENDIX II - Cont'd

The curves in the two figures show the variation of apparent conductivity (divided by upper layer conductivity) for instrument height varying from 0 to 2 meters and for five values of upper layer thickness vis. 0.5, 1.0, 1.5, 2.0, and 3.0 meters. The relationship is shown for both vertical dipoles (meter face up, instrument in normal position) and horizontal dipoles (meter face vertical, instrument on its side) for various values of upper layer to lower layer conductivity contrast.

To use the curves one proceeds as follows:

(1) Place a piece of semi-transparent paper over either one of the graphs and on it plot the measured values of apparent conductivity versus instrument height to the scale used on the figures. Also sketch in on the transparent paper at any point a horizontal or vertical line to insure that when the transparent paper is translated over the figures in step 2 it does not rotate.

(2) Translate the transparent paper vertically and horizontally (i.e. without rotation) across the various plots shown on the figures to see whether the data points can be matched to one of the curves. In the event that no satisfactory match is achieved the earth cannot be represented by a two-layered case.

(3) If a satisfactory match can be achieved, the parameters of the two-layered earth are immediately calculated as follows: suppose that the measured values of apparent conductivity with height are

Height =	0.0	0.5	1.0	1.5	2.0 meters
σ_a (EM31 upright)	20.7	20.7	19.3	17.1	14.1 mmho/m
σ'_a (EM31 on side)	26.0	19.0	14.3	11.2	9.0 mmho/m

APPENDIX II - Cont'd

Upon plotting these data values to the scale of the figures and translating them we see that best agreement is achieved for an upper layer thickness of 1.5 meters and a conductivity contrast $k = 0.5$. We further observe that the value of 20.7 millimhos per meter for σ_a (instrument upright) corresponds to a value of σ_a / σ_1 of 0.62.

Since $\frac{\sigma_a}{\sigma_1} = 0.62$ when $\sigma_a = 20.7$

$$\therefore \sigma_1 = \frac{20.7}{0.62} = \underline{33.4} \text{ mmho/m}$$

Since $k = \frac{\sigma_2}{\sigma_1} = 0.5$

$$\therefore \sigma_2 = 0.5 \times 33.4 = \underline{16.7} \text{ mmho/m}$$

and $t = \underline{1.5\text{m}}$ from the figure.

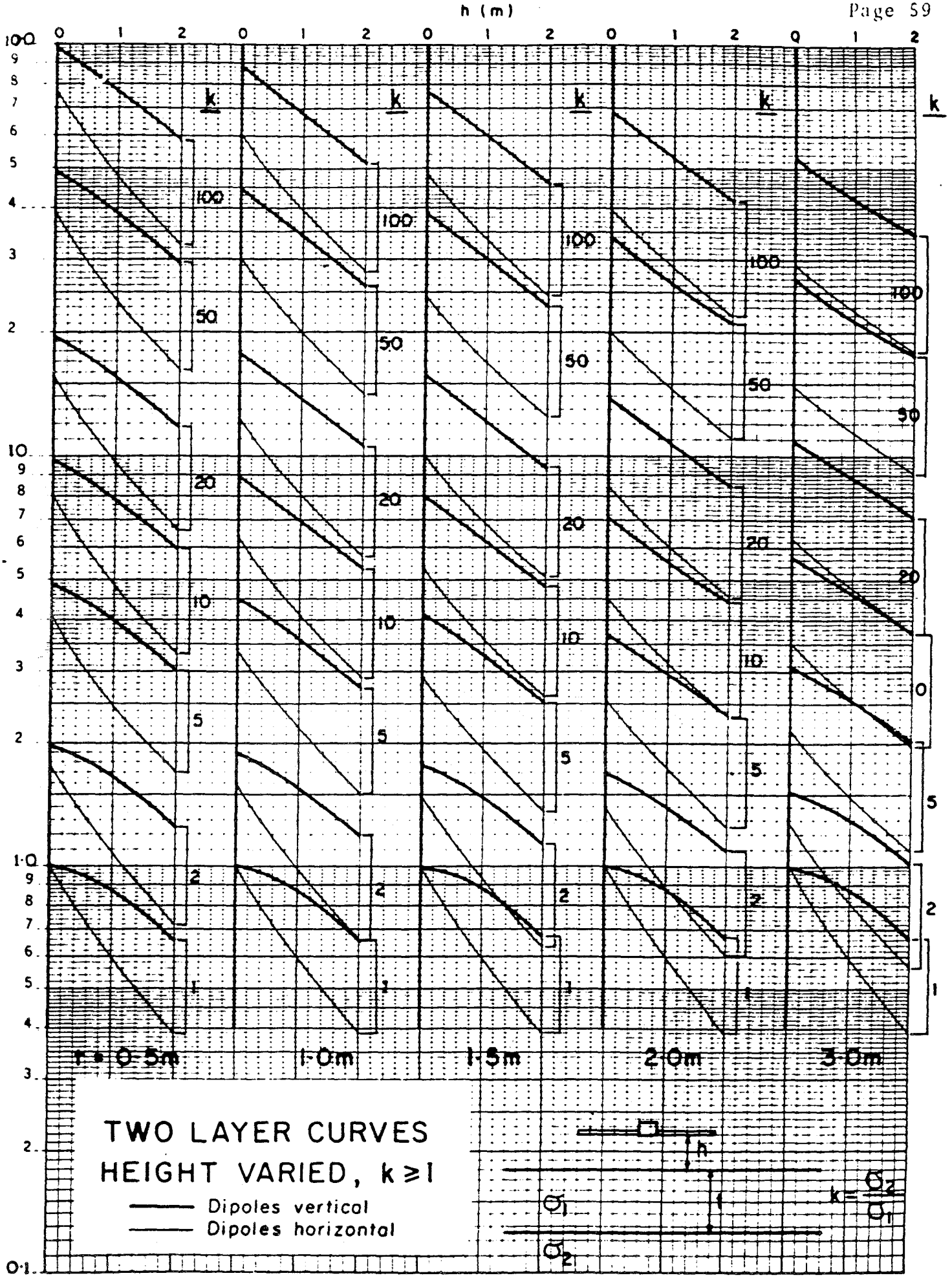
The two-layered earth is fully resolved.

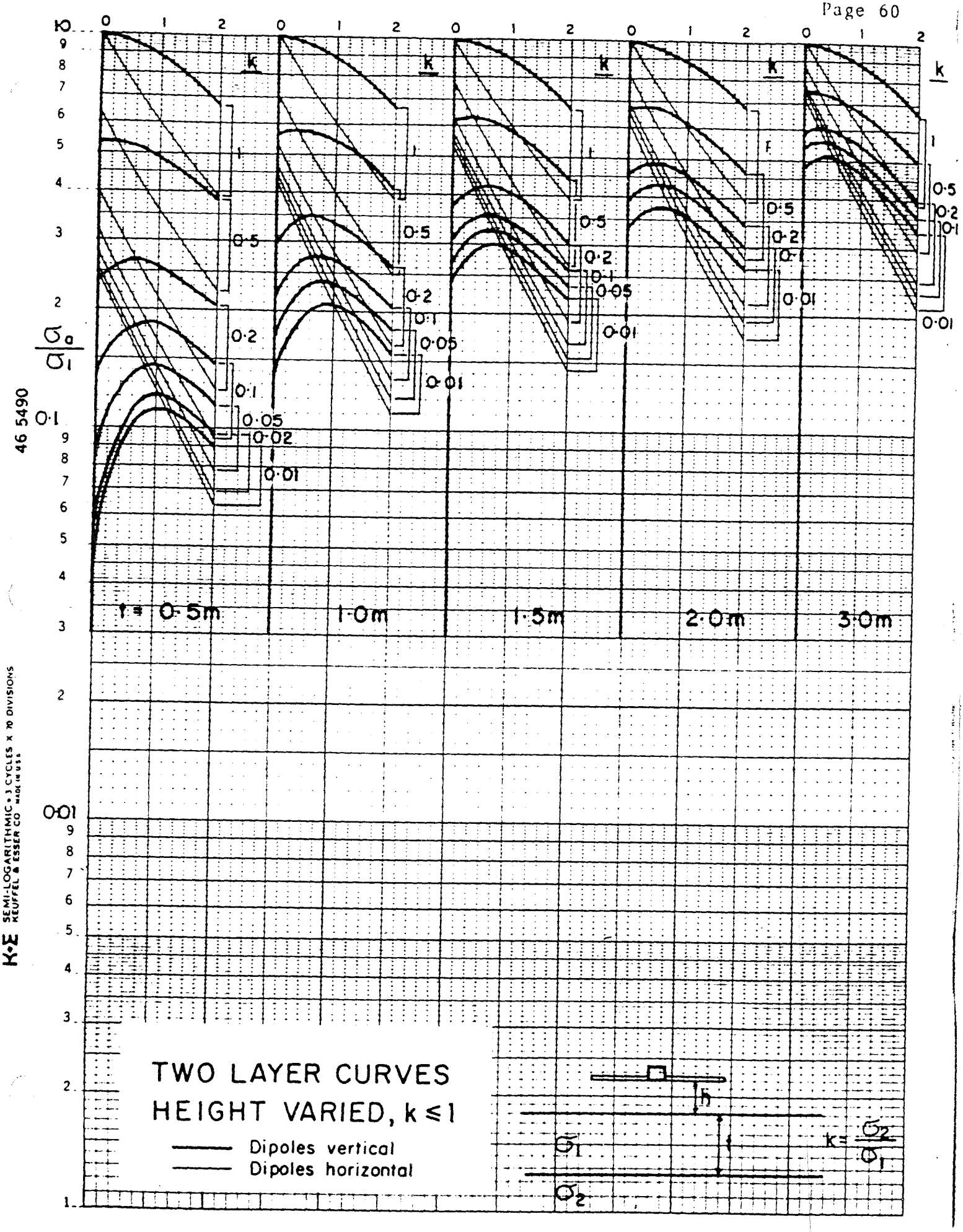
It will be observed that in some regions on these two figures the resolution or differentiation between the various curves is not very great. For example if one examines the curves for $t = 1.0$ meters, and $k = 100$, 50, or 20, one sees that these curve pairs are almost identical. If the process described in step 3 is carried out for each of these conductivity contrasts the result of the calculations will show that the lower layer conductivity and the upper layer thickness are the same, regardless of which of the three curve pairs are used, and that the only calculated parameter that will vary will be the upper layer conductivity which is very small. This is an example of the well-known property of electromagnetic systems to accurately give both the distance to a good conductor and

APPENDIX II - Cont'd

the actual conductivity of the conductor but to poorly define the intervening resistive material. A problem in unambiguously matching the curves may also occur for larger values of upper layer thickness, where the thickness is sufficiently great to prevent accurate resolution of its value.

These features notwithstanding it will be found that these curves are useful in (a) deciding whether the ground resembles a two-layer case and if so (b) giving a reasonably accurate estimate of the electrical parameters.


h (m)
k
r = 0·5m
1·0m
1·5m
2·0m
3·0m
TWO LAYER CURVES
HEIGHT VARIED, k ≥ 1
Dipoles vertical
Dipoles horizontal
h
σ_1
σ_2
$k = \frac{\sigma_2}{\sigma_1}$



TWO LAYER CURVES
HEIGHT VARIED, k ≤ 1
Dipoles vertical
Dipoles horizontal
t = 0·5m
1·0m
1·5m
2·0m
3·0m
k
$\frac{\sigma_a}{\sigma_1}$
$k = \frac{\sigma_2}{\sigma_1}$
σ_1
σ_2
h
t
46 5490
K·E SEMI-LOGARITHMIC • 3 CYCLES X 70 DIVISIONS
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NOTE TO EM31 AND EM34 USERS:

One of the most common problems with the instrument is the contamination of battery contacts. To clean these contacts use fine sand paper (#400 or higher) and wipe several times over the contacts.

Ensure that the spring action of the battery holders is maintained. Bend holder sides slightly if necessary.

July 1985.

GEONICS LIMITED

1745 Meyerside Drive, Unit 8, Mississauga, Ontario, Canada L5T 1C5 Tel. (416) 676-9580 Cables: Geonics

EM34-3 OPERATING INSTRUCTIONS

The following is the set-up and operating procedure for the EM34-3 Terrain Conductivity Meter.

1. Initial Set-up: At the beginning of the survey select an area free of "cultural interference" and man-made conductors such as buried pipes, buildings, power lines and steel reinforced concrete, etc.

1.1 Having determined the coil separation to be used for the survey, lay the instrument out on the ground accordingly. Connect the reference cable (10,20 or 40 meters) - one end to the 8-pin connector on the transmitter (Tx) coil and the other end to the "REFERENCE" connector on the receiver console.

1.2 Connect the transmitter console to the transmitter coil using the appropriate short cable.

1.3 Put the "LEVEL" switch on the transmitter console to the "NORMAL" position (see section 6).

1.4 Set the receiver and transmitter coils to the selected coil separation with red circles on the coils both facing in the same direction.

1.5 Set transmitter "SEPARATION" switch to selected value and turn on transmitter ("POWER/OFF" switch to "POWER" position).

1.6 Check to see that Battery Monitor Meter indicator is in the black area of the scale. If not, batteries are low or are not making proper contact to the battery clips.

1.7 Check condition of receiver battery by rotating receiver "SEPARATION" switch to "BATT" position with "POWER/OFF" switch in "OFF" position (see section 5.2).

1.8 Set receiver "SEPARATION" switch to selected value.

2. Electronic Nulling: to remove any offsets in the output (DC) circuitry.

2.1 Prior to turning receiver on insure that meters read zero by adjusting mechanical meter zero control.

2.2 Turn on receiver ("POWER/OFF" switch to "POWER" position).

2.3 With receiver coil disconnected depress "NULL MODE" push button switch. Both meter needles should go to zero.

REVISED
November, 1980

2.4 If either needle is not at zero reading, release the lock on the appropriate "NULL" control potentiometer. With "NULL MODE" switch still depressed adjust the "NULL" control to zero the meter.

2.5 Lock the "NULL" control.

2.6 Connect the receiver coil to the receiver console "COIL" connector via the appropriate short cable.

3. Receiver Compensation and Gain Check

3.1 Maintaining the receiver and transmitter coils in the same plane adjust the coil separation to obtain zero reading (centre of green area) on the "COIL SEPARATION" meter. (Insure that red circles on coils face in the same direction). The coil separation should now measure the selected value and allow from 2-4 meters of slack reference cable between the hooks which attach to the console leather cases.

3.2 With the "SENSITIVITY RANGE" switch set to the 300 millimho/meter position move the receiver coil toward the transmitter until the "COIL SEPARATION" meter deflects to full scale mark.

3.3 Measure the distance that the receiver coil has moved. This distance should be 10.4% of intercoil spacing.

4. Taking a Reading : the instrument is now operational, reading apparent terrain conductivity directly in millimhos/meter in either the horizontal or vertical dipole mode.

4.1 At each measurement station the transmitter operator positions himself and remains stationary. The receiver operator should position the receiver coil such that the "COIL SEPARATION" meter is in the green area.

4.2 The "SENSITIVITY RANGE" switch should be set to the position which positions the"CONDUCTIVITY"reading in the upper 70% of the scale. The meter reading should then be recorded in millimhos/meter. (The "SENSITIVITY RANGE" switch setting indicates full scale meter reading).

NOTE: In order to minimize reading errors particularly on the most sensitive settings it is necessary to keep the receiver and transmitter consoles separated from their respective coils by 0.7 - 1.0 meter.

5. Periodic Daily Checks

5.1 Nulling: To make sure that any possible drift is kept under control, we suggest that you repeat the electronic nulling procedure (steps 2.1 to 2.6) at least once per day during the survey.

5.2 Receiver Battery Check: The receiver battery test is done simply by switching the "SEPARATION" switch to "BATT" position and power switch to "OFF" position. The meters will indicate

the condition of the two sets of receiver batteries. If the indicator is below the markings replace the batteries, or see that the battery contacts are clean.

With new batteries, meter reading could be on the upper limit of the scale.

5.3 Transmitter Batteries: With the Tx coil connected and the "LEVEL" switch in the "HIGH" position, needle of the Battery Monitor Meter should be in the black area of the scale. Keeping the transmitter batteries warm in cold weather will improve battery lifetime.

6. Transmitter Output Power

As earlier mentioned transmitter output power should be kept at the "NORMAL" level for increased battery life. Under very noisy conditions (power line or spherics) the transmitter power should be increased by switching the "LEVEL" switch to "HIGH" position.

7. Instrument Calibration

Prior to leaving the factory, the instrument is calibrated to read correctly but due to its high sensitivity fine adjustment of the instrument in the field may be helpful, particularly in regions of low conductivity and where the conductivity values are known to a good degree of confidence.

NOTE: As a precautionary move the readings and exact location should be recorded prior to making any adjustments so that if the correction is found to be unsatisfactory the original settings can be recovered without returning the instrument to the factory.

7.1 Having decided what the new reading should be the instrument "zero" can be adjusted by controls inside the receiver console. To gain access to these controls remove the receiver chassis from its metal cover by undoing the two side screws and battery lid.

7.2 The "zero" adjustment potentiometers are located on printed circuit board No.5 - one poteniometer for each coil separation.

10 meters - R15
20 meters - R14
40 meters - R13

7.3 The appropriate potentiometer should then be adjusted to give the desired meter reading.

NOTE: Each control should be adjusted only with the corresponding coil separation.

7.4 After adjusting any of the "zero" controls check the Electronic Null (section 2). Re-Null if necessary and repeat "zero"adjustment.

7.5 The switch with positions "N" (normal) and "R" (reversed), which is not shown on the accompanying illustration, is used to reverse the meter deflection. This switch is operated when the meter deflects negatively as may occur when traversing vertical dikes.

EM34-3 INSTRUMENT SPECIFICATIONS

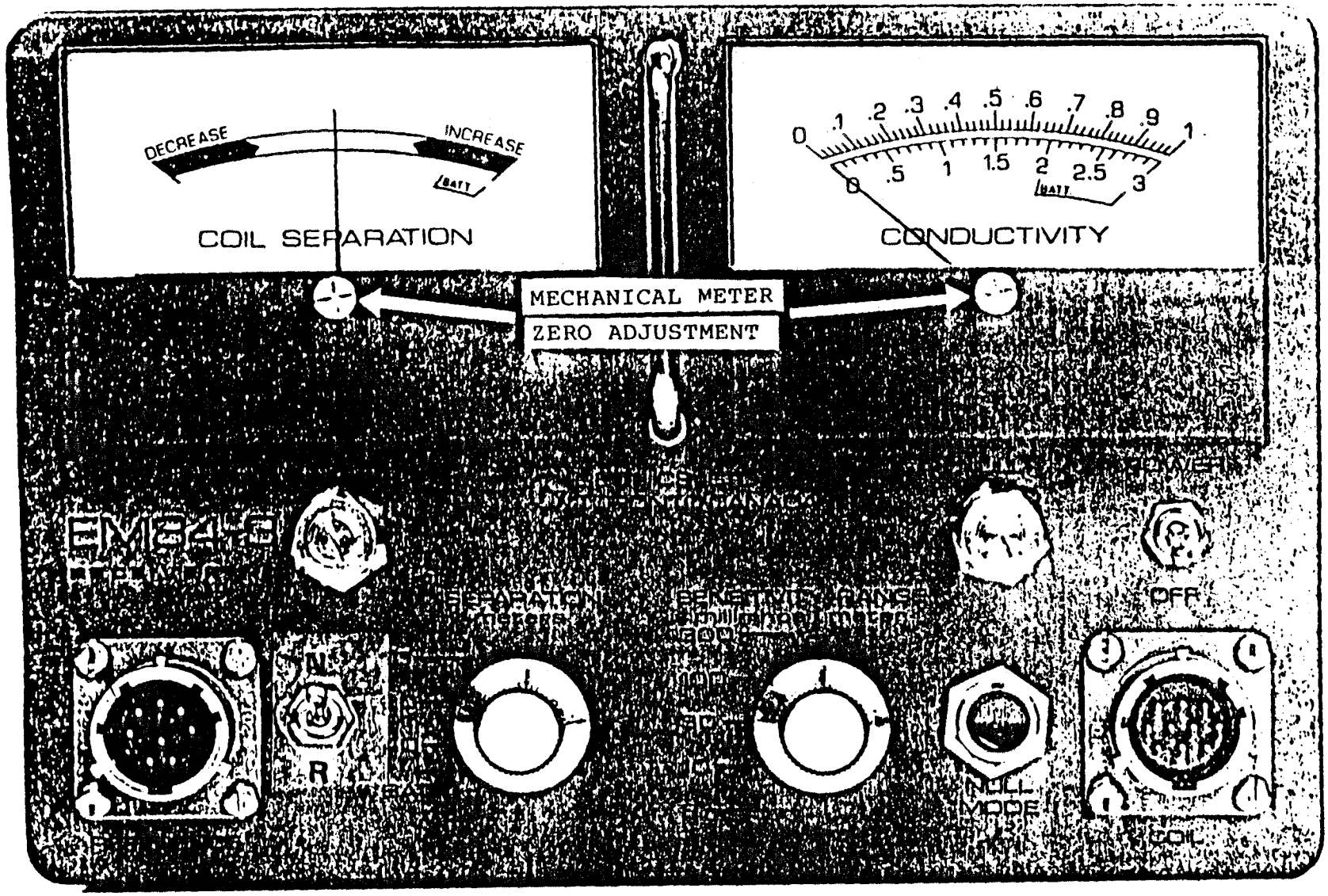
Measured Quantity	Apparent conductivity of the ground, in millimhos per meter (divided into 1000 gives ohm meters)
Range of Conductivity	0-3, 10, 30, 100, 300 millimhos per meter
Instrument Noise Level	Less than 0.2 millimho per meter
Measurement Accuracy	±5% at 20 millimhos per meter
Measurement Precision	±2% of full scale deflection
Primary Field Source	Self-contained dipole transmitter
Sensor	Self-contained dipole receiver
Intercoil Spacing	Interchangeable 10 meters, 20 meters or 40 meters
Power Supply	Transmitter: 8 size D cells Life: 20 hrs continuous duty-"NORMAL" Life: 7 hrs continuous duty-"HIGH" Receiver: 8 size C cells Life: 20 hrs continuous
Reference Cable	Lightweight 2 wire shielded cable

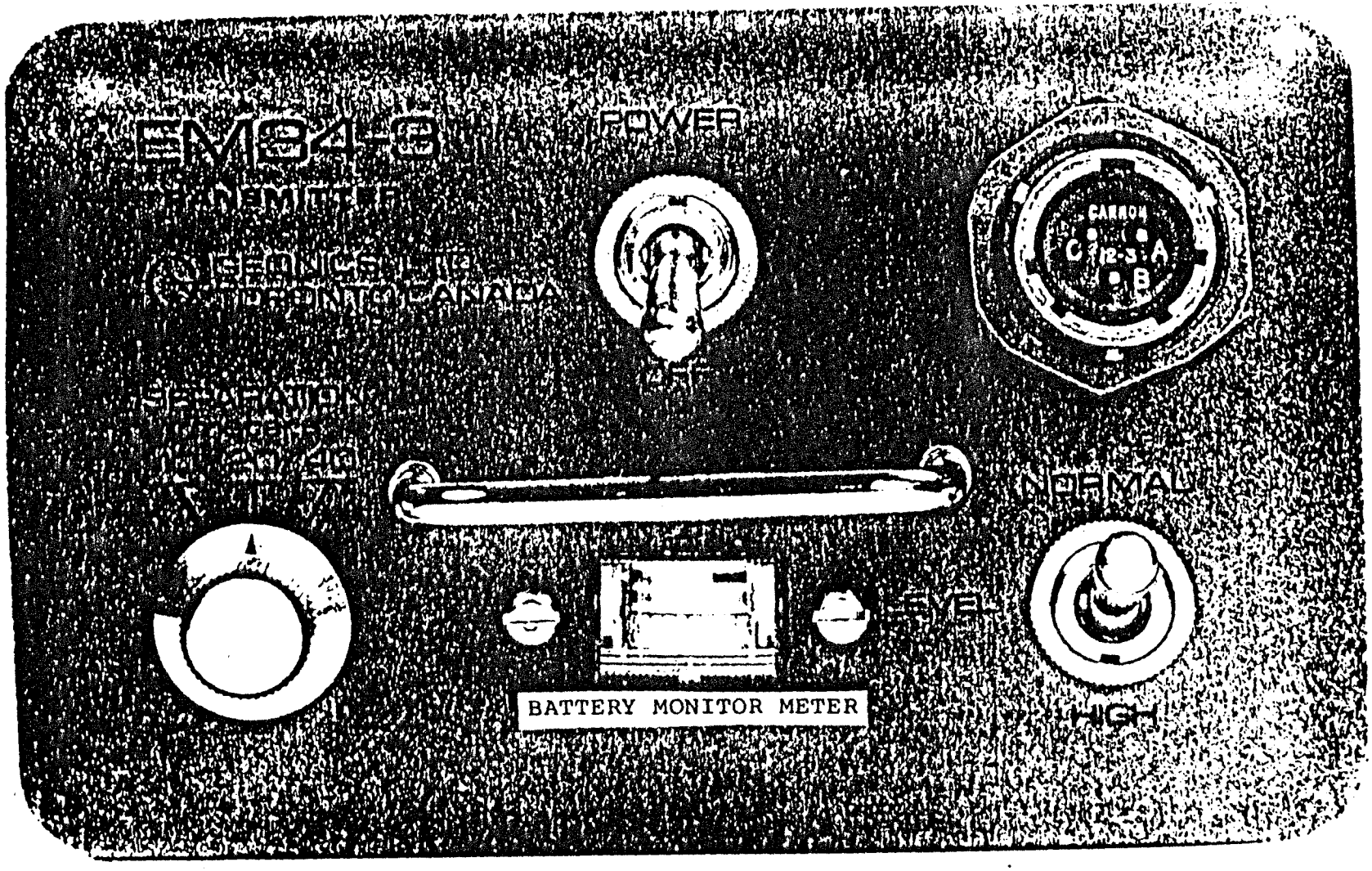
Dimensions:

Receiver Console	19.5 x 13.5 x 26 cm (7.7 x 5.3 x 10.2")
Receiver Coil	63 cm (25 inches diameter)
Transmitter Console	15 x 8 x 26 cm (5.85 x 3.15 x 10.2")
Transmitter Coil	63 cm (25 inches diameter)

Weights:

Receiver Console	3.1 kg (6.83 lbs)
Receiver Coil	3.2 kg (7 lbs)
Transmitter Console	3.0 kg (6.62 lbs)
Transmitter Coil	7.0 kg (15 lbs)
Shipping Weight	41 kg (91 lbs)


DECREASE
INCREASE
BATT
COIL SEPARATION
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1
0 .5 1 1.5 2 2.5 3
BATT
CONDUCTIVITY
MECHANICAL METER
ZERO ADJUSTMENT
SEPARATION
OFF
NULL
MODE
COIL


EM84-3
POWER
CANNON
C
12-3
A
B
NORMAL
HIGH
BATTERY MONITOR METER

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Technical Note TN-6

ELECTROMAGNETIC TERRAIN CONDUCTIVITY MEASUREMENT at LOW INDUCTION NUMBERS

JD McNEILL

October, 1980

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I. INTRODUCTION

The measurement of terrain resistivity to map geology has been utilized for over half a century. Several shortcomings, however, have prevented this technique from being widely accepted for engineering purposes. The first of these is that conventional galvanic resistivity surveys require a relatively large amount of manpower to execute and are thus expensive. Secondly, the actual value of resistivity itself is seldom diagnostic; it is the lateral or vertical variations of resistivity which form the basis of any interpretation. However the high cost of resistivity surveying generally means that fewer measurements are made than would be desirable, with the result that either (i) the survey area is not made large enough to establish a reasonable background against which the anomalous areas are to be delineated or (ii) the anomalous area itself is obscure and lacks definition.

An additional problem inherent to conventional resistivity techniques is that although the effective depth of exploration is determined by the selected inter-electrode spacing, resistive inhomogeneities which are small compared to this depth but which are located near the potential electrodes can cause a significant error in the measurement. Such fluctuations in the measured results are truly geological "noise" because it is not possible to determine the physical size, resistivity contrast, or location of the source. As a result of such inhomogeneities resistivity profiles carried out at constant interelectrode spacing tend to be noisy, limiting the resolution in resistivity that can be achieved, even though the instrumentation itself is capable of producing much higher accuracy.

It was an awareness of both the advantages of resistivity for engineering geophysical surveys and the disadvantages of conventional resistivity techniques that led Geonics Limited to examine the possibility of employing electromagnetic (inductive) techniques as an alternative for resistivity surveys. With the development of the EM31 and the EM34-3 it is now possible to map terrain conductivity virtually as fast as the operator(s) can walk; furthermore the sample volume is averaged in such a manner as to yield unexcelled resolution in conductivity.

These patented instruments have been designed to cover the range of depths generally useful for engineering geophysics; the EM31, one-man portable, has an effective depth of approximately 6 meters and the EM34-3, two-man portable, has stepwise selectable depths from 7.5 meters to a maximum of 60 meters.

Typical applications for the EM31 and EM34-3 instrumentation are:

(i) Delineating regions of permafrost (frozen pore water)
(ii) Locating gravel
(iii) Extending known gravel deposits
(iv) Mapping saline intrusions
(v) Detecting cavities in carbonate rocks
(vi) Mapping pollution plumes in groundwater
(vii) Mapped bedrock topography
(viii) Mapping terrain conductivity for electrical grounding
(ix) General geological mapping (soil types, fault and fracture zones, etc.)
(x) Archaeological exploration
(xi) Locating pipes (EM31) and metallic-type conductors

This technical note describes both the principles and the instrumentation employed to measure terrain conductivity using electromagnetic techniques at low induction numbers. For a detailed discussion of the concept of terrain resistivity/conductivity and of the various factors that control this parameter the reader is referred to Geonics Limited Technical Note "Electrical Conductivity of Soils and Rocks".

II. PRINCIPLE OF OPERATION

The application of electromagnetic techniques to the measurement of terrain resistivity, or more properly, conductivity* is not new and excellent descriptions of this technique are given in the literature [1], [2].

*Conductivity is preferred with inductive techniques since the response is generally proportional to conductivity and inversely proportional to resistivity.

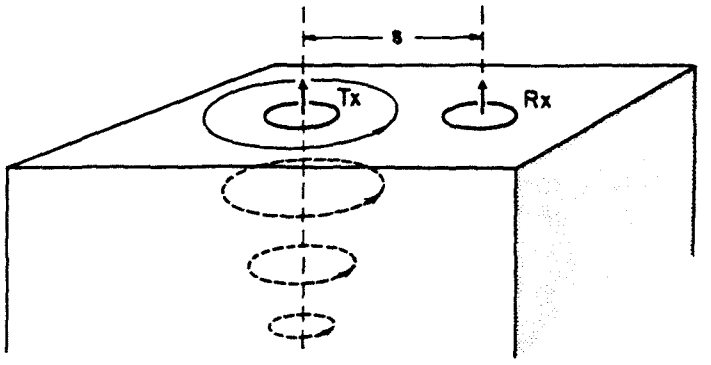


FIGURE 1. Induced current flow (homogeneous halfspace).

Consider Figure 1 in which a transmitter coil Tx energized with an alternating current at an audio frequency, is placed on the earth (assumed uniform) and a receiver coil Rx is located a short distance s away. The time-varying magnetic field arising from the alternating current in the transmitter coil induces very small currents in the earth. These currents generate a secondary magnetic field H_s which is sensed, together with the primary field, H_p, by the receiver coil.

In general this secondary magnetic field is a complicated function of the intercoil spacing s, the operating frequency, f, and the ground conductivity σ. Under certain constraints, technically defined as "operation at low values of induction number" (and discussed in detail in the appendix) the secondary magnetic field is a very simple function of these variables. These constraints are incorporated in the design of the EM31 and EM34-3 whence the secondary magnetic field is shown to be:

$$\frac{H_s}{H_p} \simeq \frac{i\omega\mu_o\sigma s^2}{4} \tag{1}$$

where H_s = secondary magnetic field at the receiver coil
H_p = primary magnetic field at the receiver coil
$\omega = 2\pi f$
f = frequency (Hz)
μ_o = permeability of free space
σ = ground conductivity (mho/m)
s = intercoil spacing (m)
$i = \sqrt{-1}$

The ratio of the secondary to the primary magnetic field is now linearly proportional to the terrain conductivity, a fact which makes it possible to construct a direct-reading, linear terrain conductivity meter by simply measuring this ratio. Given H_s/H_p the apparent conductivity indicated by the instrument is defined from equation (1) as

$$\sigma_a = \frac{4}{\omega\mu_o s^2}\left(\frac{H_s}{H_p}\right) \tag{2}$$

The MKS units of conductivity are the mho (Siemen) per meter or, more conveniently, the millimho per meter.

III. INSTRUMENTATION

The EM31 (shown in Figure 2) has an intercoil spacing of 3.7 meters, which yields an effective depth of exploration of about 6 meters. The instrument can also be operated on its side, in which

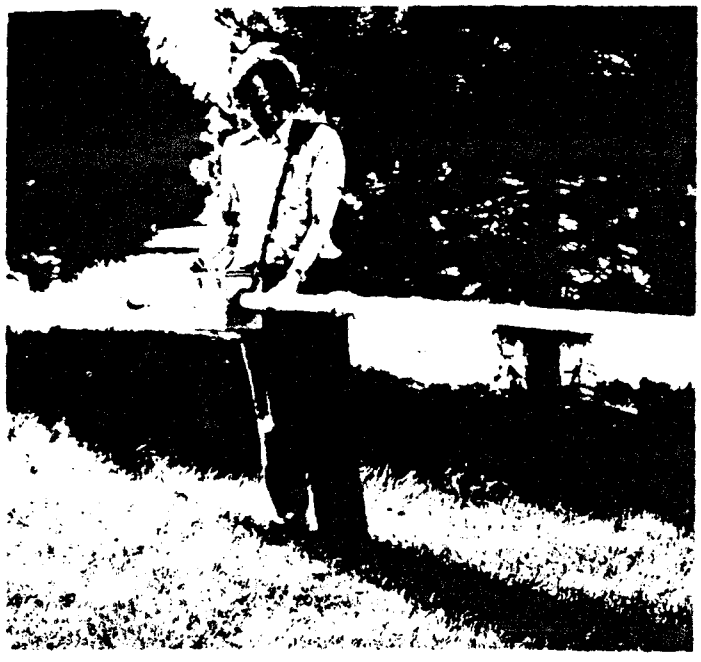


FIGURE 2. EM31 in field operation.

case as will be seen in Section IV., the effective depth of exploration is reduced to approximately 3 meters. The instrument is one-man portable and can be used either in "station-by-station" mode or read continuously. The presence of layering in the earth can be detected by raising the instrument and noting the readings as a function of instrument height. If the earth is two-layered the conductivity of both layers and the upper layer thickness can be resolved.

The EM34-3 which is two-man portable has the two coils flexibly connected (Figure 3). The intercoil spacing is measured electronically so that the receiver operator simply reads a meter to accurately set the coils to the correct spacing, which can be 10, 20, or 40 meters so as to directly vary the effective depth of exploration as shown in Table 1.

FIGURE 3. EM34-3 in field operation.

TABLE 1. Exploration depths for EM34-3 at various intercoil spacings

Intercoil Spacing (meters)	Exploration Depth (meters)	
	Horizontal Dipoles	Vertical Dipoles
10	7.5	15
20	15	30
40	30	60

To measure terrain conductivity the transmitter operator stops at the measurement station; the receiver operator moves the receiver coil backwards or forwards until his meter indicates correct intercoil spacing and he reads the terrain conductivity from a second meter. The procedure takes 10 to 20 seconds. The coils are normally carried with their planes vertical (horizontal dipole mode) since in this configuration the measurement is relatively insensitive to misalignment of the coils. In the event that the greater depth of penetration resulting when the two coils are in the vertical dipole mode is desired, more care must be taken with intercoil alignment. Because of the relatively short intercoil spacing correct alignment is usually not difficult to achieve.

Both instruments are calibrated to read terrain conductivity in millimhos per meter. To convert these readings to resistivity (in ohmmeters) one simply divides them into 1,000, i.e. 50 millimhos per meter is the equivalent of 20 ohmmeters.

IV. SURVEY TECHNIQUES AND INTERPRETATION

For either the EM31 or EM34-3 it can be shown that in a homogeneous or horizontally stratified earth the current flow is entirely horizontal. Furthermore under the constraints by which the instruments are designed the current flow at any point in the ground is independent of the current flow at any other point since the magnetic coupling between all current loops is negligible. Finally, under the constraints the depth of penetration is limited only by the intercoil spacing. We say that the depth of penetration is "source" or "geometry" limited rather than "skin depth" limited since it is now controlled by the fall-off with distance of the dipolar transmitter field. For this reason all dimensions are normalized with respect to the intercoil spacing in subsequent sections of this technical note.

IV. 1. Instrumental Response as a Function of Depth (Homogeneous Halfspace)

Consider a homogeneous halfspace on the surface of which is located an EM31 or an EM34-3 transmitter as shown in Figure 4. Fixing our attention on a thin layer of thickness dz at depth z (where z is the depth divided by the intercoil spacing s) it is possible to calculate the secondary magnetic field in the receiver coil arising from all of the current flow within this or any other horizontal thin layer. One can thus construct the function $\phi_V(z)$ shown in Figure 4 which describes the relative contribution to the secondary magnetic field arising from a thin layer at any depth z. We see from this figure that material located at a depth of approximately 0.4 s gives maximum contribution to the secondary magnetic field but that material at a depth of 1.5 s still contributes significantly. It is interesting to note that the ground at zero depth, i.e. the near surface material,

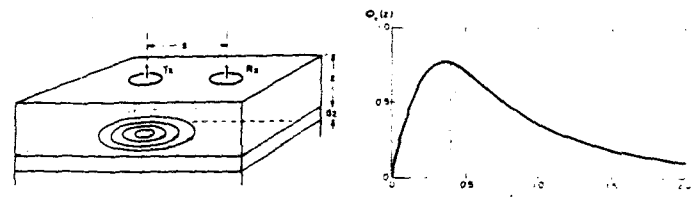


FIGURE 4. Relative response versus depth for vertical dipoles. $\phi_v(z)$ is the relative contribution to H_s from material in a thin layer dz located at (normalized) depth z.

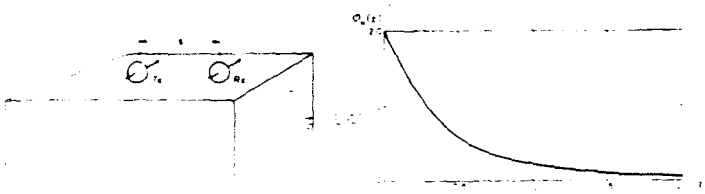


FIGURE 5. Relative response versus depth for horizontal dipoles

makes a very small contribution to the secondary magnetic field and therefore this coil configuration is insensitive to changes in near surface conductivity.

Figure 5 illustrates the function of Figure 4 for the case of both transmitter and receiver dipoles horizontal coplanar rather than vertical coplanar. For the coil configuration of Figure 5 (commonly used for the EM34-3 since it is less critical to intercoil alignment) the relative contribution from material near-surface is large and the response falls off monotonically with depth.

A comparison of the function ϕ for both coil configurations in Figure 6 emphasizes the different manner in which they respond to material at different depths. The difference is important since either instrument can be rolled over so that the vertical dipole transmitter/receiver geometry becomes a horizontal dipole transmitter/receiver geometry and vice versa. As will be seen later, this feature is useful in diagnosing and defining a layered earth. The figure also shows that for regions greater than one intercoil spacing in depth the vertical transmitter/receiver dipole gives approximately twice the relative contribution of the horizontal transmitter/receiver dipole.

To summarize, with either horizontal or vertical transmitter/receiver dipole orientation it is possible to construct a function which gives the relative response to the secondary magnetic field at the receiver from a thin layer of ground at any depth. That this is possible arises from the fact that (i) all current flow is horizontal and (ii) all current loops are independent of all other current loops. It should be noted that it is not possible to construct such functions for conventional resistivity techniques.

Finally, since as shown in Section II the definition of apparent conductivity is given in terms of the secondary magnetic field at the receiver, the functions in Figure 6 also give the relative contribution from material at different depths to the *apparent conductivity* indicated by the instrument meter. The integral of either function from zero to infinity gives the total secondary magnetic field at the receiver coil from a homogeneous halfspace which is directly related to the electrical conductivity of the halfspace by equation (1). It is therefore possible to state with great precision the relative influence of material at different depths to the indicated apparent conductivity.

IV. 2. Multi-Layered Earth Response

The functions shown in Figure 6 are useful for describing the relative sensitivity of either of the two coil configurations to material at various depths. However a function derived from them is more useful for performing calculations. It is defined as the relative contribution to the secondary magnetic field or apparent conductivity from all material below a depth z and is given by

$$R_{\substack{V\\H}}(z) = \int_z^{\infty} \phi_{\substack{V\\H}}(z)dz \qquad (3)$$

Called the cumulative response, this function is illustrated in Figure 7 for vertical coplanar transmitter/receiver dipoles. The figure shows, for example, that for this configuration all material below a depth of two intercoil spacings yields a relative contribution of approximately 0.25 (i.e. 25%) to the secondary magnetic field at the receiver coil.

Suppose now that our homogeneous halfspace has a conductivity of 20 millimhos per meter (50 ohmmeters). The equipment having been calibrated according to equation (2), the output meter indicates 20 millimhos per meter. From Figure 7 we observed that the material below two intercoil spacings contributed 25% to the secondary magnetic field and therefore 25% to the indicated meter reading. Suppose that we replace this deep material with an infinitely resistive (zero conductivity) substance. Since we have reduced to zero the 25% that this material contributed to the meter reading the new reading will be 75% of 20, or 15 millimhos per meter. Conversely, if we leave all of the material below two intercoil spacings at 20

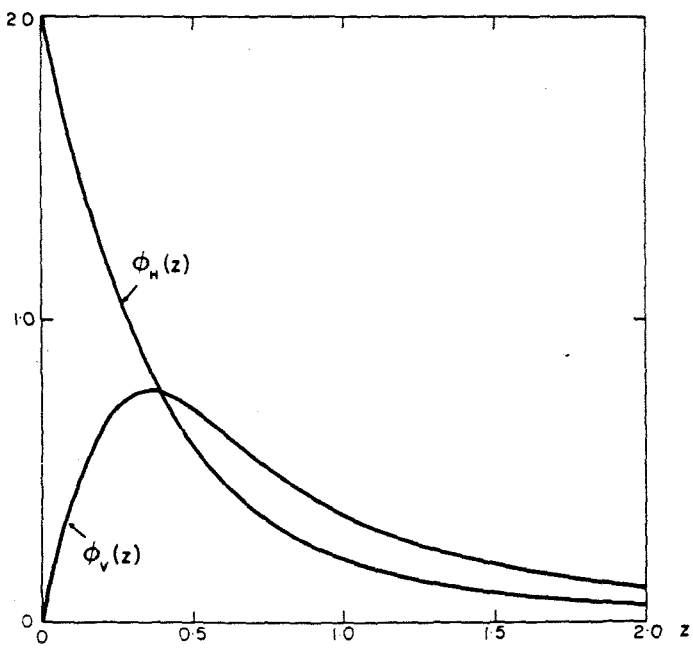


FIGURE 6. Comparison of relative responses for vertical and horizontal dipoles.

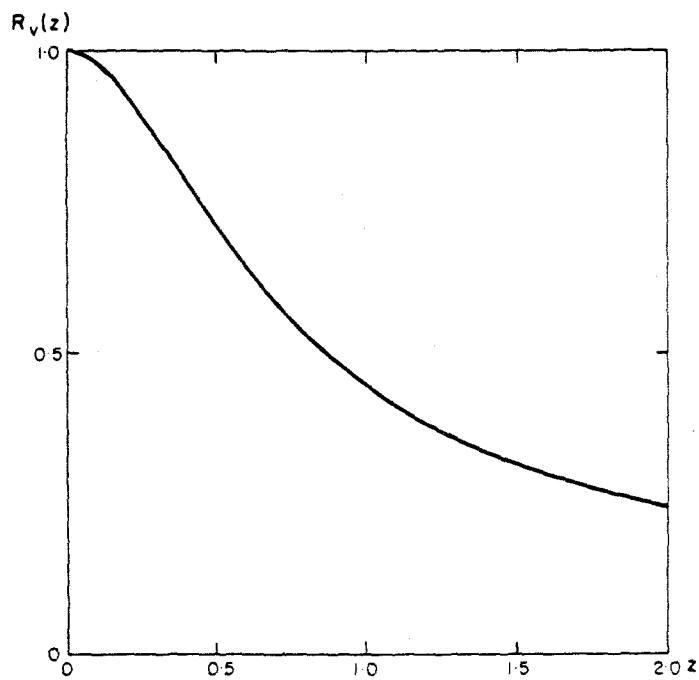


FIGURE 7. Cumulative response versus depth for vertical dipoles. $R_V(z)$ is the relative contribution to H_s from all material below a (normalized) depth z.

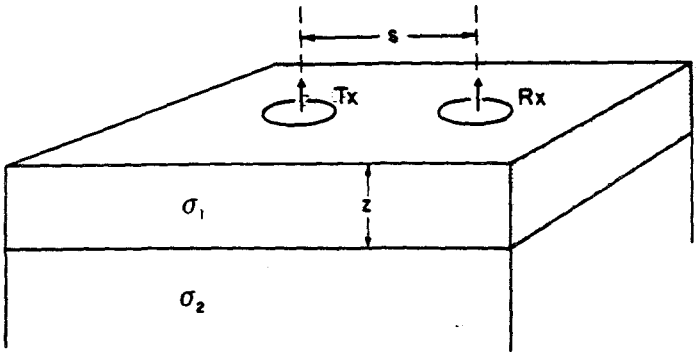


FIGURE 8. Two layer earth model.

millimhos per meter but make all material above two intercoil spacings infinitely resistive the meter reading will fall from the original 20 millimhos per meter for the homogeneous half space to 5 millimhos per meter, since, if all of the material below two intercoil spacings contributed 25% of the meter reading, all of the material above two intercoil spacings must contribute 75%; when removed the meter reading becomes 0.25 × 20 or 5 millimhos per meter.

From this example we see that there is a simple way to calculate the instrument reading on an arbitrarily layered earth as long as the intercoil spacing is much less than the skin depth in all of the layers. We simply add the contribution from each layer independently, weighted according to its conductivity and depth according to Figure 7. For example assume that we have a two-layer case as shown in Figure 8. The contribution from the upper layer is given by

$$\sigma_a = \sigma_1[1 - R_V(z)] \tag{4a}$$

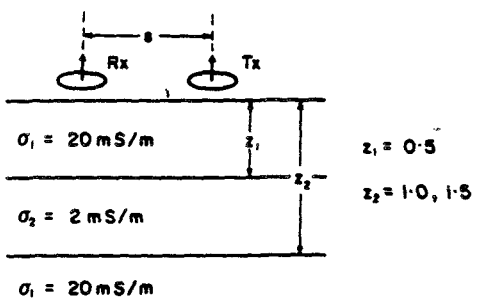
since all of the material below zero depth yields a relative contribution of unity or 100% to the meter reading. Conversely all of the material in the lower layer adds a contribution given by

$$\sigma_a = \sigma_2 R_V(z) \tag{4b}$$

and the actual instrument reading will therefore be the sum of these two quantities

$$\sigma_a = \sigma_1[1 - R_V(z)] + \sigma_2 R_V(z) \tag{5}$$

If the earth is three-layered as shown in Figure 9 the same procedure is employed to determine the instrumental response. In this example the calculations are performed for different middle layer thicknesses.



$$\sigma_a = \sigma_1[1 - R(z_1)] + \sigma_2[R(z_1) - R(z_2)] + \sigma_3 R(z_2)$$

$$z_2 = 1{\cdot}0,\ \sigma_a = 20[1 - 0{\cdot}70] + 2[0{\cdot}70 - 0{\cdot}44] + 20 \times 0{\cdot}44 = 15{\cdot}3 \text{ mmho/m}$$

$$z_2 = 1{\cdot}5,\ \sigma_a = 20[1 - 0{\cdot}70] + 2[0{\cdot}70 - 0{\cdot}32] + 20 \times 0{\cdot}32 = 13{\cdot}2 \text{ mmho/m}$$

FIGURE 9. Calculation of response to three layer earth – center layer thickness varying.

The ease with which such calculations are performed facilitates survey preparation and interpretation. It is sometimes possible to make advance estimates of the electrical properties of the materials to be encountered during a survey or, alternatively, once on-site the operator can obtain the same information from sample measurements of the different materials. The procedures outlined above are then employed to estimate the apparent conductivity measured under various terrain conditions. Examples of such calculations for the EM31 are shown in Figure 10. As is seen in the appendix the algebraic expressions for $\phi(z)$ and $R(z)$ are very simple and are easily programmed on hand held calculators.

In Figure 10 the vertical dimensions are greatly exaggerated with respect to the horizontal dimensions. The question arises as to what degree of lateral uniformity is required before the earth can be considered as horizontally stratified or homogeneous. Survey experience indicates that if the ground conductivity does not significantly vary with horizontal distance within a radius of one intercoil spacing from the instrument the ground can be considered to be laterally uniform.

The above discussion referred to the use of vertical transmitter/receiver dipoles; it is equally possible to construct a cumulative response function for the horizontal coplanar dipole configuration and Figure 11 illustrates this function for both coil configurations. A comparison of the two curves illustrates that the vertical dipole mode of operation has approximately twice the effective exploration depth of the horizontal dipole mode.

IV. 3. Comparison with Conventional Resistivity Techniques

Many readers will be familiar with the two-layer curves employed to interpret data from conventional resistivity surveys using a Wenner array of four equally spaced electrodes. Using the techniques described in the previous section it is a simple matter to calculate two-layer curves for the electromagnetic technique; Figure 12 shows such curves for both the vertical and horizontal dipole configurations superimposed on standard Wenner curves. The general shape is similar but there are marked differences in detail. For vertical coplanar transmitter/receiver dipoles we see that when the substrate is the more resistive the response of the two systems is similar; however when the substrate is the more conductive the electromagnetic technique sees deeper in that the influence of the substrate, for a given conductivity contrast, is felt at smaller intercoil spacing than inter-electrode spacing. This is a general characteristic of electromagnetic systems which prefer to look through an insulator to a conductor rather than through a conductor to an insulator.

For the horizontal dipole configuration if the lower layer is the more resistive the effective exploration depth of the inductive technique is slightly less than the Wenner array; however, once again, in the case where the lower layer is the more conductive the exploration depth of the inductive technique is substantially greater.

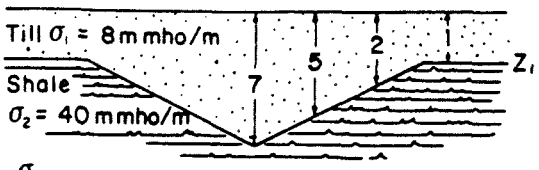
IV. 4. Resolution of Two-Layered Earth by Varying Intercoil Spacing

The principal advantage of the inductive electromagnetic technique over conventional resistivity lies in the speed and accuracy with which lateral changes of terrain conductivity can be measured. However this technique can also be used to measure the vertical variation of conductivity by expanding the intercoil spacing in a manner analogous to that in which the electrode spacing is expanded in conventional resistivity sounding techniques. The current state-of-the-art, however, is such that relatively few intercoil spacings can be employed; for example the EM34-3 can be operated with an intercoil spacing of 10, 20 or 40 meters. This feature is somewhat mitigated by the fact that the instruments can be used in either the vertical or horizontal dipole modes which, as shown in a previous section, exhibit different sensitivity to various depths thus yielding more information than would be available by simply using three spacings with one coil orientation.

To interpret a two-layer geometry the two-layer curves for both dipole configurations are superimposed on a common plot as shown

CROSS-SECTIONS

BURIED RIVER VALLEY

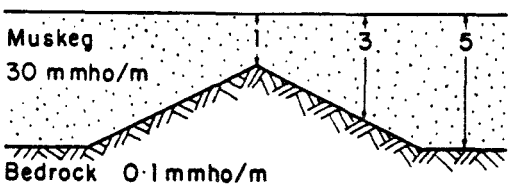


$$\frac{\sigma_a}{\sigma_1} = 1 - R(Z_1) + k_2 R(Z_1)$$

$$k_2 = \frac{\sigma_2}{\sigma_1} = \frac{40}{8} = 5$$

Z_1 (m)	σ_a (mmho/m)
1	32·6
2	26·9
5	18·6
7	16·0

BEDROCK HIGH

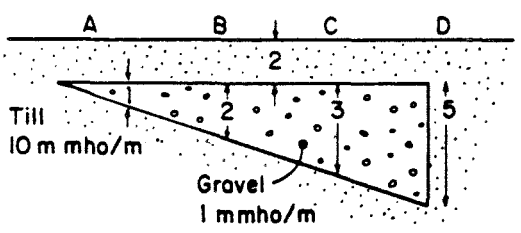


$$\frac{\sigma_a}{\sigma_1} = 1 - R(Z_1) + k_2 R(Z_1)$$

$$k_2 = \frac{\sigma_2}{\sigma_1} = \frac{0{\cdot}1}{30} = 0{\cdot}0033$$

Z_1 (m)	σ_a (mmho/m)
1	6·9
3	15·9
5	20·1

GRAVEL DEPOSIT



$$\frac{\sigma_a}{\sigma_1} = 1 - R(Z_1) + k_2[R(Z_1) - R(Z_2)] + k_3 R(Z_2)$$

$$k_2 = \frac{\sigma_2}{\sigma_1} = \frac{1}{10} = 0{\cdot}10$$

$$k_3 = \frac{\sigma_3}{\sigma_1} = 1{\cdot}00$$

station	σ_a (m mho/m)
A	8·9
B	8·2
C	7·7
D	6·9

FIGURE 10. EM31 calculated response across various geological features, using R (Z) corrected for instrument operation at waist (1 meter) height. Coil separation s = 3.67 meters.

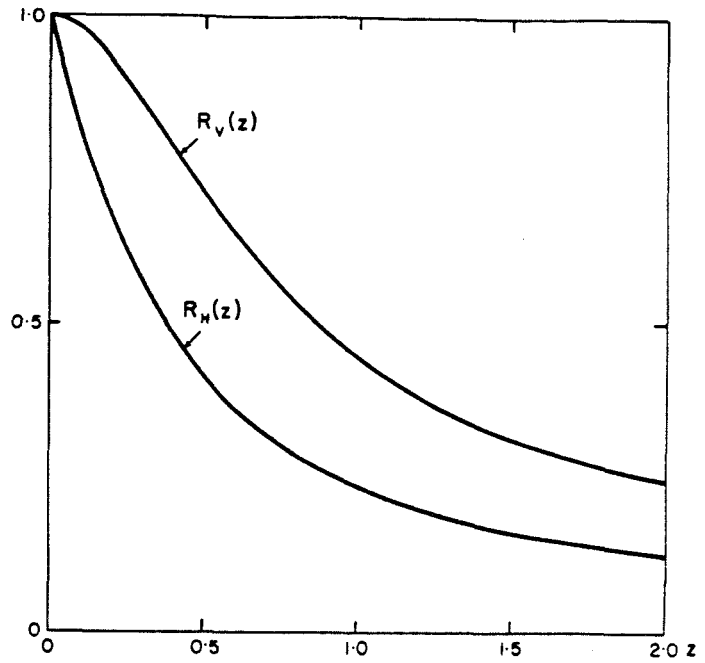


FIGURE 11. Cumulative response versus depth for vertical and horizontal dipoles.

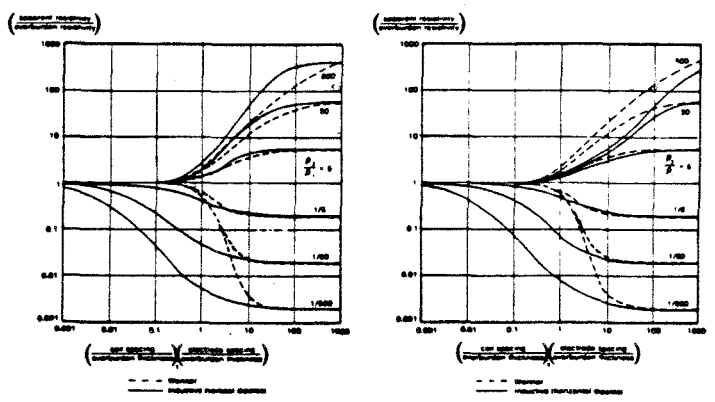


FIGURE 12. Comparison of Wenner array and inductive electromagnetic sounding curves for a two layer earth.

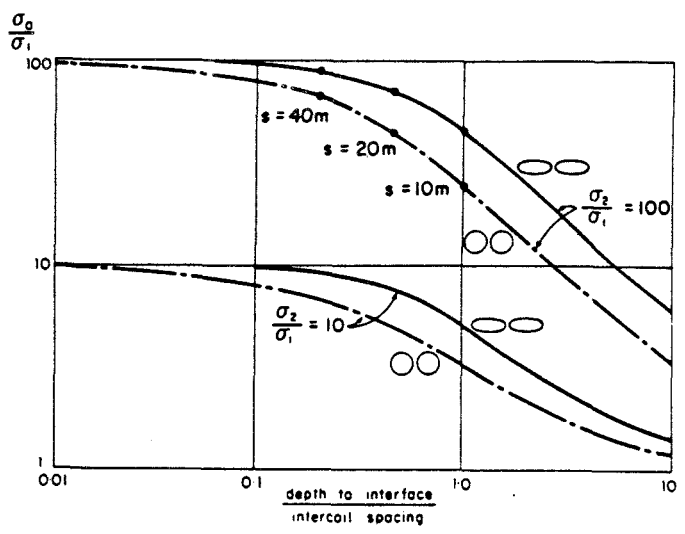


FIGURE 13. Two layer earth response curves (σ_2/σ_1 = 10,100; intercoil spacing varied). Dots indicate typical survey results.

in Figure 13. The six data points obtained by making measurements with two coil orientations and three intercoil spacings are plotted to the same scale on a piece of transparent paper and are translated vertically and horizontally on the two-layer curves to ascertain whether a satisfactory fit can be achieved. In the event that such a fit can be made, the earth does exhibit two-layer characteristics and the values of conductivity for both layers and the thickness of the upper layer are directly read off.

IV. 5. Resolution of Two-Layered Earth by Varying Instrument Height

In the case of the EM31 the intercoil spacing is rigidly fixed so that the technique described above is not available to analyse a layered earth. It is, however, possible to raise the instrument above the ground, measuring the apparent conductivity as a function of instrument height for both the vertical and horizontal dipole configurations. This has the effect of shifting the response curves of Figure 6 upwards through the various regions of the earth and the variation of apparent conductivity with height is therefore of diagnostic value in determining the nature of any layering. It is a straightforward matter to calculate the response of the instrument as a function of height for various two-layered earth geometries and typical curves are shown in Figure 14b. To use the curves one simply plots the measured apparent conductivity versus height for both coil configurations on a piece of transparent paper to the same scale as Figure 14b and shifts the plotted data vertically until good agreement is achieved with one of the curves, whereupon the two conductivities and the upper layer thickness are immediately determined as in the illustrated case history of Figure 14c.

In the event that the conductivity of either one of the two layers is known to be much less than the other, so that its contribution to the meter reading is negligible, it is simply necessary to lay the instrument on the ground, take a reading, lay it on its side, take a second reading, and from these two values one can immediately calculate the conductivity of the more conductive layer and the thickness of the upper layer.

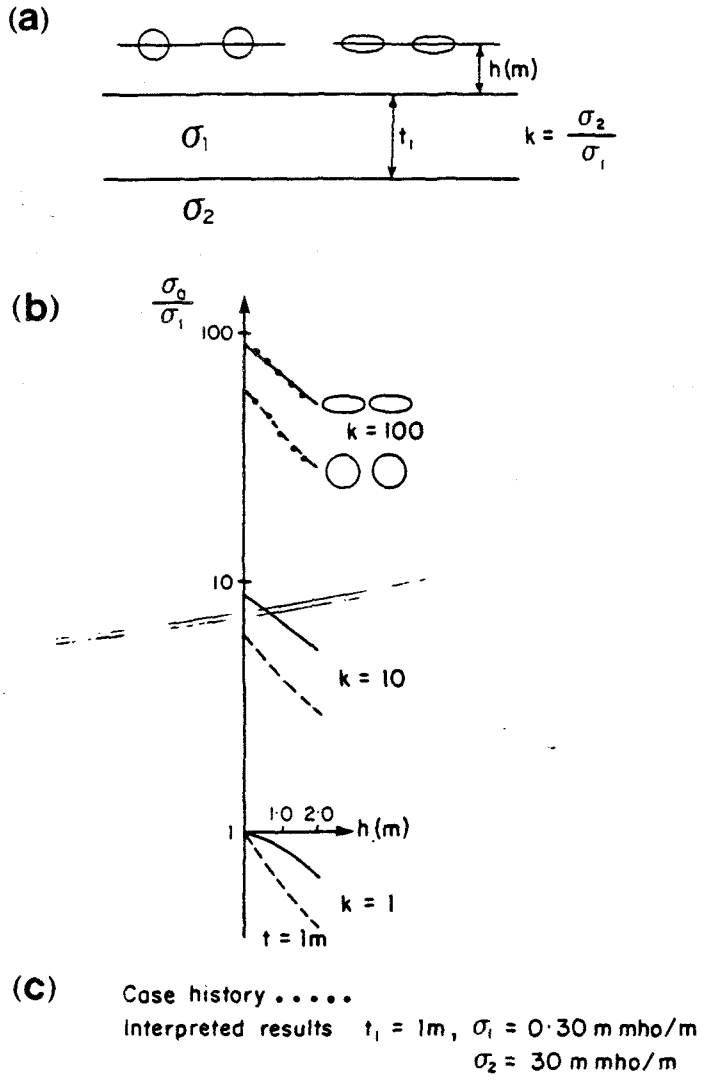


FIGURE 14. Two layer earth response curves (σ_2/σ_1 = 1, 10, 100; instrument height varied). Dots are actual survey results.

V. ADVANTAGES AND DISADVANTAGES OF INDUCTIVE TERRAIN CONDUCTIVITY MEASUREMENTS

V. 1. Advantages

The advantages of the use of inductive electromagnetic techniques to measure terrain conductivity are as follows:

(i) *Excellent resolution in conductivity.* It was stated in Section I that a problem with conventional resistivity was that the presence of localized resistivity inhomogeneities near the potential electrodes caused large errors. If we examine the current flow in a homogeneous halfspace for the inductive technique described herein we realize that in the vicinity of the transmitter the current density is very high and we might expect the presence of a conductive inhomogeneity located here to have a large effect. However where the current density is high, the radius of the current loops is small and their distance from the receiver coil large, so that these loops do not couple well magnetically with the receiver. The effect of changing this current by varying the local conductivity is consequently negligible. The lateral extent of the volume of earth whose conductivity is sensed by the inductive technique is approximately the same as the vertical depth. The result is that small changes in conductivity, for example of the order of 5% or 10%, are easily and accurately measured.

(ii) *No current injection problems.* Since currents are magnetically induced in the earth, current injection problems encountered with conventional resistivity in materials such as gravel, bedrock, permafrost, snow and ice, etc., are not encountered with this type of instrumentation.

(iii) *Simple multi-layered earth calculations.* This matter is dealt with at length in Section IV.

(iv) *Easy, rapid measurements.* A problem with the conventional Wenner array is that in order to survey to an effective depth a the array must be 3a in length and the total length of wire required 4a, used in four sections. This presents many opportunities for snagging and breaking the wire. Furthermore each measurement requires insertion of four electrodes and relatively careful measurement of the inter-electrode spacing. These features are avoided with the inductive electromagnetic techniques and it is no exaggeration to say that a survey can often be carried out five to ten times faster using this technique. Indeed with either the EM31 or the EM34-3 it is usually possible under average terrain conditions to survey 5 to 7 line-kilometers a day with a station spacing of 25 or 50 meters.

V. 2. Disadvantages

As with all geophysical instruments, there are some limitations and disadvantages to the use of inductive electromagnetic techniques and these are as follows:

(i) *Limited dynamic range (1 – 1000 mmhos per meter).* At low values of terrain conductivity it becomes difficult to magnetically induce sufficient current in the ground to produce a detectable magnetic field at the receiver coil. Conversely at high values of conductivity the quadrature component of the received magnetic field is no longer linearly proportional to terrain conductivity as is shown in the appendix.

(ii) *Setting and maintaining the instrument zero.* Ideally in order to set the zero the instrument would be suspended in free space

and the zero set there. The more acceptable alternative is to search out a region of very resistive ground, to accurately measure its conductivity using conventional techniques, and to set the instrumental zero at that location. This is the procedure which is actually followed.

It is necessary that this zero be accurately maintained over long periods of time and over the wide variations of temperature encountered during geophysical survey in various parts of the world. This produces tight constraints on the circuitry, with the result that the zero may be in error by up to ±0.2 mmhos per meter. Such an error would be negligible over the usual range of terrain conductivities; however in the event that measurements are being made on highly resistive ground the zero error can become significant.

(iii) *Limited Vertical Sounding Capability*. In theory it is possible to use a system such as the EM34-3 at a continuum of intercoil spacings to yield more information about electrical layering in the ground. To achieve a wide variety of inter-electrode spacings with conventional resistivity equipment is simple; in the case of the inductive electromagnetic technique the rapid fall-off of the magnetic field from the dipole transmitter introduces a serious dynamic range problem. In due course there will undoubtedly be instrumentation with a wider variety of spacings at the expense of additional complexity.

VI. CASE HISTORIES

This section describes several case histories obtained with the EM31 and the EM34. The surveys (i) illustrate the resolution in conductivity that can be achieved, (ii) compare the results obtained with conventional resistivity and (iii) illustrate the use of the latter for locating sand, gravel and conductive minerals, determining bedrock topography (including locating a buried river channel) and mapping the pollution plume from a land-fill site. In some cases the indicated conductivity has been converted to resistivity to facilitate comparison with conventional resistivity survey results.

Case History #1

Location: Mississauga, Ontario
Instrument: EM31
Application: Illustrates resolution and repeatability of EM31

For this case history a Rustrak chart recorder was used to monitor the output of an EM31. A line of length 200 meters was traversed in a field in both easterly and westerly directions. Figure 15 demonstrates that the instrument is resolving conductivity changes of less than 1 mmho/m (1% of full scale deflection) and that the repeatability is of the same order. In fact the repeatability is limited in this case by the resolving power of the chart recorder itself. It should furthermore be noted that the instrument is detecting spatial changes in conductivity of a few meters in length – compatible with the intercoil spacing of 3.7 meters.

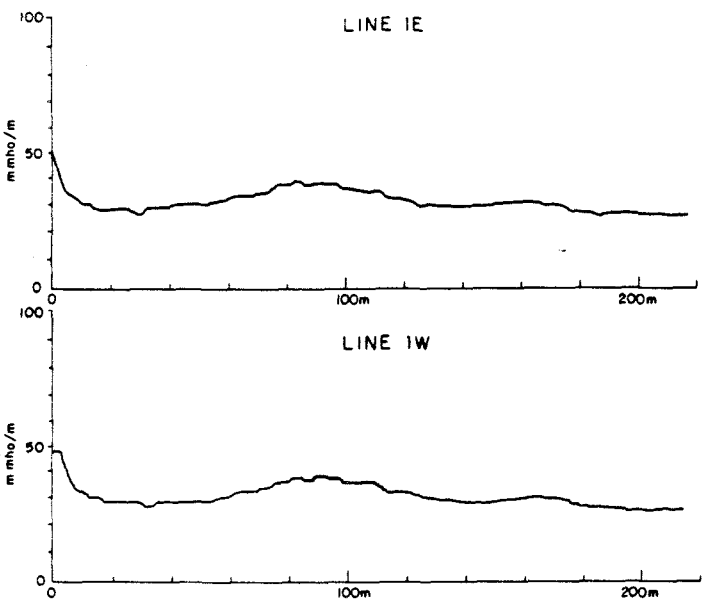


FIGURE 15.

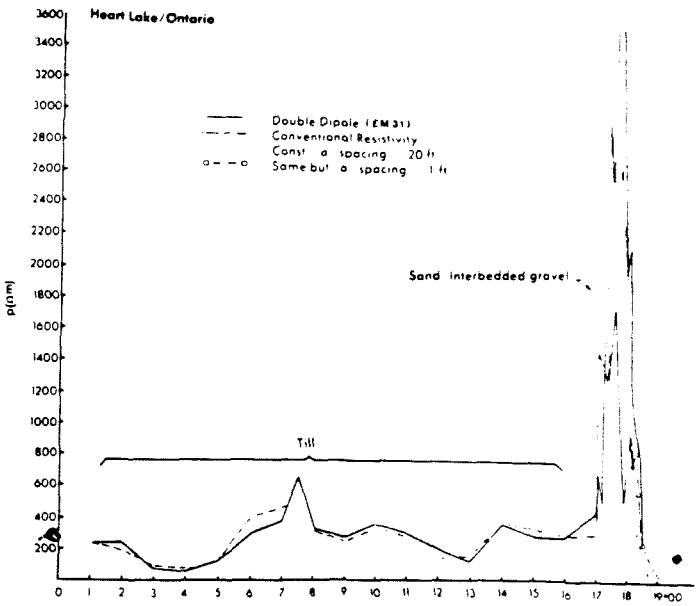


FIGURE 16. Test survey line – Heart Lake, Ont.

Case History #2

Location: Hearth Lake, Ontario
Instruments: EM31
Conventional resistivity apparatus
Application: Location of sand/gravel
Comparison of EM31 and conventional resistivity

In this survey a line 1900 ft. (580 meters) in length was surveyed with a measurement interval of 100 ft. (30 meters). The survey area was generally located on a buried esker, however the last few survey stations, 17 + 00 to 19 + 00, traversed a region of exposed sand and gravel (often occurring in the form of concretions) and over this portion of the line measurements were made every 10 ft. (3.0 meters).

The conventional resistivity profile was carried out using a Wenner array with an a spacing of 20 ft. (6.1 meters) except between stations 17 + 00 and 19 + 00 where the a spacing was reduced to 1 ft. (0.30 meters).

In general the correlation between the two sets of data is excellent, and demonstrates the ability of the EM31 to generate good quantitative data even in regions of low conductivity. Over the esker the EM31 was actually read continuously down the line – the data was recorded only at the 100 ft. intervals, with the exception of the reading at station 7 + 50 which was also recorded since it was noted that a conductivity low occurred there. Such an anomaly was, of course, missed by the conventional resistivity where measurements were only made every 100 ft.

Both sets of data become rather erratic between stations 17 + 00 and 19 + 00 as a result of the very rapid lateral changes in resistivity arising from the concreted material referred to above.

Case History #3

Location: Cavendish, Ontario.
Instrument: EM31
Application: Location of metallic type conductors

This survey line, of length 2000 ft. (610 meters), is located at a site

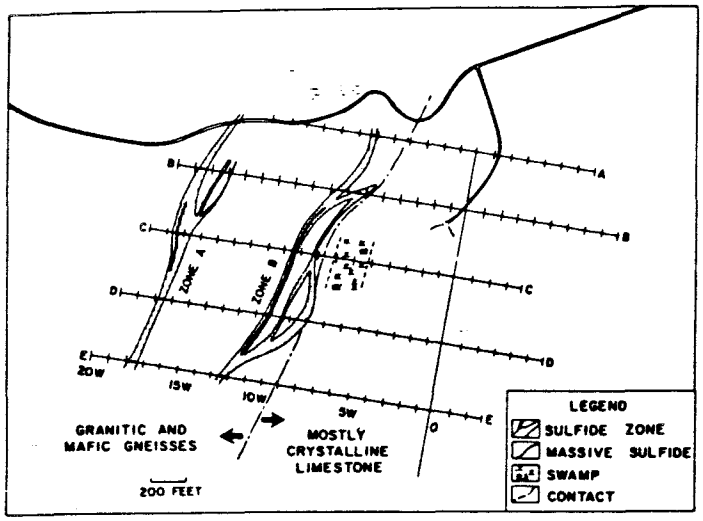


FIGURE 17. Geologic map of the Cavendish test site and the grid of traverse lines used in geophysical studies (after Ward et al [3]).

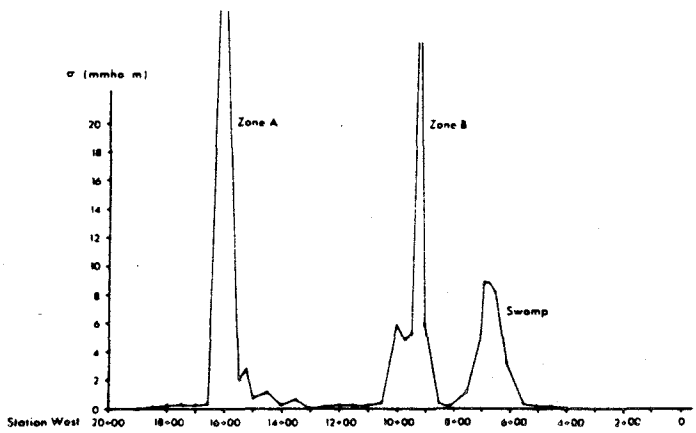


FIGURE 18. EM31 survey of Cavendish test range Line 'C'.

in Ontario which is often used by Canadian instrumentation manufacturers to test new electromagnetic geophysical equipment. The survey, along line C, illustrates response from both the swamp and the two zones of metallic mineralization. Although measurements were only taken every 50 ft. (15 meters) both zones are well delineated and when such high responses are encountered localization to within a few meters is quickly and easily carried out.

Inasmuch as the EM31 and EM34-3 were designed to map terrain conductivity at the conductivity levels encountered in typical soils both instruments are extremely sensitive electromagnetic detectors. For example on the most sensitive scale, full scale deflection for the EM31 is 800 ppm of the primary magnetic field and for the EM34-3 it is 3800 ppm. Such sensitivity makes either instrument useful for detecting metallic type conductors at what are very low conductivity levels by normal standards.

Case History #4

Location: Mississauga, Ontario
Instruments: EM31, EM34
Application: Determination of bedrock topography

Total line length for this survey was 8400 ft. (2600 meters) and measurements were made every 100 ft. (30 meters) with both the EM31 and the EM34 – an earlier version of the EM34-3 which had two intercoil spacings vis. 100 ft. (30 meters) and 50 ft. (15 meters). The survey was performed to outline the cross-sectional profile of a

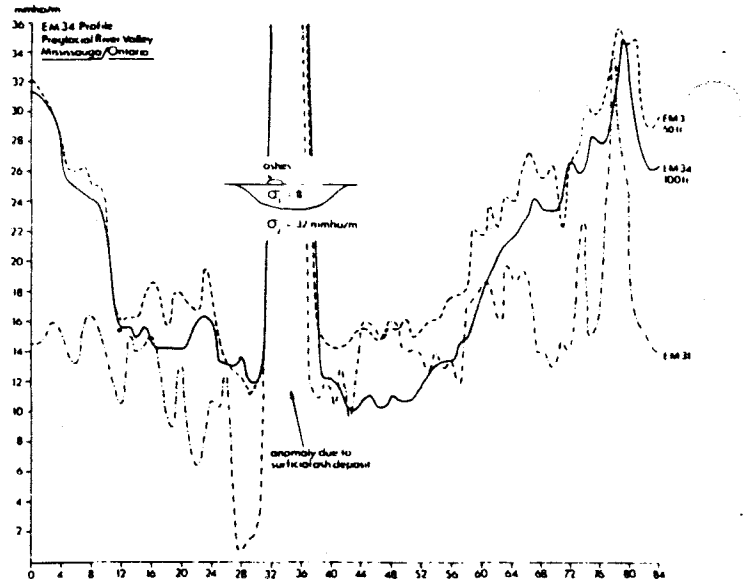


FIGURE 19. EM31 and EM34 survey line over preglacial river valley, Mississauga, Ontario.

buried preglacial river valley whose existence had been suggested from water-well data. At either intercoil spacing the time required for the EM34 profile was 1-1/2 hours, resulting in approximately one survey measurement per minute – including the time to walk the 100 feet between measurement stations. The time taken for the subsequent EM31 survey was similar.

Typical bedrock conductivity in the area is approximately 30 mmho/m, whereas an average value for the conductivity of the infilling glacial till is of the order of 8 to 12 mmho/m. Thus the EM3 at either intercoil spacing yields approximately 30 mmho/m at the valley edges where the overburden is thin and 12 to 14 mmho/m at the valley centre. The EM31 yields values of 14 to 18 mmho/m at the valley edges (slightly affected by the presence of bedrock) and approximately 10 mmho/m at the valley centre. The interpreted depth of the valley, based on the model shown in the figure, is approximately 120 feet (36 meters) which is in reasonable agreement with the water-well data value of 150 feet (45 meters), bearing in mind that the three sets of data show that a two-layer model is an over simplification.

The conductivity high which occurs between stations 32 and 38 results from a very large pile of waste furnace ash lying on the surface.

Case History #5

Location: Camp Borden, Ontario
Instruments: EM31, EM34
Conventional resistivity apparatus
Application: Mapping groundwater salinity
Comparison of EM34 and conventional resistivity

Geophysical surveys were carried out over a sanitary landfill site using, in addition to other instruments, an EM31, EM34 and conventional resistivity [4]. The survey results in the accompanying figures illustrate the good agreement between these techniques and also indicate the reduction in survey time achieved using inductive electromagnetic techniques. Particularly interesting are the vertical variations in resistivity as shown by the EM31 at 3.7 m intercoil spacing and the EM34 at 15 and 30 m spacing.

VII. SUMMARY

This technical note describes in detail the principles of mapping the electrical conductivity of the ground using magnetically induced

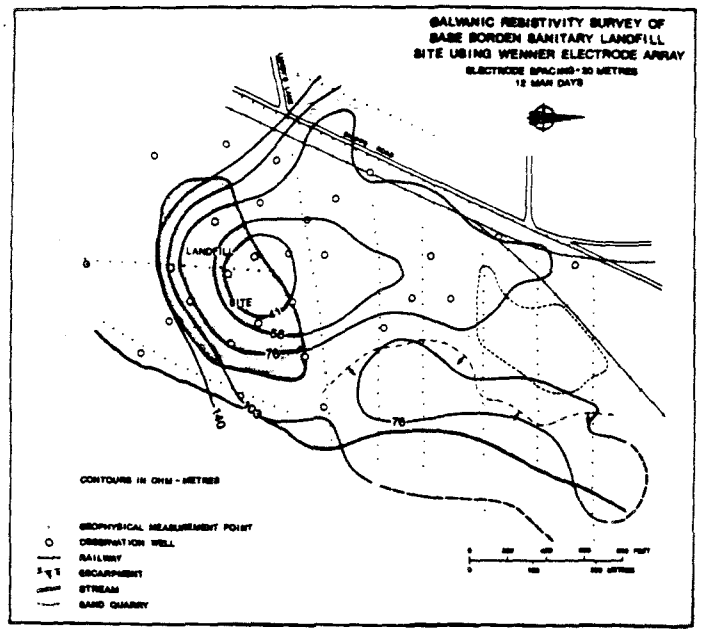


FIGURE 20(a).

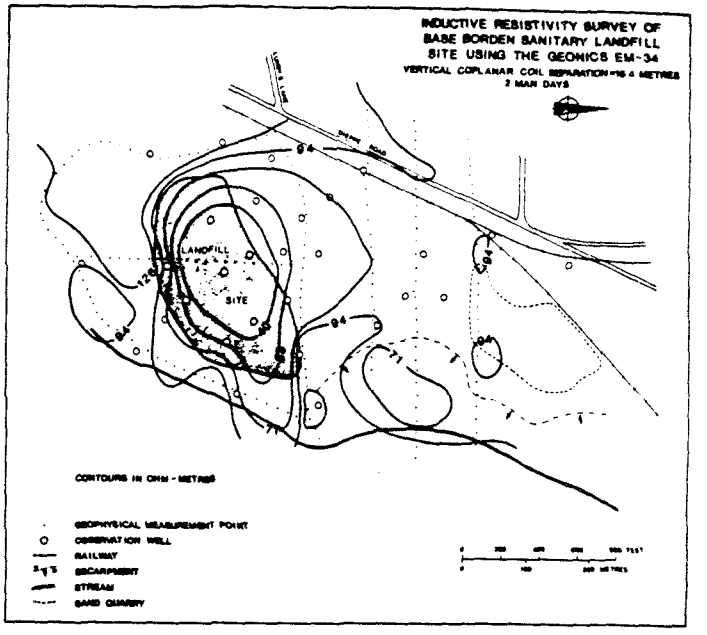


FIGURE 20(c).

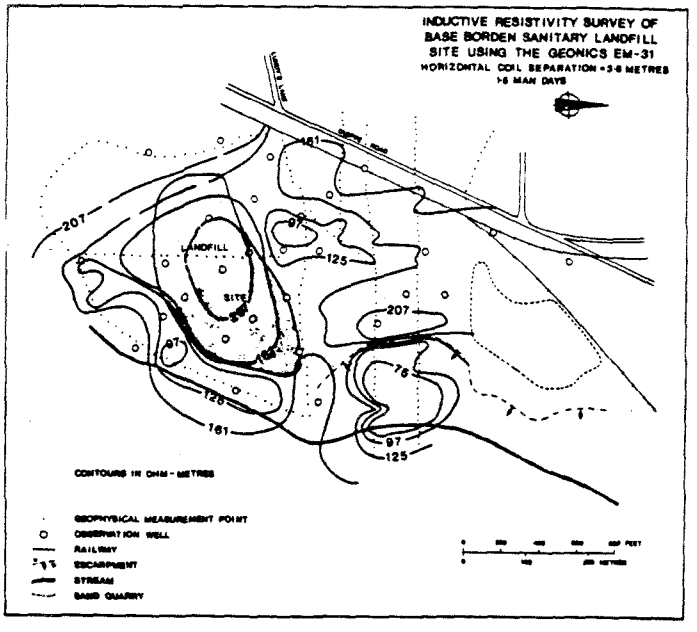


FIGURE 20(b).

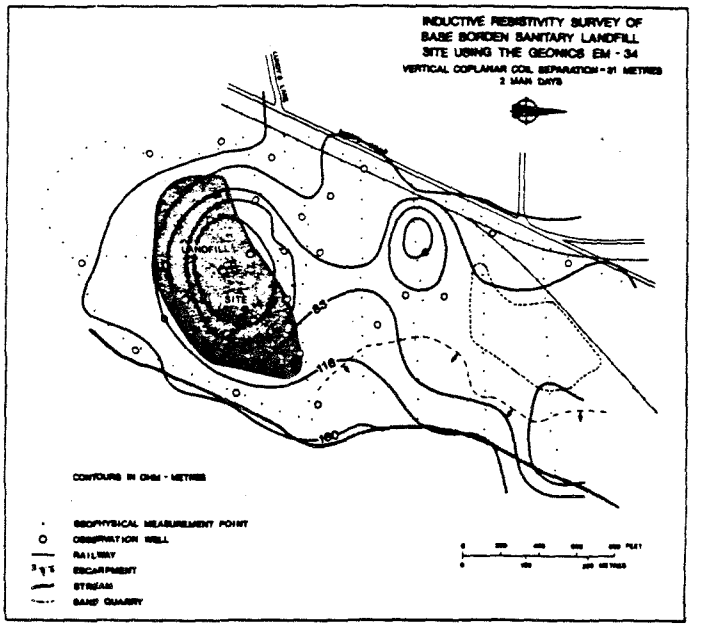


FIGURE 20(d).

currents at low frequencies. It has been shown that certain advantages can be derived from working at low values of induction number. Amongst these are excellent resolution in conductivity, a substantial reduction in man-hours necessary to carry out a conductivity survey and a simplification in the calculation of layered earth response.

Two points should be kept constantly in mind when performing surveys of this type to map geology. The first is that these instruments map only the electrical conductivity. If the conductivity does not vary significantly with the geological environment, or if parameters other than the geology also influence the conductivity, the survey results may be difficult to interpret.

The second point is that measurement of terrain conductivity, like any other geophysical measurement, must begin and end with geology. Such measurements are only an aid to help visualize geological conditions which cannot be seen. It is always necessary to interpret geophysical data against known geology from out-crops, boreholes, or any other such "bench marks". Geophysical measurements can be very effective by allowing interpolation between such sources, or extrapolation away from them. However in every case knowledge derived from geophysical measurements must be eventually reconfirmed against known geological conditions.

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(3) Ward, S.H.; Pridmore, D.F.; Rijol, Glenn W.E. Multispectral Electromagnetic Exploration for Sulphides. Geophysics Vol. 39 No. 5 p. 666. 1974.

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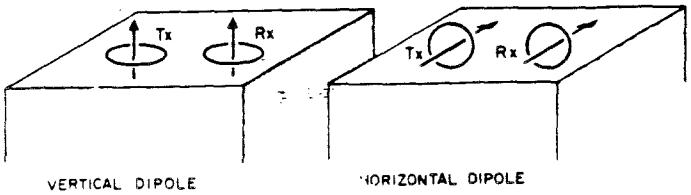


FIGURE AI. Vertical and horizontal dipole coil configurations.

APPENDIX: Theory of Operation at Low Induction Numbers

Consider the two coil configurations shown in Figure AI. In each case the transmitter coil is energized with alternating current at a frequency f Hertz. The measured quantity is the ratio of the secondary magnetic field H_s at the receiver when both coils are lying on the surface of the homogeneous half-space of conductivity σ to the primary magnetic field H_p in the absence of the half-space (i.e. as if the coils were in free space). The spacing between the coils is s meters.

The field ratios for vertical and horizontal dipole configurations are given by equations (1) and (2) respectively.

$$\left(\frac{H_s}{H_p}\right)_V = \frac{2}{(\gamma s)^2}\{9 - [9 + 9\gamma s + 4(\gamma s)^2 + (\gamma s)^3]\, e^{-\gamma s}\} \quad (1)$$

$$\left(\frac{H_s}{H_p}\right)_H = 2\left[1 - \frac{3}{(\gamma s)^2} + [3 + 3\gamma s + (\gamma s)^2]\frac{e^{-\gamma s}}{(\gamma s)^2}\right] \quad (2)$$

where $\gamma = \sqrt{i\omega\mu_0\sigma}$
$\omega = 2\pi f$
f = frequency (Hz)
μ_0 = permeability of free space
$i = \sqrt{-1}$.

These expressions are complicated functions of the variable γs which is in turn a reasonably complicated (complex) function of frequency and conductivity. However, as will be shown below, under certain conditions they can be greatly simplified.

A well known characteristic of a homogeneous half-space is the electrical skin depth δ, which is defined as the distance in the half-space that a propagating plane wave has travelled when its amplitude has been attenuated to 1/e of the amplitude at the surface. The skin depth is given by

$$\delta = \sqrt{\frac{2}{\omega\mu_0\sigma}} = \frac{\sqrt{2i}}{\gamma} \quad (3)$$

and therefore

$$\gamma s = \sqrt{2i}\,\frac{s}{\delta} \quad (4)$$

The ratio s/δ, the intercoil spacing divided by the skin depth, is defined as the induction number B, whereupon

$$\gamma s = \sqrt{2i}\, B \quad (5)$$

Now if B is much less than unity (ie $\gamma s \ll 1$) it is a simple matter to show that the field ratios of equations (1) and (2) reduce to the simple expression

$$\left(\frac{H_s}{H_p}\right)_V \simeq \left(\frac{H_s}{H_p}\right)_H \simeq \frac{iB^2}{2} = \frac{i\omega\mu_0\sigma s^2}{4} \quad (6)$$

which is the equation given in Section II.

The magnitude of the secondary magnetic field is now directly proportional to the ground conductivity and the phase of the secondary magnetic field leads the primary magnetic field by 90°.

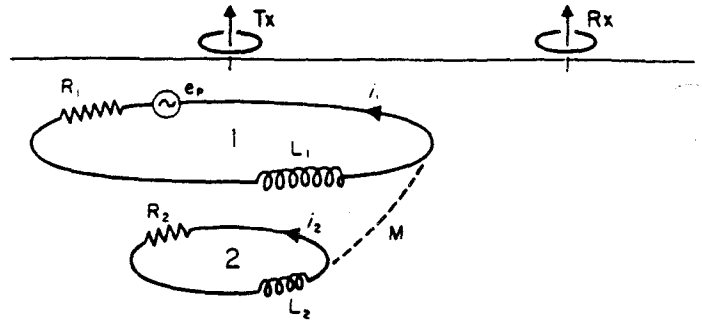


FIGURE AII. Electrical model for vertical dipoles.

To make B much less than unity we see that we must make s very much less than δ and thus

$$\omega \ll \frac{2}{\mu_0\sigma s^2} \quad (7)$$

That is, having decided on a value for s (which fixes the effective depth of penetration under the condition $B \ll 1$), the maximum probable ground conductivity is estimated and the operating frequency is chosen so that equation (7) is always satisfied.

The apparent conductivity which the instrument reads is then defined by

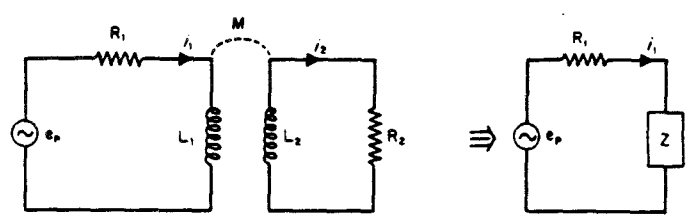
$$\sigma_a = \frac{4}{\omega\mu_0 s^2}\left(\frac{H_s}{H_p}\right)_{\substack{\text{quadrature}\\ \text{component}}} \quad (8)$$

To examine the reasons for this simplification let us focus our attention on the vertical dipole coil configuration shown in Figure AII since symmetry makes this configuration the simplest to understand.

Consider current loop 1. The primary emf e_p causing this current to flow is given (through Faraday's law) by the time rate of change of the primary magnetic flux from the transmitter through this loop. Three impedances cause the current to be limited. These arise from (i) the electrical resistance R_1 of the loop, (ii) the fact that the current i_1 generates its own magnetic field which causes a time-varying secondary magnetic flux through the loop (self-inductance, L_1), and (iii) the fact that all other current loops such as i_2 generate their own magnetic fields which in turn cause a time-varying magnetic flux to link with loop 1 (mutual-inductance, M).

The equivalent circuit for this configuration is easily derived from elementary circuit theory with the result shown in Figure AIII.

The complex impedance Z incorporates all of the affects of magnetic coupling between current loop 1 and any other current loop 2. We see from this expression that Z can be made arbitrarily small by reducing $\omega = 2\pi f$, the operating frequency. When Z is thus



$$Z = i\omega L_1 + \frac{\omega^2 M^2}{R_2 + i\omega L_2}$$

$$i_1 = \frac{e_p}{R_1 + Z}$$

FIGURE AIII. Equivalent circuit for model of Figure AII.

made much smaller than R_1 the current flow in loop 1 is simply given by

$$i_1 = \frac{e_p}{R_1} = \frac{i\omega\phi_p}{R_1} = i\omega\phi_p G_1 \tag{9}$$

where ϕ_p = primary flux linking loop 1
G_1 = conductance of loop 1($G_1 = 1/R_1$)
$i = \sqrt{-1}$

We see that the magnitude of the current is linearly proportional to the loop conductance and furthermore that the phase of the current leads the primary flux by 90°. Since the secondary magnetic field at the receiver from current i_1 is in phase with and directly proportional to i_1 it too will be directly proportional to G and will lead the primary flux by 90°. Thus

$$\left(\frac{H_s}{H_p}\right) \propto i\omega G_1 \tag{10}$$

which has the same dependence on frequency and conductance as equation (6). We infer therefore, that the condition $B \ll 1$ is equivalent to stating that for all current loops that affect the receiver output the operating frequency is so low that we can ignore any magnetic coupling between the loops. Thus the current that flows in any loop is (i) completely independent of the current that flows in any other loop since they are not magnetically coupled and (ii) is only a function of the primary magnetic flux linking that loop and of the local ground conductivity.

The lack of interaction between current loops is of great importance in simplifying the data reduction procedures. Of equally great significance is the fact that for any value of B and for any orientation of a magnetic dipole (or indeed of any magnetic source) over either a uniform halfspace or a horizontally stratified earth it can be shown that all current flow is horizontal. That this is the case for a vertical dipole is easy to see from symmetry; for a horizontal dipole it is less evident but equally true. Thus, in a horizontally layered earth no current crosses an interface which is fortunate since, if it did, changing either of the conductivities would, by virtue of refraction of the current, change the direction of the current as it flowed from one medium to the other.

If no current flow crosses an interface and if there is no magnetic coupling between current loops, changing the conductivity of any one of the layers of a horizontally stratified earth will not alter the geometry of the current flow. Varying the conductivity of any layer will proportionately vary only the magnitude of the current in that layer. To calculate the resultant magnetic field at the surface of a horizontally layered earth it is simply necessary to calculate the independent contribution from each layer, which is a function of its depth and conductivity, and to sum all the contributions.

The functions $\phi(z)$ and $R(z)$ discussed in Section II define the relative influence of current flow as a function of depth. Their derivation is involved and will not be given here. The resultant

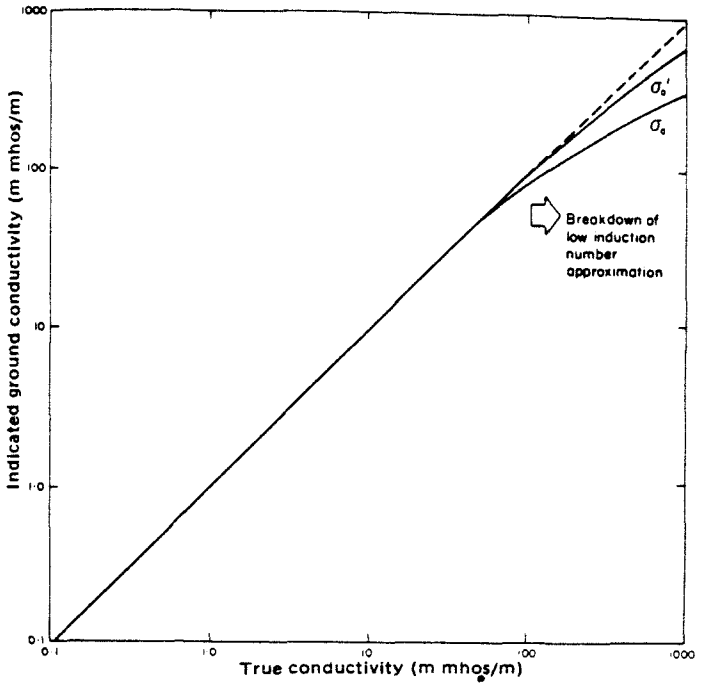


FIGURE AIV. Plot of indicated conductivity for EM31 versus true (homogeneous half-space) conductivity for both vertical (σ_a) and horizontal (σ_a') dipoles.

expressions are, however, simple and easily programmed into hand calculators:

$$\phi_V(z) = \frac{4z}{(4z^2 + 1)^{3/2}} \tag{11}$$

$$\phi_H(z) = 2 - \frac{4z}{(4z^2 + 1)^{1/2}} \tag{12}$$

$$R_V(z) = \frac{1}{(4z^2 + 1)^{1/2}} \tag{13}$$

$$R_H(z) = (4z^2 + 1)^{1/2} - 2z \tag{14}$$

where z is the depth divided by the intercoil spacing.

Finally it should be noted that for a given frequency and intercoil spacing as the terrain conductivity increases the approximation of equation (6) eventually breaks down and the instrumental output is no longer proportional to terrain conductivity. This effect is illustrated in Figure AIV, which plots apparent (indicated) conductivity against true (homogeneous halfspace) conductivity for both vertical and horizontal transmitter/receiver dipoles for the operating parameters of the EM31. As would be expected the horizontal dipoles exhibit linearity to greater values of conductivity as a result of the reduced depth of penetration in this configuration.

APPLICATIONS MANUAL
FOR
PORTABLE MAGNETOMETERS

by

S. BREINER

GeoMetrics
395 Java Drive
Sunnyvale, California 94086
U.S.A.

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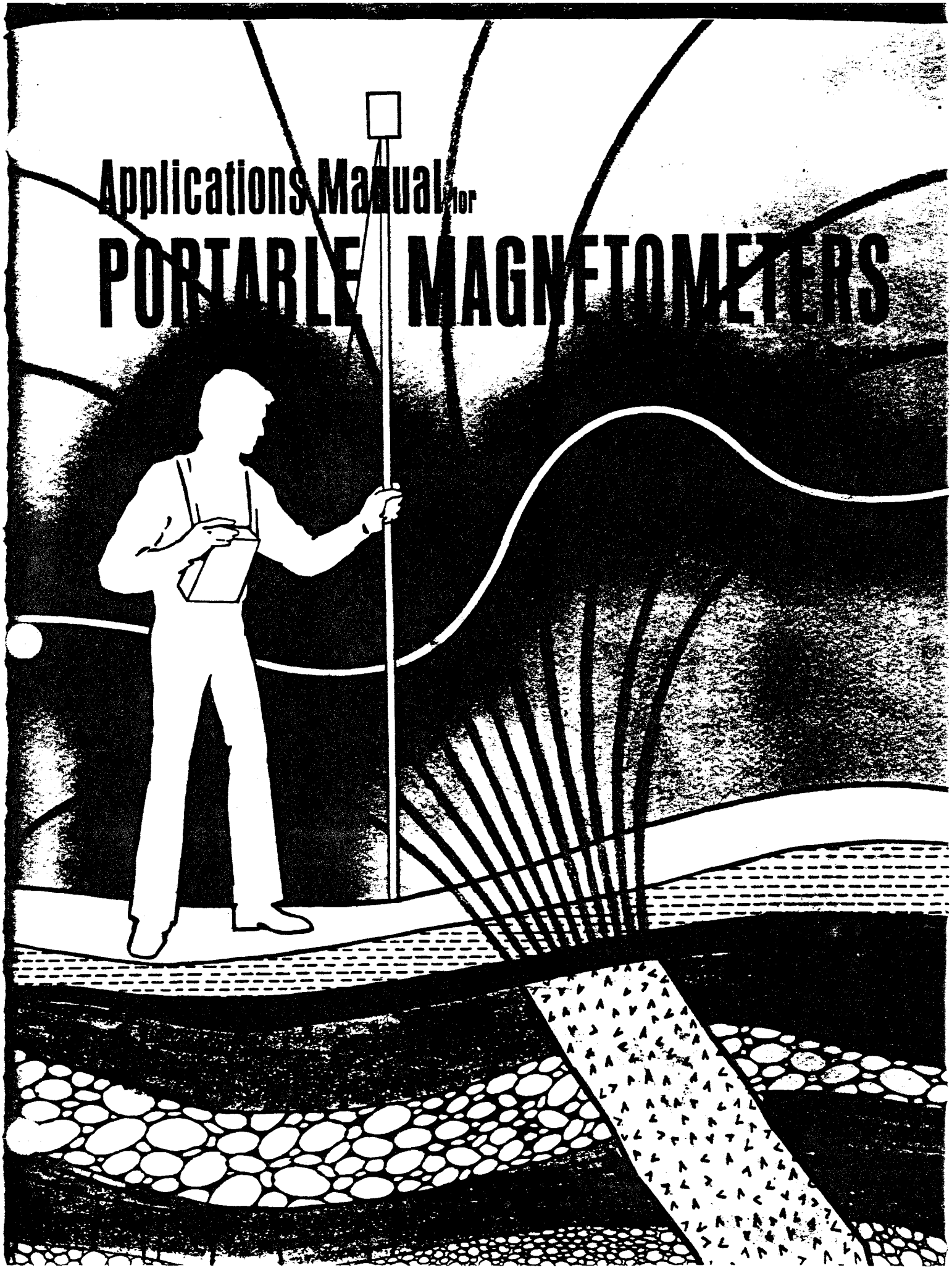
Applications Manual for PORTABLE MAGNETOMETERS



PREFACE

This Manual was written to satisfy most of the needs of the average user of a portable total field magnetometer for both conventional and unconventional applications, including geological exploration, search for lost objects, magnetic measurements of rock or iron specimens and archaeological prospecting. As the name implies, this is a manual or guide for professional and non-professional persons who may not have the time, the requisite background or the ready access to the proper libraries to delve deeply into standard texts, the few that there are, on applied geophysics.

Some of the information that I have included in this Manual may be found in the references cited or drawn from obscure sources, or uncovered amongst equations and confusing terminology in physics or engineering texts. Many of the facts and instructions in this Manual, however, do not appear anywhere else in print. For example, I know of no other readily available reference on the subjects of magnetic search of buried objects, many of the portable gradiometer applications, operational considerations of proton magnetometers and the effect of electrical currents on portable total field magnetometers. Among the less common subjects that are covered are the magnetic properties and detection of common steel objects, facts concerning the detection of buried ruins, methods for sketch-it-yourself anomaly construction, and some help in interpreting anomalies at the magnetic equator. I also tried to simplify some aspects of the potentially complex subject of magnetics using short-cuts wherever possible and deskilling somewhat the fine art of magnetic interpretation. For most portable magnetometer work, I feel this approach is quite adequate. Certainly for the more sophisticated techniques required for interpretation of the usually-more-precise aeromagnetic surveys, the reader is advised to consult the References or persons knowledgeable in the subject.

Figures and examples are used liberally in the explanations because I feel they assist or confirm one's understanding of these subjects. Almost all of the profiles were drawn free-hand according to the techniques described and should not be considered as precise computer-derived curves. They do demonstrate that one can be his own 'magnetics expert' insofar as what is required for most of these applications.

The question of units always arises in any technical publication. Many magnetic measurements, particularly magnetic properties of rocks and geophysical research, use cgs, some physics and engineering applications use mks, while geophysical exploration, for most of the readers of this Manual, still utilizes feet and miles. A mixture of units, hopefully not too confusing, was therefore unavoidable. Subsequent editions of this Manual may be written specifically in carefully selected metric units.

The various chapters were prepared to be read or utilized independent of each other if necessary. For example, someone interested in using the magnetometer for archaeology but who does not particularly enjoy wading through the mathematics of Chapter V, can proceed directly to Chapter VII. He would be aided, however, by subsequently skimming through Chapter V.

I would appreciate criticism or suggestions should anyone note errors or have suggestions on how I may improve later editions. Moreover, if the reader finds that my explanations or facts fall just short of what is required, I am available by telephone or through written correspondence.

SHELDON BREINER
GeoMetrics
395 Java Drive
Sunnyvale, California 94086
Telephone: (408) 734-4616

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I.

INTRODUCTION

This Manual is intended for use as a general guide for a number of very diverse applications of portable magnetometers, especially the total field proton (nuclear precession) magnetometers. The diversity of applications and the general complexity of magnetic field measurements limits the depth to which any one subject can be covered, but further information, if desired, can be obtained through the author or from any of the references cited.

Among the applications for which this Manual is written are mineral and petroleum exploration, geological mapping, search for buried or sunken objects, magnetic field mapping, geophysical research, magnetic observatory use, measurement of magnetic properties of rocks or ferromagnetic objects, paleomagnetism, archaeological prospecting, conductivity mapping, gradiometer surveying, and magnetic modeling. The terminology, units of measurement, and assumed prerequisite knowledge are those employed in the field of geology and geophysics.

II.

MAGNETOMETERS

Instrument Use

The common types of portable magnetometers in use today are fluxgate, proton precession, Schmidt field balance, dip needle and other special purpose instruments. Field balances and dip needles are mechanical devices comprised of pivoted magnets measuring vertical or horizontal intensity or field direction, and are not much used today being replaced by the more sensitive and less cumbersome fluxgate and proton magnetometers. Portable fluxgate magnetometers employ a saturable core sensor held in a vertical direction to measure vertical intensity with an effective sensitivity on the order of several gammas. Fluxgate magnetometers, too, are slowly being replaced by the proton magnetometer which has greater sensitivity (1 gamma or better), absolute accuracy, no moving parts, and measures total field intensity with freedom from orientation errors. For reasons of its increasing utilization and because many applications require these features, the proton magnetometer will be the principal instrument under discussion in the Manual. Much of the Manual from Chapters III through IX nevertheless applies to vertical component flux gate magnetometers as well. Anomaly signatures at high latitudes (magnetic dip 70° or greater) are practically identical for the two instruments; at other latitudes they differ significantly.

Proton Magnetometer

The proton precession magnetometer is so named because it utilizes the precession of spinning protons or nuclei of the hydrogen atom in a sample of hydrocarbon fluid to measure the total magnetic intensity. The spinning protons in a sample of water, kerosene, alcohol, etc., behave as small, spinning magnetic dipoles. These magnets are temporarily aligned or polarized by application of a uniform magnetic field generated by a current in a coil of wire. When the current is removed, the spin of the protons causes them to precess about the direction of the ambient or earth's magnetic field, much as a spinning top precesses about the gravity field. The precessing protons then generate a small signal in the same coil used to polarize them, a signal whose frequency is precisely proportional to the total magnetic field intensity and independent of the orientation of the coil, i.e., sensor of the magnetometer. The proportionality constant which relates frequency to field intensity is a well known atomic constant: the gyromagnetic ratio of the proton. The precession frequency, typically 2000 Hz, is measured by modern digital counters as the absolute value of the total magnetic field intensity with an accuracy of 1 gamma, and in special cases 0.1 gamma, in the earth's field of approximately 50,000 gammas.

Total Field Measurement

The total magnetic field intensity, as measured by a proton magnetometer, is a scalar measurement, or simply the magnitude of the earth's field vector independent of its direction. The measurement can be expressed as in *Figure 1a* as simply the length of the earth's field vector, F, shown here to be 50,000 gammas. A local perturbation, T, of 10 gammas, as might be measured in any of the applications discussed herein, is shown in *Figure 1b* as a vector of arbitrary direction. This disturbance vector adds to the undisturbed field in the usual manner of vector addition as shown in *Figure 1b*, paying special notice to how the figure would actually appear if both the 50,000 and 10 gamma vectors were drawn to scale. It is clear from the figure, then, that since the proton magnetometer measures only the *magnitude* of the resultant vector whose direction is almost exactly parallel

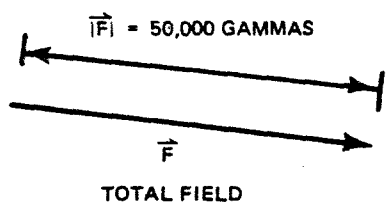


Figure 1a.

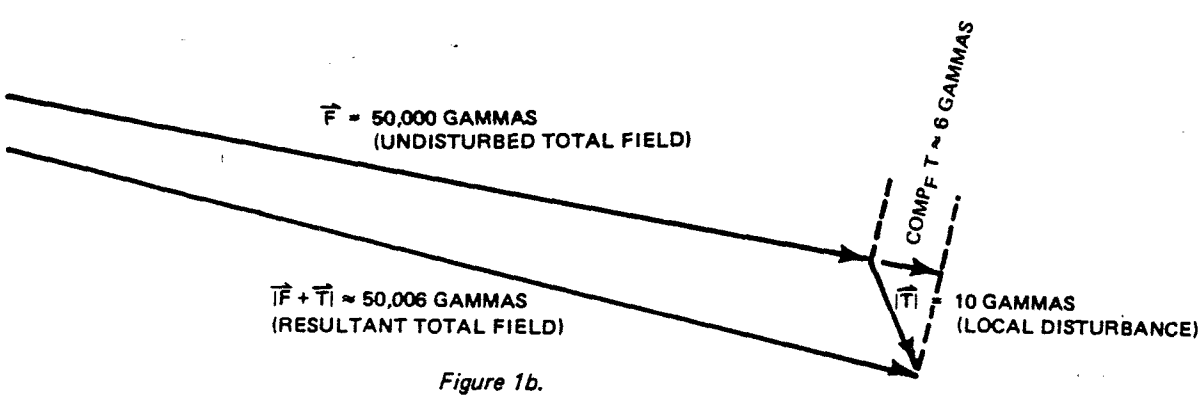


Figure 1b.

to the undisturbed total field vector, that which is measured is very nearly the component of the disturbance vector in the direction of the original undisturbed total field, or where

$$|\vec{F} + \vec{T}| \approx F + \mathrm{comp}_F T$$

where $$|\vec{F}| \gg |\vec{T}|.$$

Such conditions are almost always valid except in the near field of large steel objects or in the vicinity of iron ore deposits or certain ultrabasic rocks which produce anomalies larger than 10,000 gammas. Thus, the change in total field, $\Delta F = \mathrm{comp}_F T$, i.e., the component of the anomalous field, T, in the direction of F. (Except where noted, $\mathrm{comp}_F T$ will be referred to simply as the anomaly T.) The proton precession magnetometer, for small perturbations, can therefore be considered to be an *earth's-field-determined component magnetometer.*

This property of measuring this scalar magnitude of the field, otherwise called total field intensity, is very significant with respect to the asymmetric signatures of anomalies, interpretation of anomalies, and in various special applications. Furthermore, the fact that what is measured is independent of the orientation of the sensor, allows the magnetometer to be operated without attention to orientation or leveling such as would be the case with a fluxgate magnetometer on the mobile platform of a person, vehicle, or aircraft. The only limitation of such a scalar measurement, albeit a minor one, is the fac that the component of the anomalous field which is measured is not normally under the control of the observer, but rather at the whim of the local direction of the earth's magnetic field.

Limitations of a Proton Magnetometer

The proton magnetometer has no moving parts, produces an absolute and relatively high resolution measurement of the field and usually displays the measurement in the form of an unambiguous digital lighted readout. Several operational restrictions exist, however, which may be of concern under special field conditions. First, the proton precession signal is sharply degraded in the presence of a large magnetic field gradient greater than 200 gammas per foot (approximately 600 gammas per meter). Also, the signal amplitude from the sensor is on the order of microvolts and must be measured to an accuracy of 0.04 Hz of the precession frequency of several thousand Hz. This small signal can be rendered immeasurable by the effects of nearby alternating current electrical power sources. For these two reasons, *a proton magnetometer cannot usually be operated within the confines of a typical building.* Developments and procedures are presented which minimize these effects for the applications to be described in the Manual.

III.

EARTH'S FIELD MAGNETISM

Introduction

The earth's magnetic field resembles the field of a large bar magnet near its center or that due to a uniformly magnetized sphere. The origin of the field is not well understood, but thought to be due to currents in a fluid conductive core. On the surface of the earth the pole of this equivalent bar magnet, nearest the north geographical pole, is actually a 'south' magnetic pole. This paradoxical situation exists since by convention a north-seeking end of a compass needle is defined as pointing north yet must point to a pole of opposite sense or south pole of the earth's magnetic field. To avoid possible confusion, though, the magnetic pole near the geographical north pole is, and will be referred to as, a 'north' pole.

The field, or flux, lines of the earth exhibit the usual pattern common to a small magnet as shown in *Figure 2*. Note that the direction of the field is vertical at the north and south magnetic poles, and horizontal at the magnetic equator. An understanding of this geometry is important with respect to interpretation of magnetic anomalies. The intensity of the field, which is a function of the density of the 'flux lines' shown in *Figure 2*, again behaves as a bar magnet being twice as large in the polar region as in the equatorial region, or approximately 60,000 gammas and 30,000 gammas respectively. The inclination from

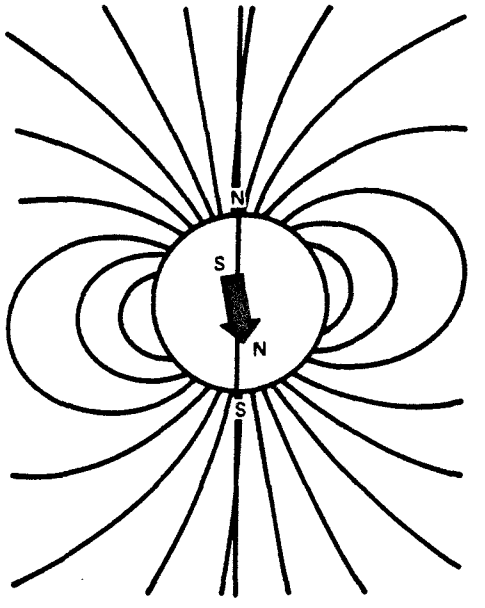


Figure 2.

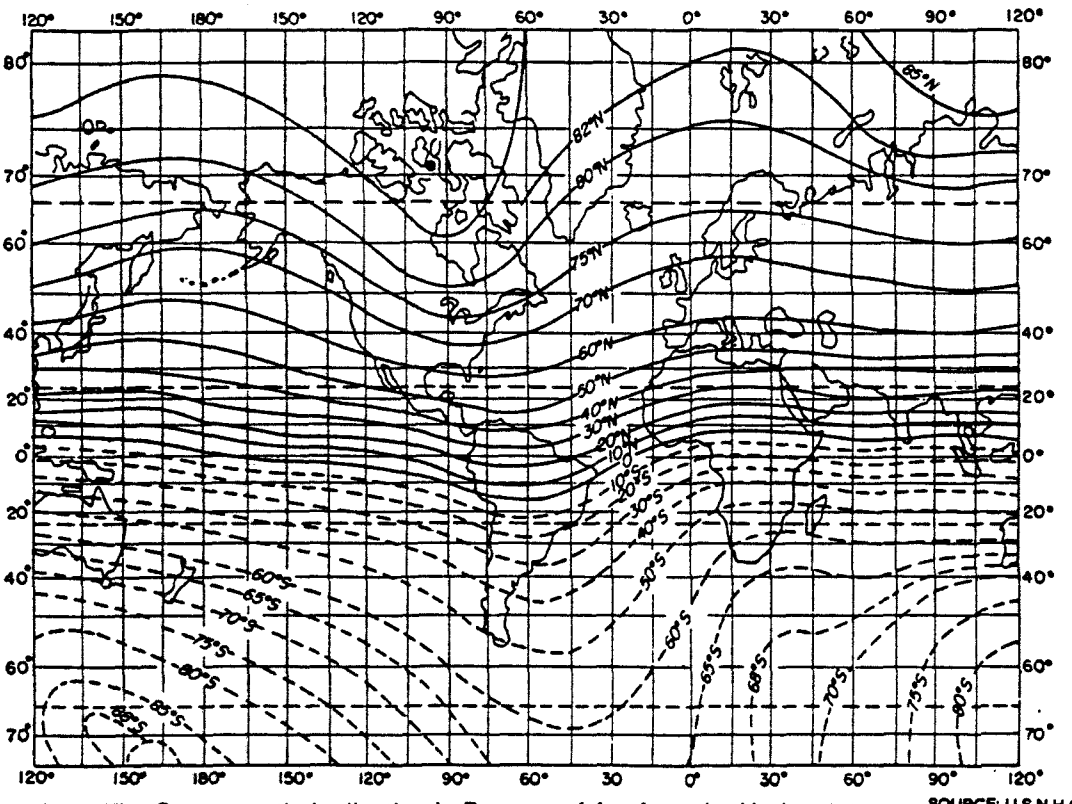


Figure 3. The Geomagnetic Inclination in Degrees of Arc from the Horizontal

SOURCE: U.S.N.H.O.

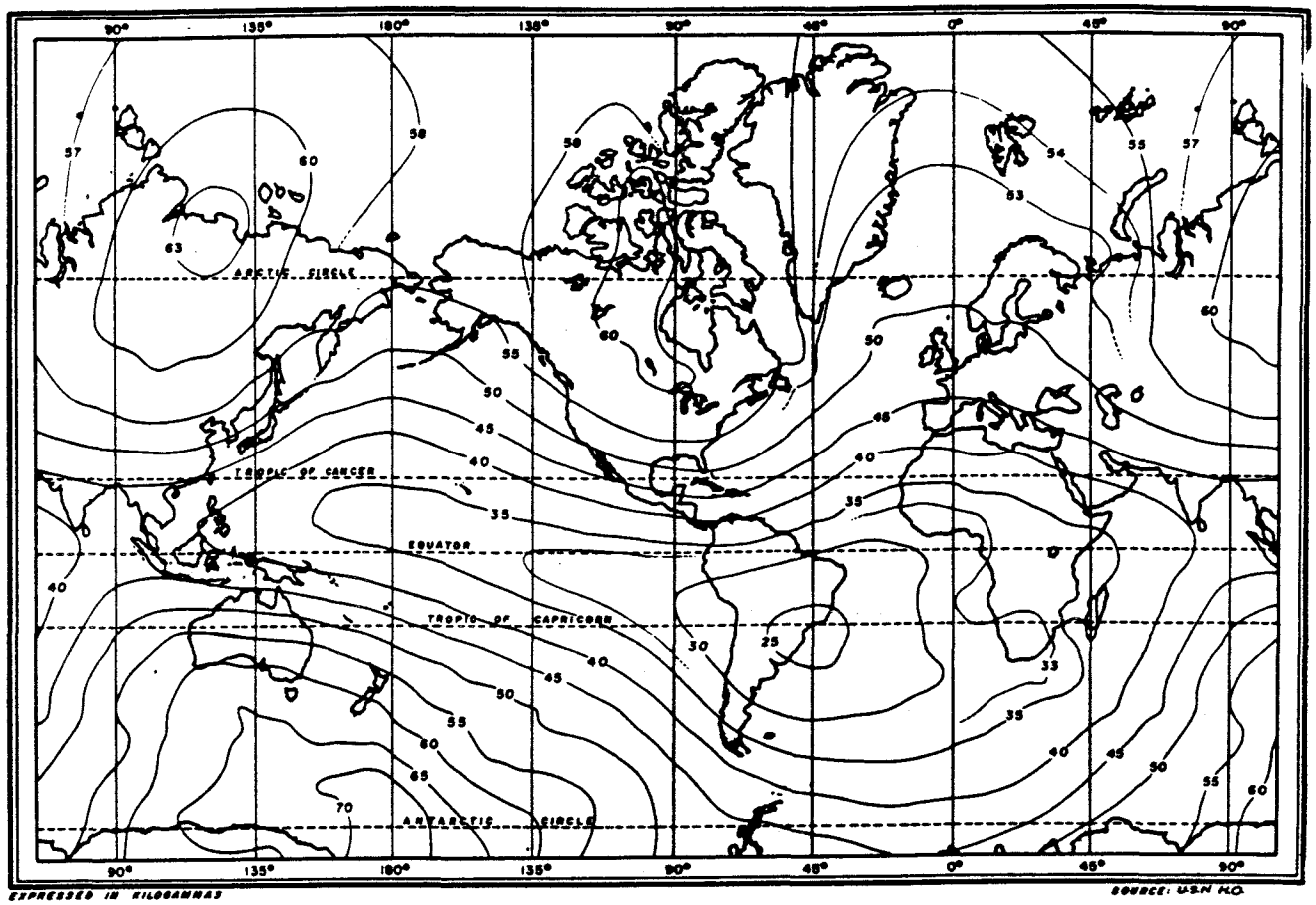


Figure 4. The Total Intensity of the Earth's Magnetic Field

the horizontal and the total intensity are shown in *Figures 3 and 4.* (NOTE: 1 gamma = 10^{-5} gauss. Gauss is actually a unit of magnetic induction and oersted a unit of magnetic intensity—B and H respectively, in physics nomenclature. By convention in the geophysical community, however, gauss is the unit in cgs of magnetic intensity. In any event, numerically, 1 gamma = 10^{-5} gauss = 10^{-5} oersted = 10^{-9} webers/M^2 = 10^{-9} tesla.)

The earth's total field intensity is not perfectly symmetric about the geographical north pole. First, the north magnetic pole is in northern Canada more than 1000 miles from the geographical pole (note again *Figure 2*). Also, the earth cannot exactly be represented by a single bar magnet, but has numerous higher order poles and very large-scale anomalous features owing to unknown characteristics of the generating mechanism in the earth's core. In addition, the solar wind or constant flux of particles and electric currents from the sun distort the field lines from what is shown in *Figure 2* to a more or less tear-drop shape with the blunt end towards the sun. The last, but for the purposes of this Manual, most relevant deviation from a symmetric field is the anomalous set of features in the earth's crust caused by local variations in the magnetic minerals or other features of interest which distort the local earth's magnetic field.

Time Variations

The variations described above all refer to the spatial variations in the earth's magnetic field, but there are variations in time as well. Significant time variations with periods of seconds, minutes and hours are the direct or indirect effect of the solar wind referred to above as it distorts the magnetosphere or external magnetic field of the earth. Daily or diurnal variations are primarily seen during the local daylight hours shown for typical days in *Figure 5.* Diurnal variations are not predictable, may exhibit changes as large as 100 gammas or more and are often removed from portable magnetometer data by methods described in Chapter IV. Superimposed upon these diurnal variations are more short-period phenomena called micropulsations *(Figure 6)* which are more random in behavior, generally smaller in amplitude and may occur at any time of the day or night. Micropulsations occur in a broad range of periods between 0.01 seconds up to several tens of minutes with amplitudes from a thousandth of a gamma to several tens of gammas.

Of still greater concern as a possible source of erroneous data are magnetic storms occurring as often as several times per month with their onset suddenly and simultaneously throughout the world. Such storms may exhibit variations of up to several hundred gammas and may last one day or up to several days. (See *Figure 7.*) For very important field measurements, particularly for higher resolution measurements, a recording base station or reference monitor is often used which is examined at the start of each day for an indication of magnetic storm activity and also for subsequent removal of the diurnal variations from field data using time as a correlation.

The earth's internal or main field also changes slowly over years, tens and thousands of years through what is termed the secular variation. The inclination, intensity

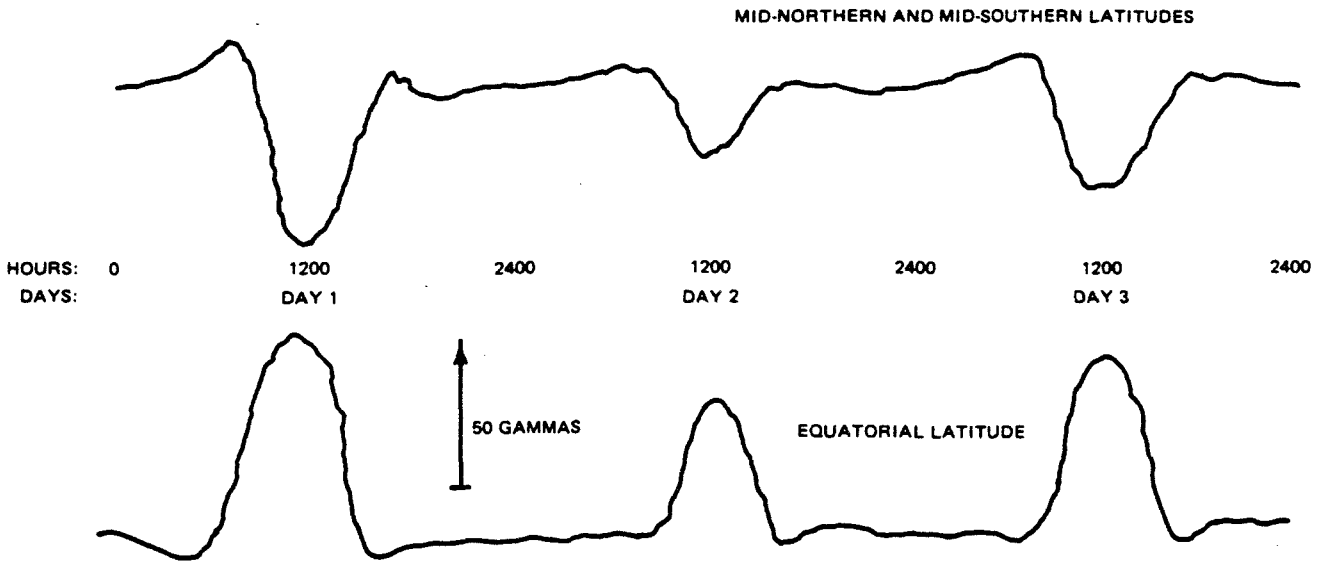


Figure 5. Typical Diurnal Variations in Total Field Intensity

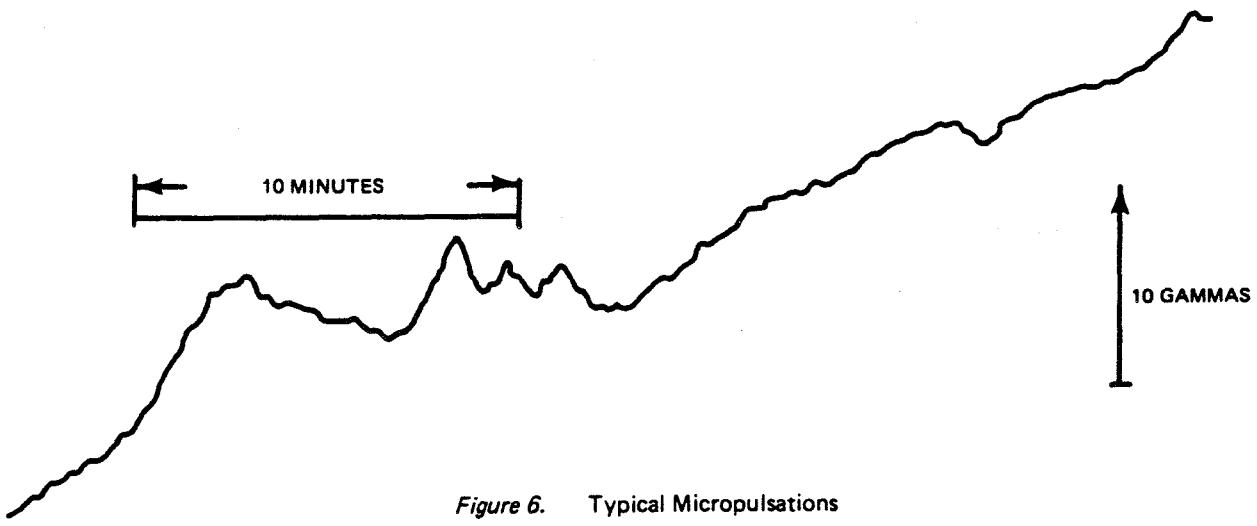


Figure 6. Typical Micropulsations

Figure 7. Typical Magnetic Storm

and even the location of the poles varies slowly at a rate relevant, in the context of this Manual, only to observatory and archival interests. From time-to-time through geologic history, the main field has even reversed and the consequences of these events are extremely important for a number of portable magnetometer applications covered in the Manual.

Magnetic Minerals and Iron

The application of portable magnetometers as treated herein has, as its primary objective, the identification and description of spatial changes in the earth's field. The time changes described above simply represent noise or interference in the measurements of interest. The spatial variations or anomalies to be mapped for these applications are those which might occur over several feet or several thousands of feet and are usually caused by an anomalous distribution of magnetic minerals or by iron objects or cultural features which may be of interest. The anomalies from naturally occurring rocks and minerals are due chiefly to the presence of the most common magnetic mineral, magnetite (Fe Fe_2O_3), or its related minerals, ulvospinel, titanomagnetite, maghemite, etc. which will collectively be referred to as magnetite, a dark, heavy, hard and resistant mineral. The rust-colored very common forms of iron oxide are not usually magnetic and are seldom related to the source of magnetic anomalies. Other magnetic minerals which occur to a far lesser extent are ilmenite, pyrrhotite (with sulphide mineralization), and others of even lesser consequence.

All rocks contain some magnetite from very small fractions of a percent up to several percent, and even several tens of percent in the case of magnetic iron ore deposits. The distribution of magnetite or certain characteristics of its magnetic properties may be utilized in exploration or mapped for other purposes. Iron objects in the earth's magnetic field, whether something buried or intentionally planted for subsequent retrieval, would also create a detectable magnetic anomaly. Cultural features associated with man's habitation can frequently be detected through magnetic surveys owing to the contrast in magnetite associated with numerous artificial features such as man-made structures, voids, or the enhanced magnetic effects of baked clays and pottery (see Chapter VII).

Induced Magnetization

Magnetic anomalies in the earth's magnetic field are caused by two different kinds of magnetism: induced and remanent (permanent) magnetization. Induced magnetization refers to the action of the field on the material wherein the ambient field is enhanced and the material itself acts as a magnet. The magnetization of such material is directly proportional to the intensity of the ambient field and to the ability of the material to enhance the local field—a property called magnetic susceptibility. The induced magnetization is equal to the product of the volume magnetic susceptibility, k, and the earth's or ambient field intensity, F, or

$$I_i = kF$$

where I_i is the induced magnetization per unit volume in cgs electromagnetic units, and F is the field intensity in gauss. (Note: in some texts, the specific magnetic susceptibility or susceptibility per unit weight (gram) is used) For most materials, k is much less than 1 and, in fact, is usually $\pm 10^{-6}$ cgs or smaller. If k is this small and positive, the material is said to be paramagnetic and, when negative, diamagnetic. For magnetite, *k is approximately 0.3 cgs* and is ferrimagnetic while for iron alloys, k may vary between 1 and 1,000,000, and such materials are called ferromagnetic. Both ferrimagnetic and ferromagnetic susceptibility are also a function of the field intensity in which they are measured. In all cases, in this Manual, the field intensity is assumed to be the ambient earth's field intensity between 0.3 and 0.6 gauss.

A parameter similar to k is the magnetic permeability, μ, which is the ratio of the magnetic induction, B, to the field intensity, F (Magnetic induction is the magnetization induced in the material). B includes not only the magnetization of the material, but also the effect of the field itself and is expressed by

$$B = F + 4\pi I$$

where B is in gauss. Therefore as stated above,

$$\mu = \frac{B}{F}$$

and

$$\mu = 1 + 4\pi k$$

Thus when k is very small, as in air, $\mu \approx 1$ and when k is 0.1 or larger μ is generally one order of magnitude larger. The susceptibility k can be thought of as the *absolute* ability and μ the *relative* ability of a material to create local magnetization. The measurement of permeability is most often used for materials where μ is much greater than 1, typically iron, steel and other ferromagnetic alloys.

Inasmuch as magnetite and its distribution is of such great importance for a number of these applications, it is important to understand its relation to common rock types. The susceptibility k of magnetite was given as approximately 0.3 cgs which may actually vary between 0.1 and 1.0 depending upon its grain size and other properties. The magnetic susceptibility of a rock containing magnetite is simply related to the amount of magnetite it contains. For example, *rock containing 1% magnetite will have a volume susceptibility of 3 x 10^{-3} cgs*, etc. Typical susceptibilities of rocks are given below, but may vary by an order of magnitude or more in most cases:

altered ultrabasic rocks	—10^{-4} to 10^{-2} cgs
basalt	—10^{-4} to 10^{-3}
gabbro	—10^{-4}
granite	—10^{-5} to 10^{-3}
andesite	—10^{-4}
rhyolite	—10^{-5} to 10^{-4}
shale	—10^{-5} to 10^{-4}
shist and other metamorphic rocks	—10^{-4} to 10^{-6}
most sedimentary rocks	—10^{-6} to 10^{-5}
limestone and chert	—10^{-6}

Typically, dark, more basic igneous rocks possess a higher susceptibility than the acid igneous rocks and the latter, in turn, higher than sedimentary rocks.

Remanent or Permanent Magnetization

The remanent or permanent magnetization, I_r, (the former ascribed to rocks, the latter to metals) is often the predominant magnetization (relative to the induced magnetization) in many igneous rocks and iron alloys. Permanent magnetization depends upon the metallurgical properties and the thermal, mechanical and magnetic history of

the specimen, and is independent of the field in which it is measured. Magnetite may have a remanent magnetization, I_r, of perhaps 0.1 to 1.0 gauss, ordinary iron may have a permanent magnetization between 1 and 10, and a permanent magnet may be between 100 and 1,000 gauss or larger. Chapter VI will describe simple methods for measuring both the remanent and induced magnetizations and the magnetic susceptibility of rocks and miscellaneous objects. Chapter VII more fully describes the magnetization of iron objects.

The remanent magnetization is of great importance in mapping and interpretation, and in the fields of paleomagnetism, archaeological exploration, and archaeomagnetism. The remanent magnetization of magnetite is as stated, independent of the present earth's field. By and large, the high values of remanent magnetization are related to the effects of heating, whether naturally heated, as in the case of igneous rocks, or artificially heated, as in the case of baked clay, pottery, and other man-made objects found in archaeological sites. Prior to such heating, small regions, called domains, within each magnetite crystal would be more or less randomly-oriented. During heating, particularly at high temperatures, the domains reorient themselves, which upon cooling, tend to align themselves more or less in the direction of the ambient magnetic field and thus parallel to each other, thus creating a net magnetization fixed with respect to the object. This remanent magnetization may be as much as 10 or more times greater than the induced magnetization for many rock types. Thus, the net magnetization might be considerably higher than would be indicated merely by consideration of the susceptibilities listed above.

The remanent magnetization of a rock or object may or may not be in the same direction as the present earth's field for the object may have been reoriented and because the earth's field is known to have changed its orientation in geologic and even historic time. Rocks are frequently reversely magnetized so that measurement of this remanent magnetization is a useful aid to interpretation if the rocks which produce an observed anomaly are, indeed, accessible. The fields of paleomagnetism and archaeomagnetism in particular depend upon the precise determination of the orientation of the 'frozen paleofield' as it is measured in a given rock or other specimen, and methods for measuring such will be described in Chapter VI.

IV.

FIELD PROCEDURES AND DATA REDUCTION

Magnetic Cleanliness and Sensor Positions

Most of the applications for portable magnetometers require that *the operator be relatively free of magnetic materials on his person.* The importance of checking oneself cannot be over-estimated if measurements on *the order of 1 gamma are desired. In field surveys,* the usual magnetic material one may have may include, of course, the obvious such as a rock pick, Brunton compass, pocket knife, or instrument console and the not-so-obvious effects of the pivot in eyeglasses, the pants clip at the top of men's trousers, the light meter in a camera, the magnet in the speaker of a tape recorder, metal in a clipboard, some mechanical pencils, some keychains, and the steel shank in one's shoes or boots. Of course, some of these items cannot be altered or left behind and some are not significant in any event. The sensor itself should be kept clean to avoid possible contamination by magnetite-bearing dirt on the sensor surface. In order to check the 'heading effect', i.e., the effect of orientation on the observed field intensity during a field survey, the operator can take readings at each of the four cardinal directions while pivoting about the position of the sensor and note the changes. If the maximum change is typically less than 10 gammas, the average readings on a line will probably not be affected by more than 5 gammas and individual readings by less than this inasmuch as readings along the profile are more-or-less along a given heading ± perhaps 30° about one orientation. If a sensitivity of 1 gamma is desired, the heading error should be less than several, preferably 2 gammas or less and depending upon the desired sensitivity, the operator should make some effort to face in the same direction, if possible, for all readings on a given traverse.

The sensor for a proton magnetometer may be carried on a 8-foot (2.2 meter) staff, on a backpack, on an extended staff to 12 feet (4 meters) or more as necessary, or by a second person as represented in *Figure 8.* The sensor on an 8-foot staff is by far the most common means for field measurements removing the sensor sufficiently far from the console and from the operator so as not to be much affected by normal items of clothing, etc. The purpose of mounting a sensor on an extended 12 foot or longer staff is to remove the sensor from the locally disturbing effects of highly magnetic surface materials, such as surface laterite, glacial till, or highly magnetic outcropping rocks. The sensor may also be raised in the case of very high magnetic gradients which would otherwise ruin the magnetometer signal and prevent any reading whatsoever (see following sections). An additional reason for an extended staff will be described in Chapter VIII in reference to vertical gradient measurements. There are also occasional reasons for a second person carrying the sensor while the first person carries the console together, perhaps, with magnetic or other materials that must necessarily be on his person such as pick, tape recorder, another instrument or rock samples.

The sensor may be carried in a backpack pouch for more convenient field operation where 5 or 10 gamma sensitivity is all that is desired, but care should be taken to check the effects of the batteries and console (particularly the very magnetic alkaline batteries). The backpack pouch frees the hands for taking notes, pushing aside the underbrush and, in general, balances the load of the console and decreases fatigue.

Operational Considerations

Valid Readings Vs. Noise

It is important to establish that, in fact, the magnetometer is providing valid readings. The simplest means of confirming that what is being observed is a magnetic field reading and not random, meaningless instrument readings (i.e., noise) is to take several readings in succession in one location without moving anything, and note the repeatability. Successive readings should be within ± 1 gamma, ± 0.25 gamma or ± 1 count for whatever the sensitivity setting. Valid readings should not, under any naturally-occurring circumstances including magnetic storms, vary by as much as ± 10 or ± 100 gammas in a few seconds; if such is observed, the readings represent either noise or a degradation of the signal-to-noise ratio with the observed corresponding loss in terms of sensitivity. Under certain circumstances even successive readings repeating to within several gammas may still represent noise. To confirm that these readings are indeed magnetic field, simply 'kill' the signal by placing,

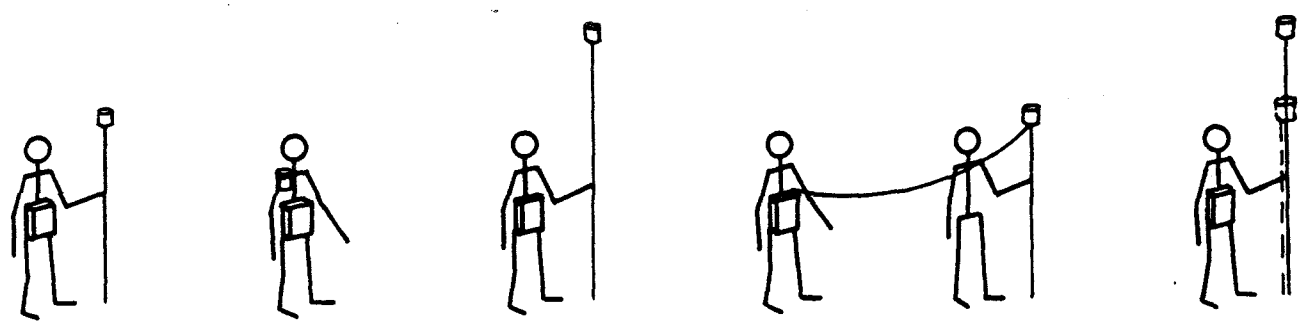


Figure 8. Sensor Carrying Positions

momentarily during the reading, something magnetic adjacent to the sensor such as one's shoe, watch, certain rocks, etc. Random readings varying by 10 or 100 gammas or more would then be observed in addition to their deviating considerably from the readings without the object present. Another but less certain method is to take readings at intervals of increasing distance from an object or location known to produce a magnetic anomaly.

Typical reasons for a proton magnetometer not producing valid readings may be: electrical noise from AC power lines, transformers or other radiating sources; high magnetic gradients from underlying rocks, nearby visible or hidden iron objects, fence lines or improvised iron hardware improperly used near the sensor; improper orientation of the sensor (even when 'omni-directional'); expired batteries, incorrect range setting or instrument failures, broken or nearly broken sensor cable, and other malfunctions usually described in the instrument operating manual.

Valid but distorted readings may result from several other conditions including the above effects of high magnetic gradients, magnetic dirt or other magnetic contamination on the sensor and any magnetic bias on the operator. Time variations (Chapter III and following) and the effects of direct current in distant power lines and trains (Chapter IX) can also distort magnetic observations.

Sensor Orientation

According to the theory of operation of the proton magnetometer, *the total intensity, measured as the frequency* of precession, is independent of the orientation of the sensor. The *amplitude* of the signal, however, does vary (as $\sin^2\theta$) with the angle between the direction of the applied field within the sensor and the earth's field direction. Variation of signal amplitude does not normally affect the readings unless there is simply insufficient signal to be measured accurately, i.e., a minimum signal amplitude is required above which a variation in amplitude does not affect the readings.

Ideally, the applied field in the sensor should be at right angles to the earth's field direction. The direction of the applied field is governed by the configuration of the polarizing coils in the sensor which are commonly either solenoids (cylindrical) or toroids (ring or doughnut-shaped). The solenoid produces an applied field parallel to its axis, whereas the toroid produces a field which is ring-shaped about the axis of the toroid (consult the instrument operations manual to determine the direction of these axes with respect to the sensor housing). Solenoids are used because they produce somewhat higher signal than a toroid and are less perturbed by electrical noise, whereas a toroid is inherently omnidirectional. In the ideal case, a solenoid should be held horizontal and in any direction in a vertical field, and should be held vertical in a horizontal (equatorial) field for maximum signal amplitude. A toroidal sensor should be held with its axis vertical in a vertical field, and pointing north in an equatorial field to obtain maximum signal. A field which dips greater or less than 45°, should be treated as though it were a vertical or horizontal field respectively.

Instrument Readings

Measurements are normally made at regular intervals along a grid or otherwise selected path whose locations are noted for subsequent plotting. Simple pacing is usually adequate with readings every 6, 10, 50, 100, 500, or even 1,000 feet (2 to 300 meters), as anomalies, field, and either geological or search requirements dictate. Traverses may be selected along pathways or other accessible routes and occasional locations noted on an aerial photograph or map using paced distances in between. The density of readings along the traverse should be related to the wavelength of anomalies of interest such that several readings are obtained for any such anomaly. A single trial line with relatively dense stations is usually attempted first to determine the required station density. It is important never to hold the magnetometer sensor within one or two feet of the ground, if possible, in order to avoid effects of minor placer magnetite which usually collects on the surface of the ground, and also to avoid the effects of microtopography or outcropping rock surfaces.

Readings may be noted in a field notebook or, if desired, on a miniature tape recorder, but care must be taken to magnetically compensate the speaker magnet and motor following the theory given in Chapter VI if one is to use a recorder. The convenience of the recorder is *that only one hand is needed and the data may be* played back for fast, convenient plotting.

Correction for Time Variations

Some ground magnetic surveys require correction for diurnal and micropulsation time variations. Correction is required if the anomalies of interest are broad (thousands of feet) and typically less than 20 to 50 gammas, or if the profile lines are very long, or if the objective of the survey is a good magnetic contour map expressive of deep-seated anomaly sources. Also, if the survey is performed in the high magnetic latitudes in the auroral zone where typical micropulsations are 10 to 100 gammas, correction for such variations would be necessary. On the other hand, if one is merely interested in profile information of anomalies of several hundred gammas or if the anomalies are only 20 gammas but can be traversed completely in less than 5 minutes, no time variation correction is needed. Perhaps *most surveys* fit the latter criteria and *do not actually require any such correction for time variations.*

The simplest method of correcting for time variations involves repeated readings in the same orientation at the same station at different times during the survey. If a smooth curve is drawn through the readings plotted as a function of time (every hour or so), these values can be subtracted from all other readings provided that each reading also includes the time at which it was observed. To avoid an extremely long and repeated walk to a single reference station, it is also possible to 'double-back' to take a second or third reading on each given traverse to determine at least the time variations for that traverse. Still another technique is to emulate what is done on aeromagnetic surveys, namely, obtain rapidly acquired measurements on tie lines or lines which cross the principal traverse lines at each end and perhaps in the center. The stations common to each traverse and tie lines should be known and occupied while facing the same direction to avoid heading errors. The simplest method for using these tie lines is to make each intersection agree by linearly distributing the error on each traverse line and holding the tie line values fixed—provided the tie line data were acquired rapidly.

A local recording base station, i.e., diurnal station monitor, is the most ideal method and certainly the most accurate for removing time variations. The time variations can readily be removed from each reading, again assuming that the time is noted for each reading on the traverse to within a minute or so of the base station. The base station should not be further away than 100 miles from the area of the survey for agreement within a few gammas and should be positioned more than 200 feet away from local traffic and other disturbances (see Chapter VII). The diurnal base station, if left to continue recording during each evening, can indicate magnetic storms in progress and may be examined at the start of a survey day to determine if any useful measurements can actually be obtained during such conditions. During a magnetic storm, it is best not to obtain field data with the objective of removing the storm variations as the survey magnetometer and base station may not agree better than 5 or 10 gammas.

High Magnetic Gradients

In the case where an extremely high magnetic gradient destroys the signal as evidenced by successive non-repeating measurements, it may be necessary to raise the sensor up to 10 or 12, sometimes 15 feet in order to move the sensor to a region of lower gradient. This will only happen over outcropping or nearly outcropping large masses of perhaps altered ultrabasic rocks, magnetic iron ore deposits or ore bodies containing a large percent of pyrrhotite and in the near vicinity of buried iron objects in the applications for search. Such an event would only occur if the gradient exceeds several hundred gammas per foot. If the span of high gradient is not too wide, it may not actually be necessary to obtain measurements precisely at the highest gradient. Measurements on either side of the anomaly can be extrapolated or be used to at least indicate the contacts of such a highly magnetized formation. Furthermore, as the signal disappears and the readings diverge considerably from ± 1 or 2 counts, it may be worthwhile to note approximate indications of magnetic field gradient which on some instruments is displayed on the front panel as signal amplitude (which is a function of gradient). In areas of highly magnetic surface conditions, as noted in a previous section but where a signal is still obtained, another alternative in acquiring meaningful data other than that of using an extended staff would be to make 2 to 5 measurements per station, for example, at the points of a cross centered at the actual primary station location. The average of these readings would later be used to draw a profile. In this way, some of the surface noise is averaged out.

In the absence of anomalous surface conditions and for reasons more fully described in Chapter VIII, it may be useful for both geological and search applications to measure the vertical gradient of the total field. The vertical gradient is obtained by making 2 total field measurements, one over another, taking the difference in the readings and dividing by the distance between them.

Data Reduction

The profiles when plotted should be smoothly varying and expressive of the anomalies of interest. (NOTE: The nature of the disturbances or anomalies of interest, their width, character, signature, and amplitude are discussed in Chapter V, following.) Should there be an excessive amount of such geologic/magnetic noise, at a wavelength much shorter or much longer than is of interest, it is possible to apply simple filtering or smoothing techniques to facilitate interpretation of the profile. As a rule of thumb, *never remove or filter out anomalies whose wavelength is on the order of the depth to sources of interest.* A number of advanced techniques for data enhancement or filtering as employed in airborne surveys or well-gridded ground surveys will not be discussed within the scope of the Manual but are listed to acknowledge their existence: vertical derivatives, upward and downward continuation, reduction-to-the-pole, bandpass filtering, trend surface filtering, spectral analysis, trend enhancement, magnetization filtering, and others most of which are applied to two-dimensional data.

Profile Smoothing

Anomalies of very short wavelength (much shorter than the probable depths to sources of interest) may be present and caused by the magnetic effects of the magnetometer operator, or simply by surface magnetization contrasts in the surface or near-surface materials as mentioned earlier. In removing such effects, the eye itself tends to enhance what one is seeking. Another simple and obvious method is of course to pencil or trace through the noise. A more objective technique is to apply a running average or weighted running average to the data (see Figures 9 and 10). For a 3-point weighted

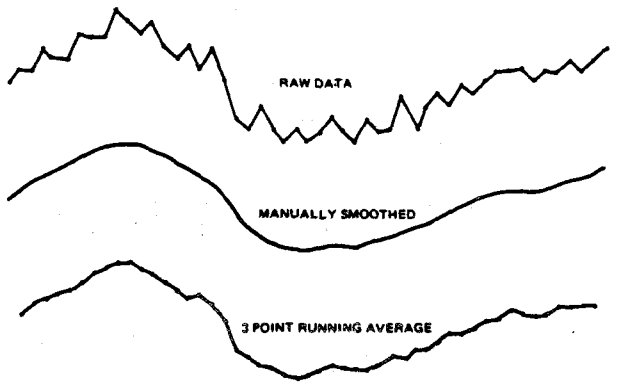


Figure 9. Profile Smoothing

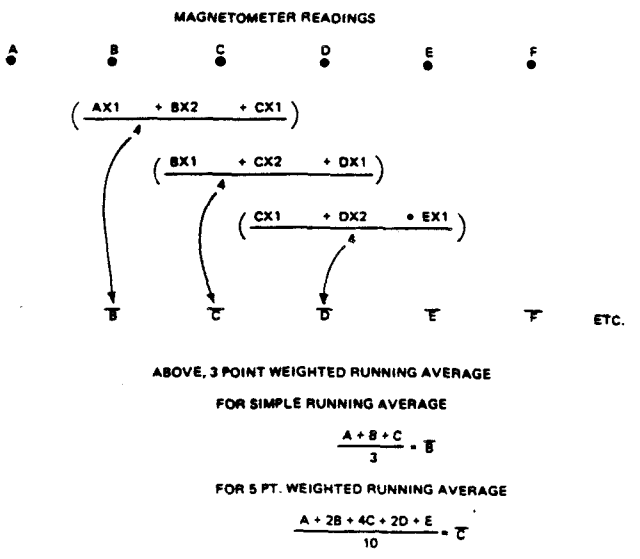


Figure 10. Running Averages

running average, for example, one would multiply the value at a given station by 2, add the values of the two adjacent stations, divide the sum by 4. This value is then set aside for that station for later recompilation of a new profile while advancing to the next station to perform the same procedure *(see Figure 10)*. A 5-point running average might utilize a weighting factor of 4 for the central point, 2 for each adjacent point, and 1 for the outside points while dividing by 10 to obtain the averaged value. More sophisticated techniques are also possible such as polynomial curve fitting, least squares, digital bandpass filtering, etc. The number of points or interval over which the averaging or filtering is to be performed for removal of such 'noise' should be much shorter (perhaps $1/5$ to $1/10$) than the anomalies of interest.

Removal of Regional Gradients

In most cases, the anomalies of interest usually appear superimposed on a much broader anomaly which is not of interest. This broader anomaly, or regional gradient, due to the main earth's field or very deep or distant sources, may appear simply as a component of slope in the curve and although it is subjectively determined, is often removed from the data in order to better examine the anomaly. This gradient is removed from a single profile as shown by *Figure 11* by drawing a straight line or broadly-curved line through the non-anomalous portions of the curve. The values are then subtracted at each station and replotted to present the 'residual' values, hopefully expressing only the anomalies of interest which in this case would be the anomalies occurring at the shallower depths. The vertical gradient, measured according to the methods prescribed in Chapter VIII, also serves to remove or largely reduce the regional gradient.

Contour Maps

Most survey traverses are not sufficiently close nor well-arranged in plan to allow the compilation of a contour map. Such is usually the case when only mineral exploration data are desired, in broad reconnaissance surveys, or when surveying in extremely rugged terrain where large areas are otherwise inaccessible. Profiles are, in fact, usually adequate particularly for anomaly sources with very long, horizontal dimensions. Contour maps are nevertheless useful in cases where little is known of the geology or magnetic sources, where the anomaly sources are either small or extremely large, or for ascertaining, on a more objective basis, the distribution of the anomalous masses or very subtle longer wavelength features. Many surveys for search also require broad coverage and perhaps contour map presentation. An alternative to the construction of contour maps for broad two-dimensional coverage is the presentation of 'offset profiles' or profiles plotted on abscissae which also serve to show the location of the traverse lines drawn on a map.

Constructing a contour map requires that large effects from diurnal variations or the heading effects, if any, be removed; that is, that there be a single datum level for all traverses or readings. The process of removing the regional gradients, as described above, frequently serves to remove these other sources of errors as well and is satisfactory as long as one is not interested in the longer wavelength anomalies removed as part of the gradient.

The following guide should be useful to one not familiar with the techniques of constructing a magnetic contour map, or plan view of the anomalous total intensity. A contour or iso-intensity map is analogous to a topographic map and is a map on which are drawn lines (contours) of equal intensity, at convenient and regular intensity intervals, as would be observed were a magnetometer used to occupy every point on the surface of the ground. The contoured values are at best extrapolations and interpolations across areas where measurements are not actually taken. Such a map is drawn with the knowledge that the magnetic field is smoothly

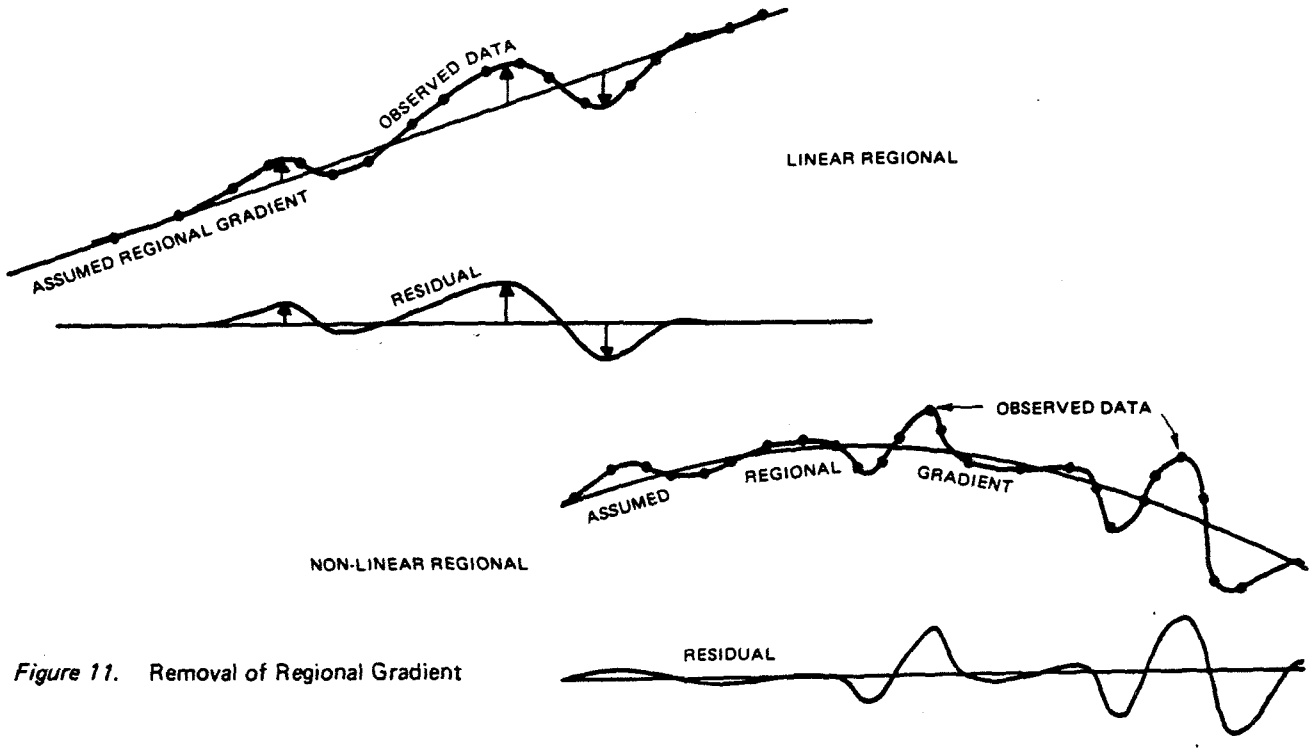


Figure 11. Removal of Regional Gradient

varying and on the assumption that one is interested only in broad features expressed by such a map. Features much smaller than the spacing between adjacent traverses should be examined on a profile basis only and should not be sought nor included on a map presentation.

Construction of a Contour Map

Given a set of readings obtained on a traverse, the time variations, if significant, should be removed, perhaps the regional gradient removed and the profiles smoothed. Values are then selected from these smoothed profiles at widely-spaced intervals not less than, say, ½ or ¼ the spacing between adjacent traverses or at similarly spaced but significant points on the profile, namely, maxima, minima, inflection points, etc. In other words, the values to be contoured should be more-or-less equally distributed in plan view. Anomalous features which 'obviously' extend across several traverses might be included also. The total intensity values thus selected and representative of the principal features are posted at their proper locations on a base map made of material which will support numerous erasing of penciled lines and including references to location.

Examine the dynamic range of the values and select 5 or 10 intensity levels through this range at convenient values such as every 20, 100, or 1000 gammas. Draw these contours according to the instructions below and then fill in the intermediate contour lines, i.e., every 10, 50, or 500 gamma contours, depending upon which coarse valuse above were originally selected, until contours appear in all segments of the map. Magnetic intensity values and contours should, in theory, be smoothly varying and should thus be smoothed at the later stages of contouring by removing sharp bends or corners. After such smoothing, other contour lines as needed to cover the map adequately are carefully drawn between the fair-drawn contours and appropriate labels applied. In areas of steep gradients, only a few coarse contour lines are drawn to avoid numerous and insignificant fine details. Since closed contours (closures) appear the same for maxima and minima, they are differentiated by applying hashure marks or other indications on the inside of the minima.

The position of the various contours is selected by manually (eye and mental calculation or by using proportional dividers, although not really necessary) interpolating linearly between all the neighboring values as shown in *Figure 12*. In this case, it was decided to draw contours at 10 gamma intervals. The contour line near data point value 91 would subsequently be smoothed to pass through this data point following the guidelines given above.

Contour lines should never cross nor pass between pairs of data points which are both higher or both lower than the value of the contour. Also in some regions of zero or near zero gradient such as at a saddle point (region between two adjacent maxima or minima), there exists an ambiguity in the direction of the lines. However, it does not matter under such conditions which of the two possible sets of contours are drawn.

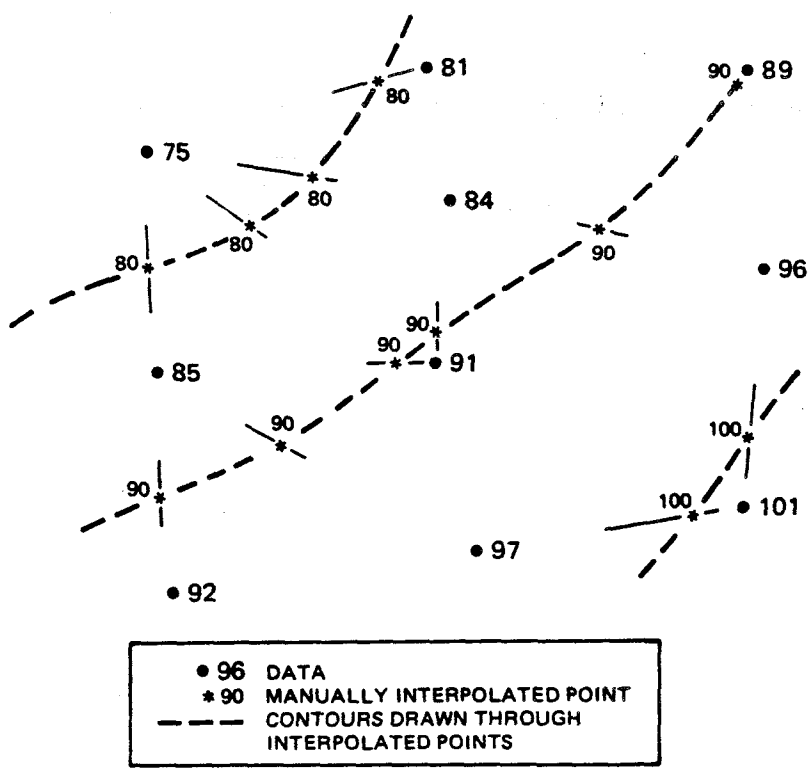


Figure 12. Interpolation and Contouring

V.

INTERPRETATION

Introduction

Total magnetic intensity disturbances or anomalies are highly variable in shape and amplitude; they are almost always asymmetrical, sometimes appear complex even from simple sources, and usually portray the combined magnetic effects of several sources. Furthermore, there are an infinite number of possible sources which can produce a given anomaly. The apparent complexity of such anomalies is a consequence of the net effect of several independent but relatively simple functions of magnetic dipole behavior. With an understanding of these individually simple functions however, and given some reasonable assumptions regarding the geology, buried object or whatever other source one is seeking to understand, a qualitative but satisfactory interpretation can usually be obtained for most anomaly sources.

The interpretation, explanation and guide presented here is directed primarily towards a qualitative interpretation for both geological reasons as well as search applications, i.e., an understanding of what causes the anomaly, its approximate depth, configuration, perhaps magnetite content or mass, and other related factors. But even if qualitative information is derived from the data, it is important to have applied a reasonable amount of care in obtaining precise measurements. Quantitative interpretations are possible, but are applied more to airborne data, entail relatively complex methods for depth determination, and are the basis for a relatively large body of literature on the subject, references to which are given in the Manual.

An anomaly represents a local disturbance in the earth's magnetic field which *arises from a local change in magnetization, or magnetization contrast* as it is termed. A profile, for example over a very broad uniformly magnetic surface, although magnetic itself, will not exhibit a magnetic anomaly as there is no local change in magnetization. A local increase or even decrease on the other hand would constitute such a change and produce a locally positive or negative anomaly.

The observed anomaly expresses only the net effect of the induced and remanent magnetizations which usually have different directions and intensities of magnetization. Since the remanent magnetization is so variable and measurements of its properties seldom made, *anomalies are all interpreted* in practice as though *induced magnetization were the total source of the anomalous effects.*

Asymmetry

The asymmetrical nature of total field anomalies is primarily a consequence of the directions of the field lines of the locally created magnet or source and the earth's-field-component nature of a total field magnetometer in the usually-inclined direction of the earth's magnetic field. Recall that a total field magnetometer measures only the component of any local perturbation which is in the direction of the earth's magnetic field at that point. Anomalies in the earth's field, whether created by induced or permanent magnetization, exist as arrangements of magnetic dipoles, monopoles (effectively), lines of dipoles and monopoles and sheet-like distributions of such poles. It is important therefore to understand the nature of the dipole or monopole field as it will be shown that a summation of such elementary forms will explain the most complex characteristics of anomalies and facilitate their interpretation. Notice, for example in *Figure 13*, the con-

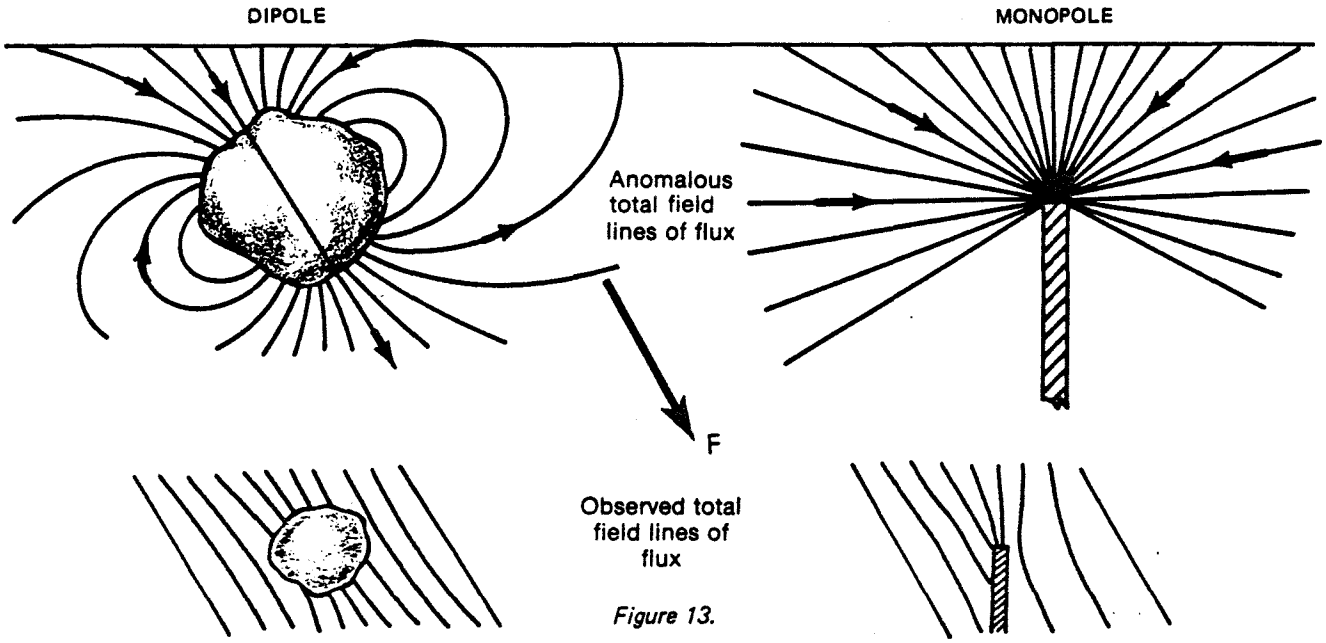


Figure 13.

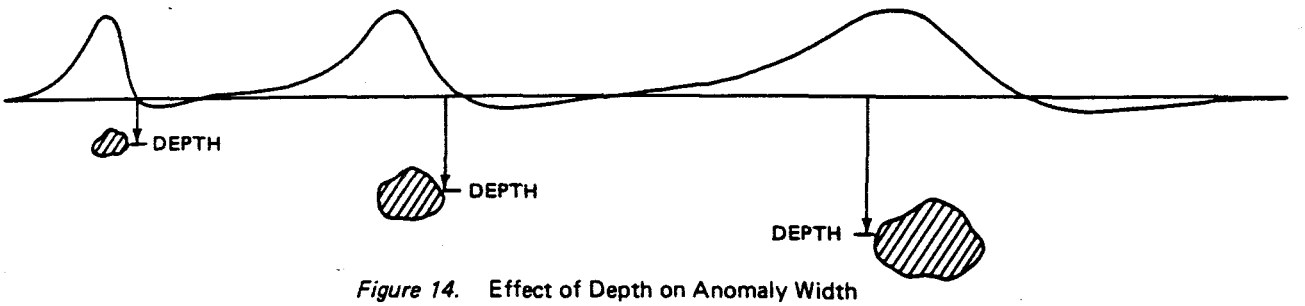


Figure 14. Effect of Depth on Anomaly Width

figuration for such fields as they would appear if one were to measure the direction of the anomalous field.

Depth Dependence

Another significant characteristic of a magnetic anomaly is its variation with the depth between the magnetometer and source, the deeper the source, the broader the anomaly as expressed in *Figure 14.* It is this property which enables one to determine the approximate depth to the source independent of any other information concerning the source. *If one familiarizes himself with only one subject in this discussion on interpretation, it should be the general characteristics of anomaly wavelength, or width, as a function of depth.* A knowledge of this subject allows rapid and easy interpretation of anomalies of interest when numerous anomalies arising from various depths appear in the observed total intensity profile.

Other Anomaly Shape Factors

Other factors which affect the anomaly shape and amplitude are the relative amounts of permanent and induced magnetization, the direction of the former, and the amount of magnetite present in the source compared to the adjacent rocks. The actual configuration of the source, that is, whether it is narrow, broad or long in one dimension and its direction in the earth's field, also control the anomaly signature.

Geological Models

Geological anomalies are interpreted in terms of much simplified geological models which very much facilitate interpretation procedures. The first simplification is the assumption that magnetization is uniform within some elementary prismatic form and that the magnetization is different outside this form, i.e., there is a magnetization contrast. Typical of the kinds of geologic sources that are assumed to cause anomalies are those which are shown in *Figure 15.*

As was stated, in any potential field method the given magnetic signature can be produced by an infinite combination of sources so that there is no unique interpretation. For example, the same anomaly could be produced by the peculiar distribution of magnetite (unrealistic geologically), and a uniform distribution of magnetite within the prismatic form (realistic), both of which are shown in *Figure 16.* It must be emphasized that not only are simplifications required, but a reasonable geologic framework must be used as a guide when considering the various possible sources. A typical set of anomaly signatures of various sources might appear as in *Figure 17.*

Elementary Dipoles and Monopoles

Since anomalies are explained herein in term of various arrays of dipoles and monopoles, it is important to examine their geometry and intensity characteristics. A magnetic dipole produces a field with imaginary lines of flux as shown in *Figure 18.* The intensity of the field, which is proportional to the density of the flux lines is drawn as lines of equal intensity to express this relationship. From *Figure 18,* notice that 1) the intensity of the dipole is twice as large off the ends of the dipole as it is at the same distance off the side of the dipole. This explains, for example, why the earth's magnetic field is approximately 30,000 gammas at the magnetic equator and 60,000 gammas at its poles; 2) the direction of the field off the side of the dipole is parallel to the dipole itself, but opposite in sense; 3) the direction of the tangent of the field lines of a dipole are parallel along any radial line from the dipole.

A monopole has field lines which point radially in or out from the positive or negative monopole respectively. The intensity is constant at a given distance and any direction from a monopole. In actual fact, there are no magnetic monopoles, but only dipoles whose ends are far apart. For all practical purposes, however, monopoles exist in terms of the distance to the source and such geological configuration as shown in *Figure 13.*

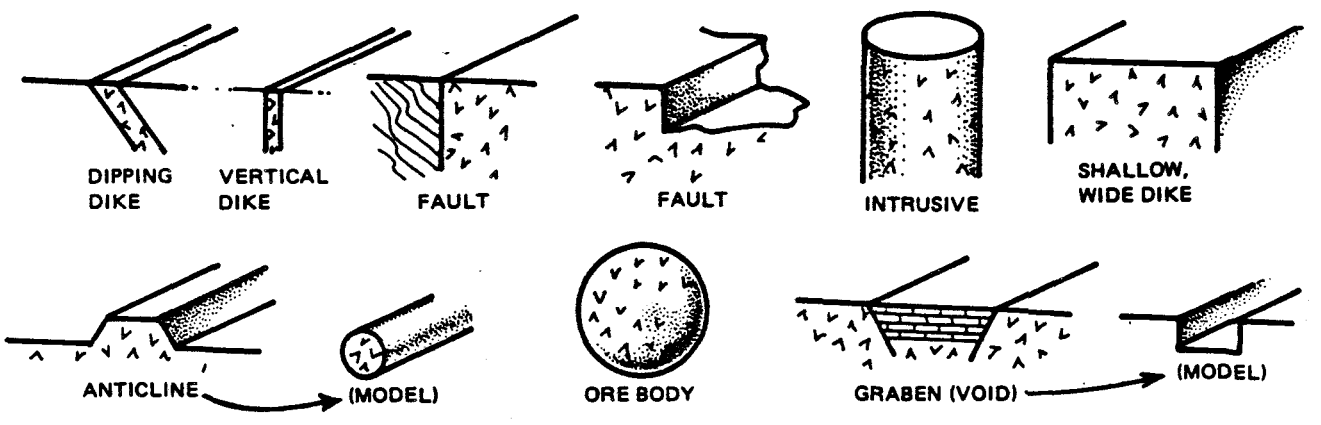


Figure 15. Geological Model Representations of Common Magnetic Anomaly Sources

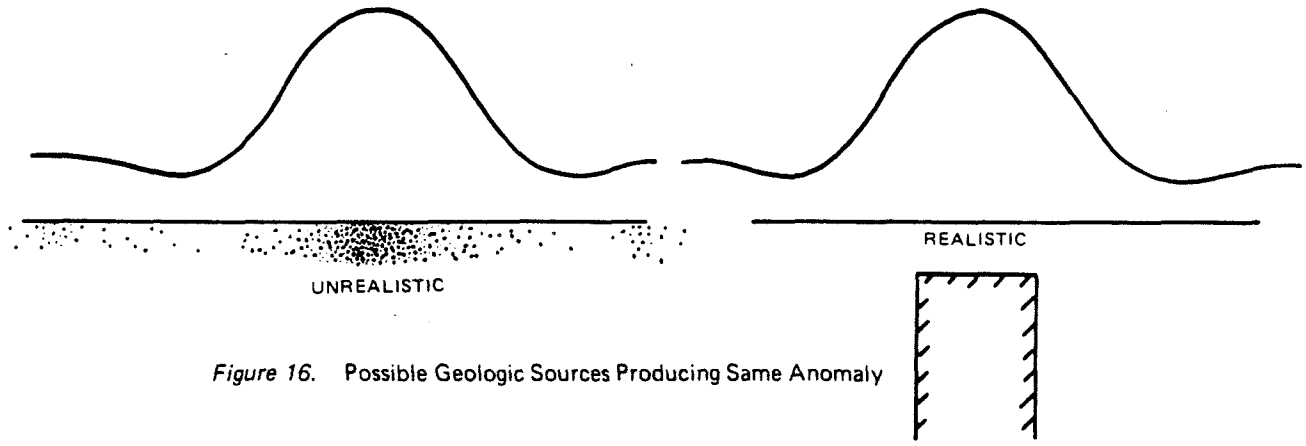
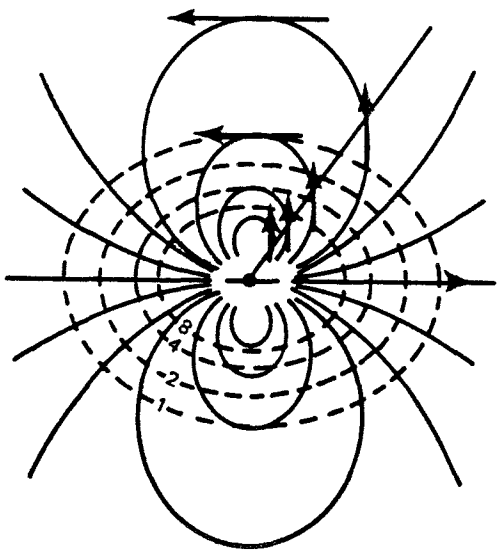


Figure 16. Possible Geologic Sources Producing Same Anomaly



LINES OF FLUX (——)
AND
LINES OF EQUAL INTENSITY (— —)
FOR A DIPOLE

Figure 18.

Having outlined the qualitative geometry of the intensity T from a dipole, the quantitative aspects can be considered as follows:

The intensity, T, from a dipole can be expressed as

$T = \frac{2M}{r^3}$ along the axis, i.e., off the end of the dipole,

and $T = \frac{M}{r^3}$ along a line at right angles to the dipole,i.e., off the side of the dipole,

and for a monopole

$T = \frac{M}{r^2}$ in any direction from a monopole, where M = magnetic moment and r is the distance to the pole. A more detailed mathematical formulation for the intensity due to a dipole is given subsequently in this Chapter.

Simplified Method for Total Field Signature

From the above description of a dipole and monopole and with the knowledge of the earth's-field-component-nature of the total field magnetometer, it is possible to sketch the signature of an anomaly for any given orientation of the dipole (orientation caused by field direction, the direction of remanent magnetization, or by the configuration of the geology). It is helpful to draw such signatures at various inclinations of the magnetic field to understand where the sources would be located with respect to the signature, the dip of the magnetization producing the anomaly, and even for information related to the depth of the source. Remember that all anomalies can be considered as caused by various distributions of dipolar and monopolar sources and it is possible to produce any anomaly simply by the super-position of such dipole or monopole signatures derived here.

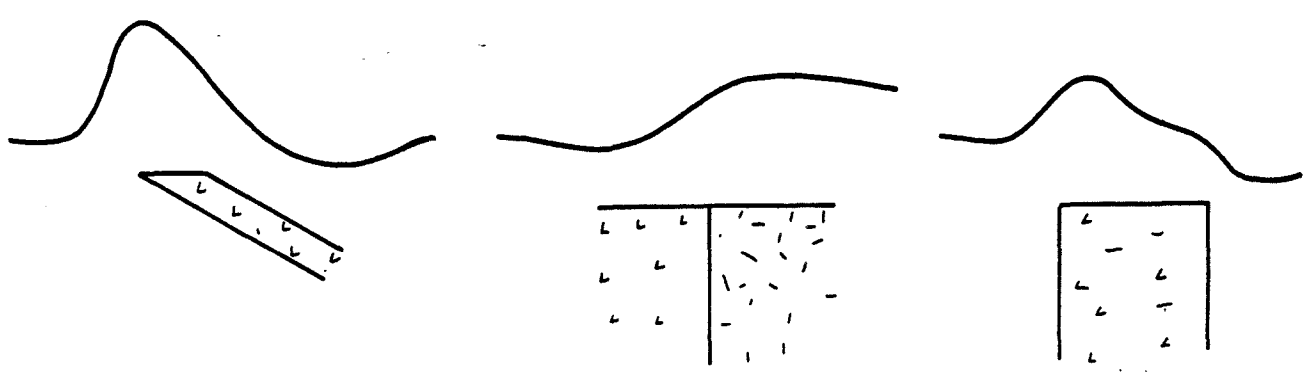


Figure 17. Typical Anomalies for Simple Geologic Models

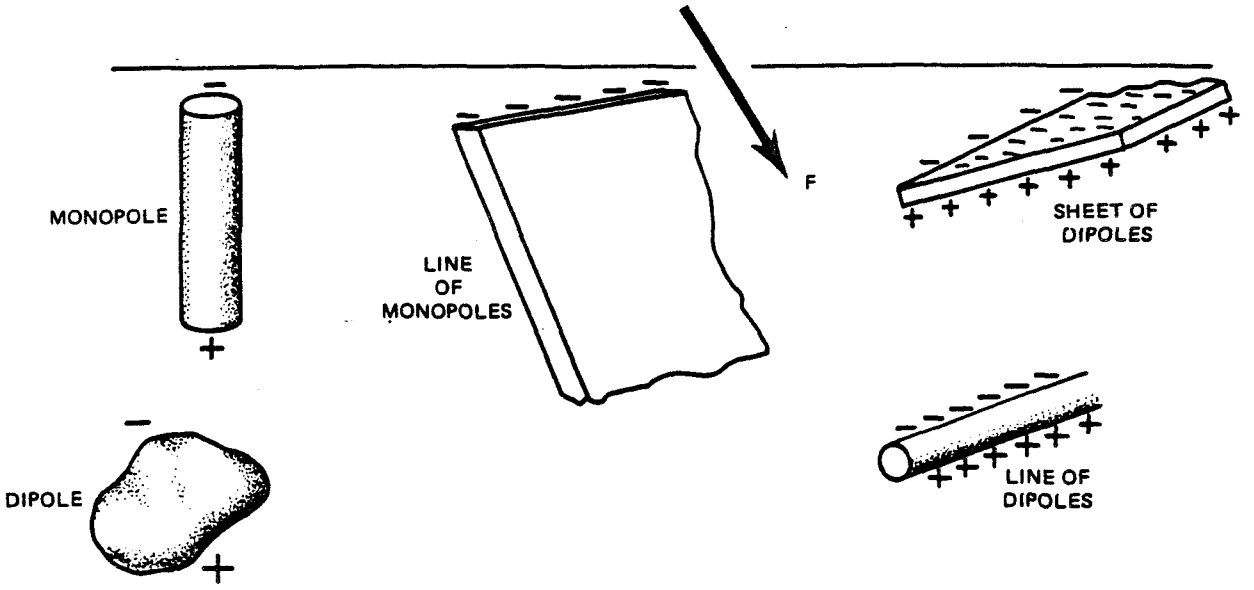


Figure 19.

Earth's Field Component Behavior

This method of predicting or drawing the anomaly signature depends upon one property of the field, namely, inclination, and three properties peculiar to the dipole or monopole source, whichever is assumed. The dip of the earth's field is first considered because this is the direction, the only direction, of the components of any local magnetic anomalies which are measured by a total field magnetometer. (If one is using a vertical component magnetometer, this guide still applies except that instead of using the earth's field as the direction of measurement, simply use the vertical.) In other words, the magnetometer will only measure the component of a local perturbation in this direction, i.e., as projected into this direction. See *Figure 20.*

Dipoles vs. Monopoles vs. Arrays of Poles

The decision to use dipoles, monopoles, or other configurations as the model is based upon the manner in which the earth's field induces a local field and this in turn depends upon the configuration of the geologic body which exhibits the magnetization contrast and the direction of the field. For example, a long body which nearly parallels the earth's field will tend to be magnetized along its long dimension. Furthermore, if the body is sufficiently long with one end near the magnetometer, the anomaly will appear as a monopole seeing only the upper pole with the lower pole removed effectively to infinity. If the same long, thin body were normal to the field, it would then be magnetized through its thinest dimension producing the sheet-like array of dipoles as shown in *Figure 19.*

One may wish to draw on the typical models depicted in *Figure 15,* the array of poles from a uniform earth's field at various inclinations and orientations of the source. Whether the monopoles or the dipoles (and its equivalent line or sheet distributions) are close or far apart, determines if the model is to be considered a dipole or monopole, respectively *(see, for example, Figure 34).*

Configuration of Field Lines

The first property of the dipole or monopole which is to be considered is the configuration of the field lines *(see Figure 13).* When superimposed upon the component which is measured by the total field magnetometer, it can be seen that the relative lengths of the disturbance vectors that are measured are those shown in *Figure 21* for an induced dipole and monopole source. It is the relative length of these disturbance vectors drawn along the total field direction that is measured, each disturbance vector, in turn, weighted by the intensity functions described below.

Dipole and Monopole Fall-Off Factor

The next factor to be considered is the variation of intensity with distance, i.e., $1/r^3$ and $1/r^2$ factors for the dipole or monopole fields respectively and as expressed in the preceding equations. The relative intensity for dipoles or monopoles as a function of distance to their centers as would be observed along a traverse is presented in *Figure 22* and described mathematically under "Anomaly Amplitude" below. This factor multiplies the length of net vectors in *Figure 21.*

Dipole Factor-of-Two

The last consideration really only applies to the dipole and that is a factor of 2 when one is off the end of the dipole compared to a position off the side. In other words, at a given distance, the intensity varies by a factor of 2 as a function of the angle between the radial line to the dipole and the dipole axis. This function is shown approximately in *Figure 23* for the dipole used in the example. The monopole possesses radial symmetry and therefore requires no such consideration.

Application of Method

A dipole and monopole signature is thus constructed in *Figure 24.* The amplitude is dimensionless, but can be compared to a real anomaly by multiplying by a single factor derived below from considerations of volume, susceptibility, etc. However, applying these factors even qualitatively should allow one to draw the dipole and monopole signatures for variously inclined fields and geometries. *Figure 25,* for example, is drawn free-hand for anomalies in vertical field (90° inclination), magnetic equator and mid-southern latitudes. By simply sketching in the earth's field direction and the dipole's field lines

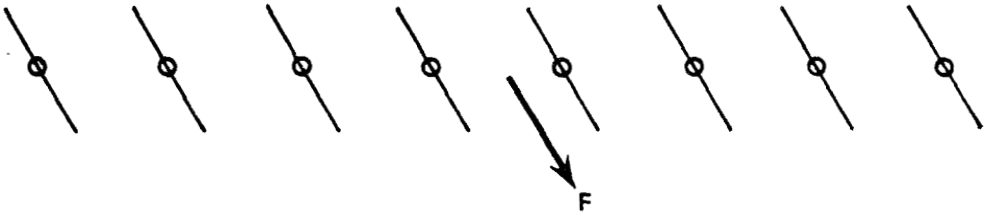


Figure 20. Direction of Components Measured by Total Field Magnetometer

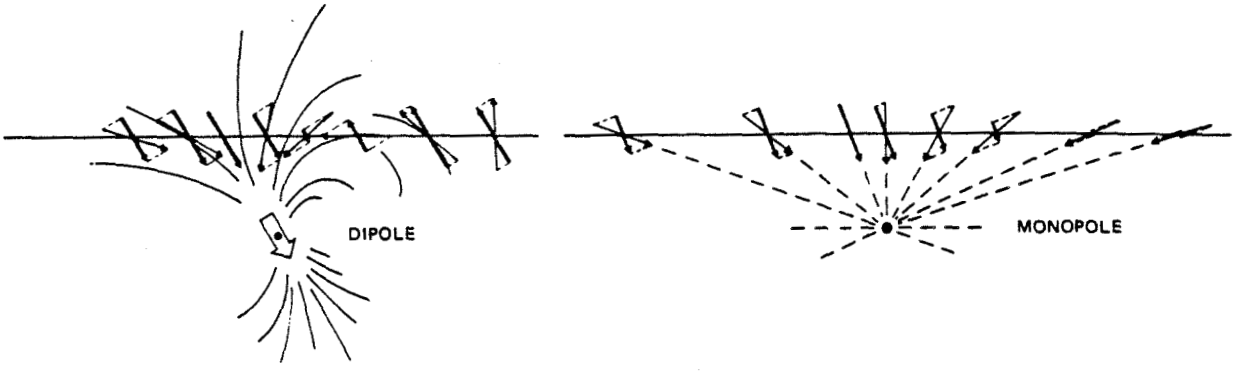


Figure 21. Total Field Components of Tangent to Field Lines of Dipole and Monopole

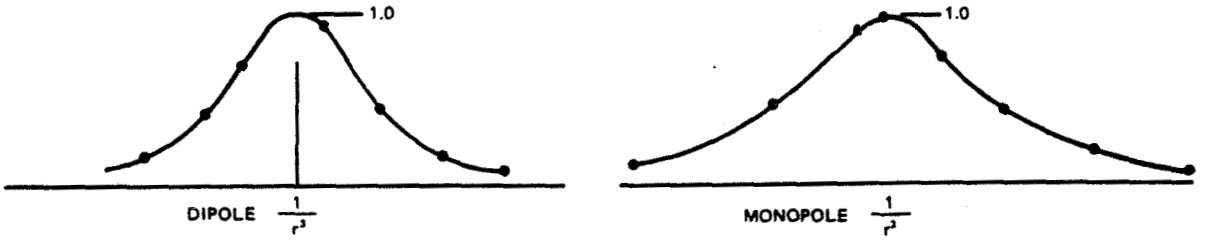


Figure 22. Fall-off Rate
(Relative intensity or length of vectors in Figure 21)

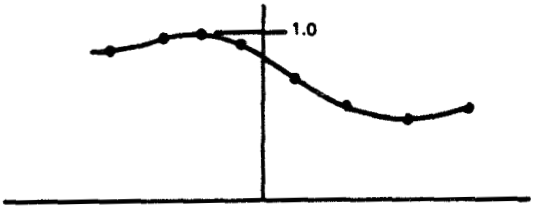


Figure 23. Aspect Factor
(Relative Intensity of Dipole of Figure 21 with Respect to Angle from Axis at Various Points Along Profile)

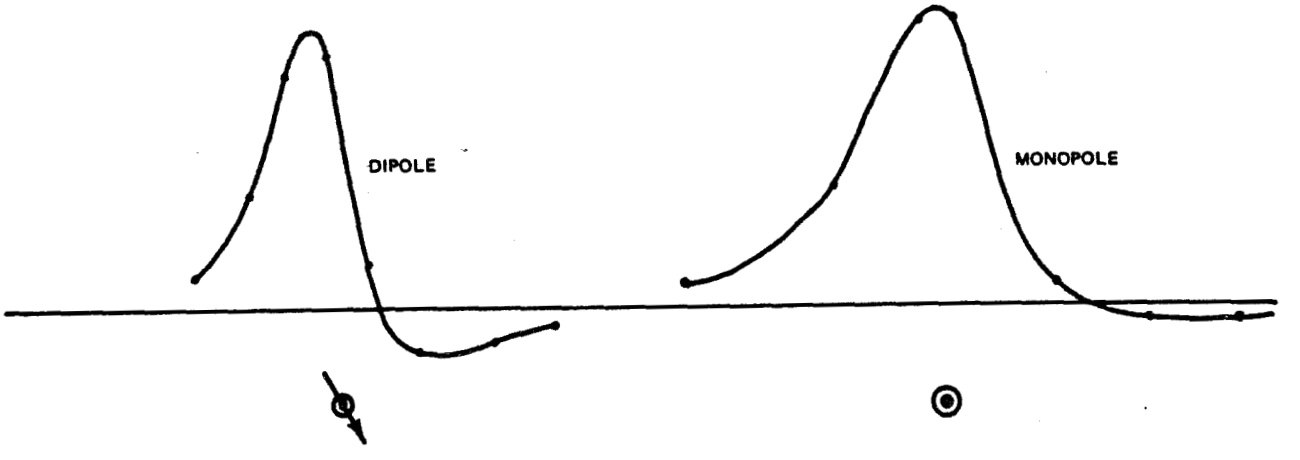


Figure 24. Dipole and Monopole Signatures (Constructed from Figures 20-23 according to methods described in text.)

without consideration of the other last two factors, it is possible to appreciate the basis for:

a negative anomaly over sources at the magnetic equator,

absence of anomalies in the central portion of elongate N-S anomalies at the equator,

both positive and negative fields for almost any anomaly,

changes in anomaly character for different directions of the dipole,

asymmetry of anomalies,

monopole which has only positive sense yet for most inclinations still produces a total intensity anomaly with both positive and negative portions.

The simple exercise of drawing such anomalies may also elucidate other characteristics of signatures, which to many not familiar with magnetics or such behavior as shown here, appear to be complex and difficult to comprehend.

Based upon the above procedures, applied qualitatively, and upon the manner in which lines of flux are induced in various configurations of geologic bodies and ambient field directions and inclinations, it is possible to derive the various signatures shown in *Figure 26* (drawn freehand). By varying the effect of depth as it produces an anomaly of longer wavelength, and by building composite anomalies such as summing the effect of 2 faults to create a single wide, shallow dike, it is also possible to generate a composite curve demonstrating the effect of different sources and different depths which is the typical observation.

Contour Presentation of Dipole and Prism Anomalies

Profiles of total intensity are usually the only form of presentation from ground measurements even when data are taken on a 2-dimensional array. If measurements are taken properly, however, it is possible to construct a contour map by the methods described in Chapter IV. It is therefore useful to examine a few special cases of contour maps that would be expected over simple sources such as a dipole and a wide, vertical prism in various latitudes. Such a contour map also allows one to extract, even by simple inspection, how a given profile would appear at various positions over such simple-shaped forms which is useful information both in search and in

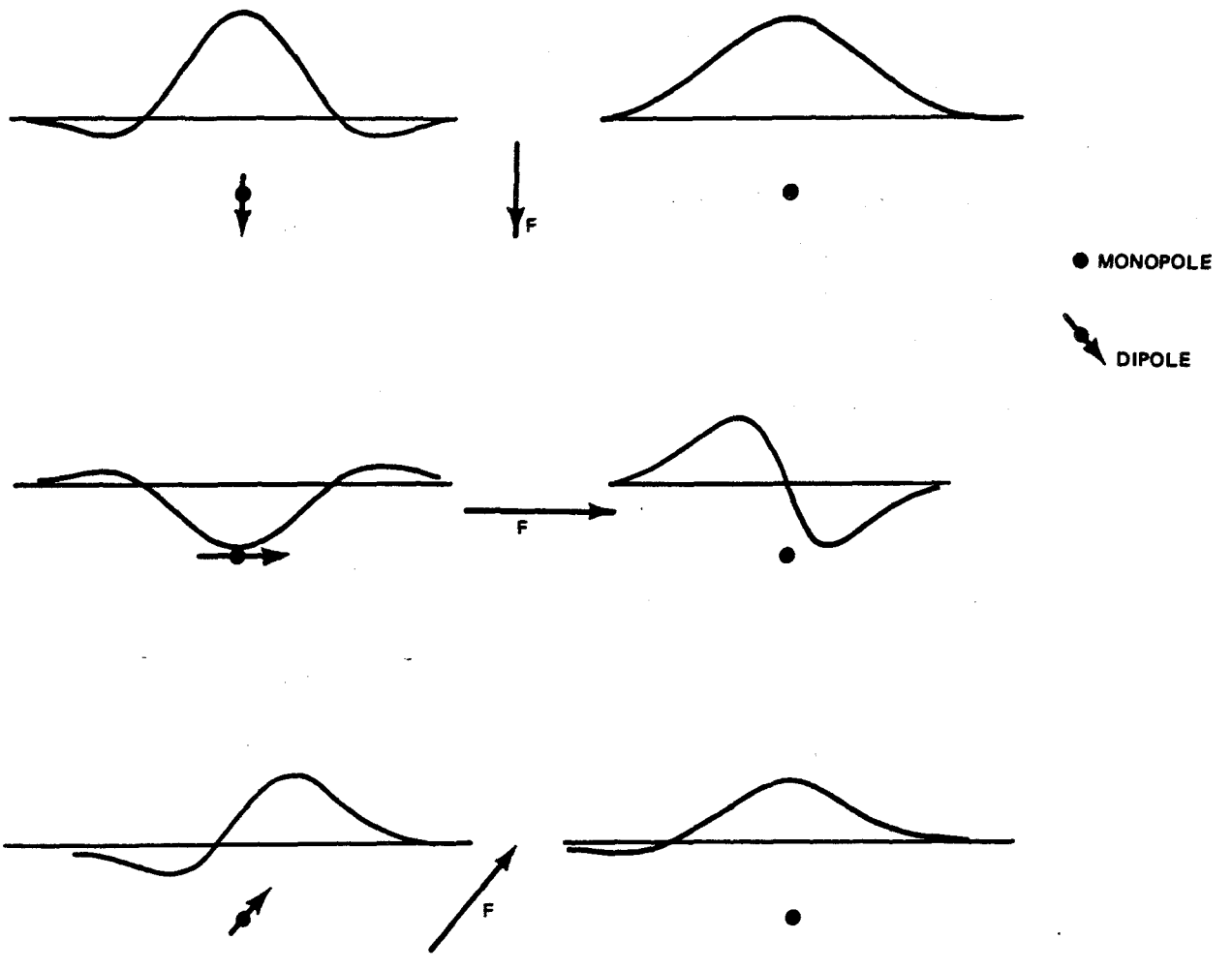


Figure 25. Free Hand Sketch of Dipole and Monopole for Various Inclinations

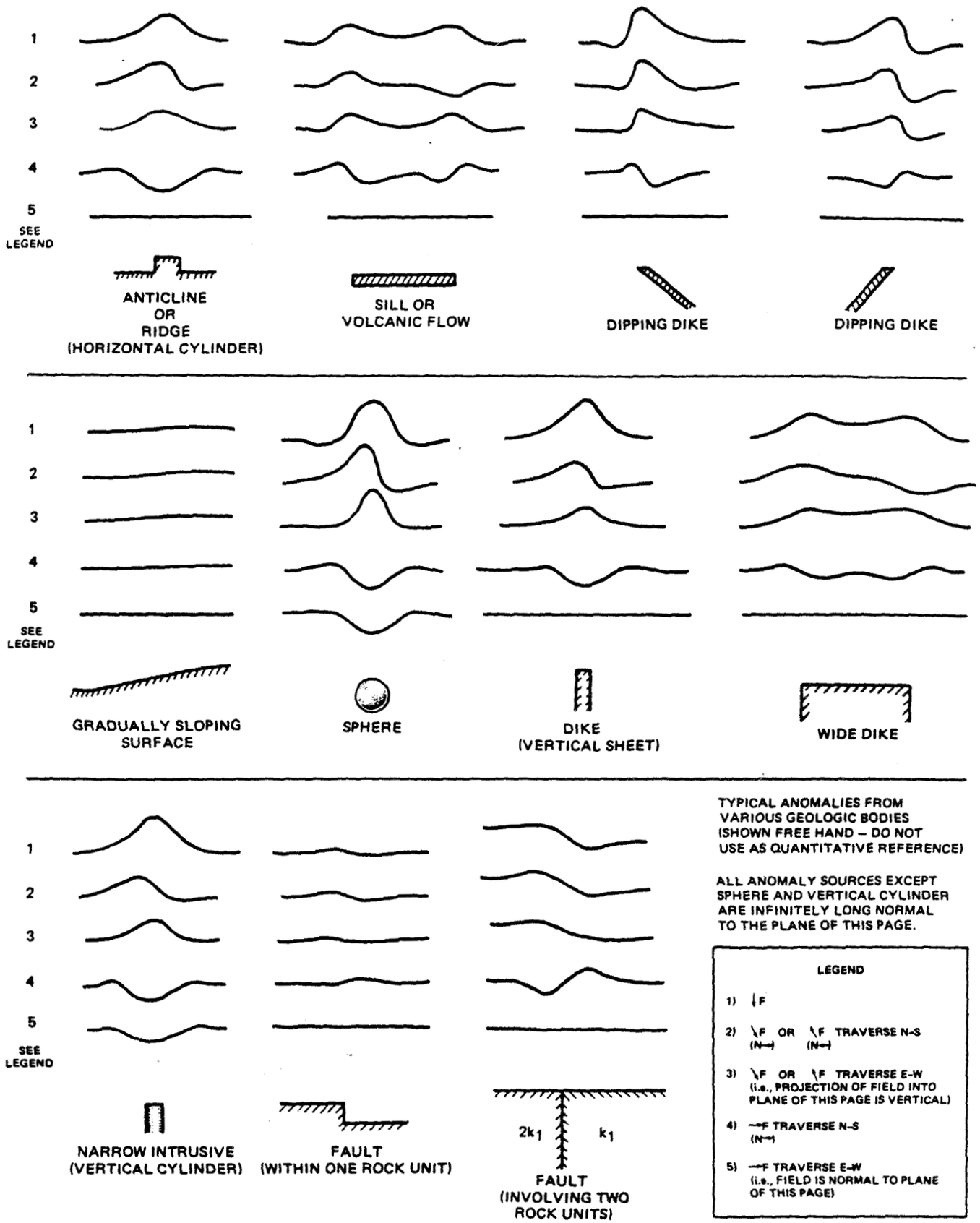


Figure 26. Anomalies for Geologic Bodies at Various Orientations and Different Inclinations of the Field

geological exploration. Contour maps and selected profiles drawn across the anomaly are sketched in *Figure 27*.

Anomaly Amplitude

Amplitude Estimates for Common Sources

The large amplitude commonly observed anomalies (several hundred gammas or larger) are almost always the result of a large magnetization contrast, i.e., change in lithology where one igneous rock is in juxtaposition with another or with a sedimentary or metamorphic rock of much lower susceptibility. It must be remembered that magnetization of common rocks varies over 6 orders of magnitude. Anomalies due to structure alone, i.e., varying configuration of a uniformly magnetized rock, seldom produces anomalies larger than 10 or 100 gammas.

The relative amplitude of a given anomaly (signature) has been shown to be a function of the earth's field direction, the configuration of the source and the remanent magnetization if any. The *maximum* amplitude of an anomaly is, on the other hand, largely a function of the depth and the contrast in the mass of magnetite (or iron, etc. in the case of search), and to a lesser extent, the configuration of the source. It is of interest to be able to estimate the maximum amplitude for a given source in order to 'model' it for the sake of interpretation. This estimated amplitude can be used with the normalized, i.e., dimensionless, anomaly signatures above and in *Figure 26* to produce the anomaly one wishes for comparison with the observed. Estimation of the maximum anomaly amplitude is also useful in planning a survey or planning the grid and coverage necessary in search applications.

For a few generalized configurations, it is relatively simple to estimate the maximum anomaly amplitude (at a single point above the source) assuming a depth, susceptibility and much simplified shape of the source. Expressions are given in the literature for calculation of anomalies of more complex figures and later in this section the calculation of the complete signature, i.e., the amplitude as a function of distance along the profile for a few simple forms. The methods described herein are merely order-of-magnitude techniques, but are useful for the applications covered by the Manual.

Estimation of the maximum anomaly for comparison with a given source requires first that the signature be studied for the nature of the source; namely, whether the source can be approximated as an isolated dipole, monopole, or line or sheet-like array of such. In the case of the latter two, adjacent traverses or a contour map may be required to determine if it is 2-dimensional, i.e., very long normal to the traverse. A depth is then assumed or crudely estimated (according to procedures that follow). In addition, the susceptibility is assumed or if source rocks are accessible, it is measured following methods outlined in Chapter VI. The formulae below can then be used remembering that they are based upon simplifications and assumptions and are often no better than a factor of two.

The basic expression for estimating the maximum amplitude of any anomaly is

$$T = \frac{M}{r^n}$$

where T is the anomaly, M the magnetic moment, r the distance (depth) to the source, and n a measure of the rate of decay with distance, or fall-off rate (n = 3 for a dipole, n = 2 or a monopole, etc.).

Since the magnetic moment M (and k) is usually given in centimeter-gram-second (cgs) units, r must be in centimeters, n is dimensionless and T is in gauss. To express T in gammas, multiply M by 10^5; if r is in feet, multiply r by 30 and raise the quantity 30r to the exponent n, e.g., if the source is a dipole, then n = 3, and if say, r = 2 feet, M = 1000 cgs,

$$\text{then } T = \frac{1000 \times 10^5}{(2 \times 30)^3} = 460 \text{ gammas.}$$

Dipole and Monopole Signatures in Vertical and Horizontal Fields

The very generalized expression for the maximum anomaly one may expect from a dipole or monopole was presented above in its very simplest form. It may be of interest, however, to construct the signature of a dipole or monopole in a vertical or horizontal earth's field as would be observed by a total field magnetometer along a traverse over the source.

Apart from any total field considerations, a dipole has a field with magnitude and direction given by the radial and tangential components, T_r and T_θ, according to the following expression and for the geometry shown.

$$T_r = \frac{2M \cos\theta}{r^3}$$

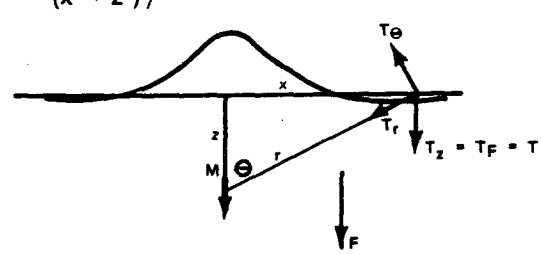
$$T_\theta = -\frac{M \sin\theta}{r^3}$$

Where the earth's field is vertical or nearly vertical (dip 70° to 90°), the dipole, if induced, would also be vertical and the total field magnetometer would measure the component, T_z, along this vertical direction, where

$$T_z = T_r \cos\theta + T_\theta \sin\theta$$

$$= \frac{2M \cos^2\theta - M \sin^2\theta}{r^3}$$

$$= \frac{M\,(2z^2 - x^2)}{(x^2 + z^2)^{5/2}}$$



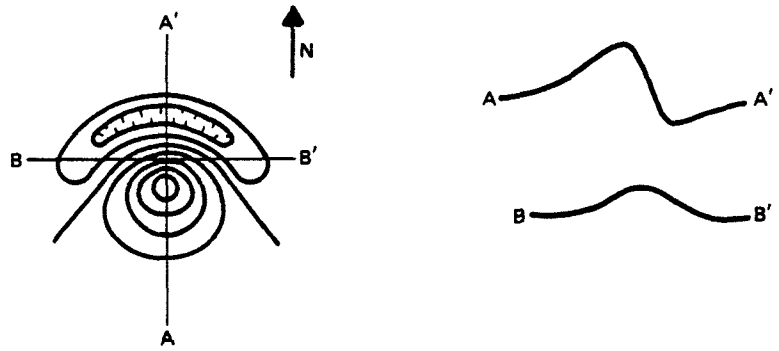
As before, $T_z = T_F = T$, the anomaly.

At x = 0, $T = \frac{2M}{z^3}$

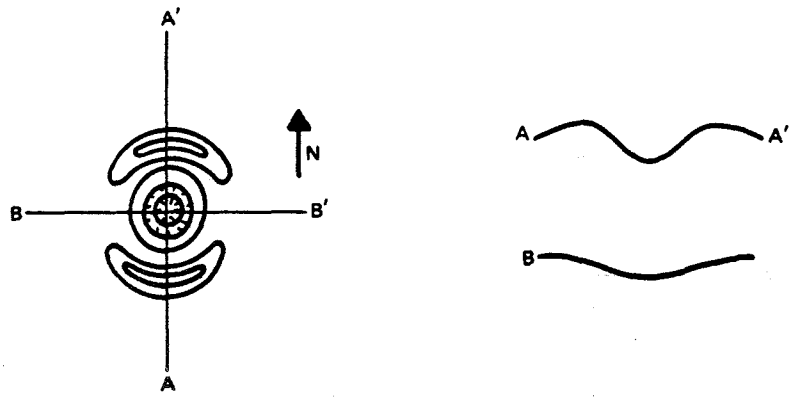
at x = ± z, $T = \frac{0.175M}{z^3}$

at x = ± √2 z, T = 0

at x = ± 2z $T = \frac{-0.04M}{z^3}$



DIPOLE, INCLINATION OF F, 60°
(FOR INCLINATION –60°, I.E., SOUTHERN HEMISPHERE, N IS ↓)



DIPOLE, HORIZONTAL FIELD

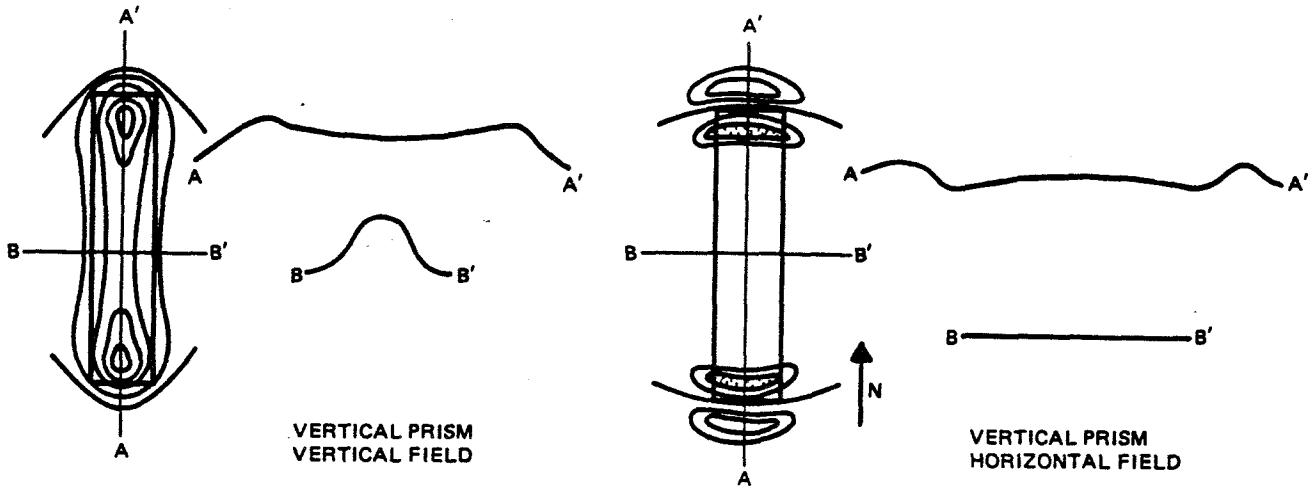
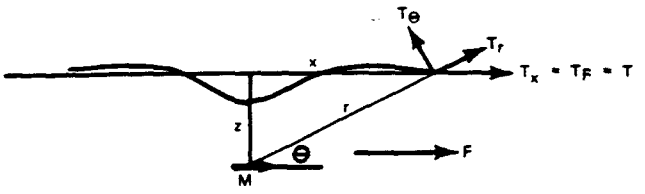


Figure 27. Contour Maps of Total Intensity

For magnetic equatorial fields, the induced anomaly is horizontal and the total field magnetometer would measure the components shown and expressed by

$$T_x = T_r \cos\theta + T_\theta \sin\theta$$

$$= \frac{2\,M\cos^2\theta - M\sin^2\theta}{r^3}$$



$$= \frac{M\,(2x^2 - z^2)}{(x^2 + z^2)^{5/2}}$$

as before, $T_x = T_F = T$ the total field anomaly, where,

at $x = 0$,

$$T = -\frac{M}{z^3}$$

at $x = \pm\frac{z}{\sqrt{2}}$,

$$T = 0$$

at $x = \pm z$,

$$T = \frac{0.175\,M}{z^3}$$

at $x = \pm 2z$,

$$T = \frac{0.125\,M}{z^3}$$

The monopole shown here has only radial components whose intensity is expressed by

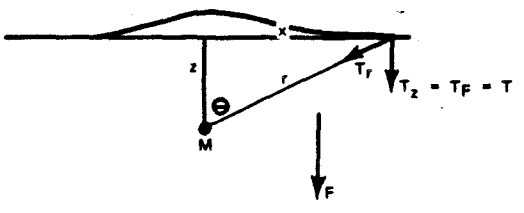
$$T_r = \frac{M}{r^2}$$

The monopole anomaly in a vertical field as measured by a total field magnetometer would be the component in the z direction (vertical) or

$$T_z = T_r \cos\theta$$

$$= \frac{M\cos\theta}{r^2}$$

$$= \frac{Mz}{(x^2 + z^2)^{3/2}}$$



assigning $T_z = T$, the anomaly

at $x = 0$,

$$T = \frac{M}{z^2}$$

at $x = \pm z$,

$$T = \frac{0.35\,M}{z^2}$$

at $x = \pm 2z$,

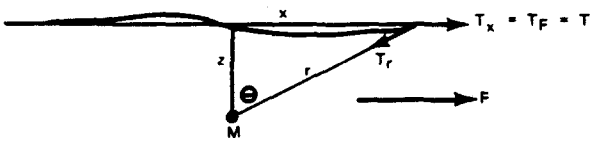
$$T = \frac{0.09\,M}{z^2}$$

The monopole field in a horizontal field would be measured by a total field magnetometer as the horizontal component, T_x where

$$T_x = T_r \sin\theta$$

$$= -\frac{M}{r^2}\sin\theta$$

$$= -\frac{Mx}{(x^2 + z^2)^{3/2}}$$



Again, $T_x = T_F = T$, the anomaly, where

at $x = 0$,

$$T = 0$$

at $x = z$,

$$T = -\frac{0.35\,M}{z^2}$$

at $x = -z$,

$$T = \frac{0.35\,M}{z^2}$$

at $x = 2z$,

$$T = -\frac{0.18\,M}{z^2}$$

at $x = -2z$,

$$T = \frac{0.18M}{z^2}$$

Maximum Amplitude Given Magnetization and Generalized Form

The magnetic moment M is more usefully expressed as

$$M = IV$$

where I is the magnetization (i.e., magnetization contrast) per unit volume and V the volume. This magnetization is composed of a usually unknown proportion of remanent magnetization, I_r, and induced magnetization I_i. The latter as expressed in Chapter III is

$$I_i = kF$$

where k is the magnetic susceptibility per unit volume and F the earth's field or ambient inducing field. (NOTE: Since I_r is seldom known, an effective magnetization, $I = I_i + I_r$, will always be used. Also it is assumed that $k<10^{-2}$, i.e., the source under consideration contains less than 10% magnetite; then one can ignore what is known as demagnetization effects in the calculation of anomaly amplitude).

Therefore, for a dipole which can always be assumed for a source all of whose dimensions are small with respect to the distance (less than 1/5 or 1/10) to the magnetometer,

$$T = \frac{M}{r^3} = \frac{IV}{r^3} = \frac{kFV}{r^3}$$

If the source is approximately spherical, then

$$T = \frac{kF\left(\frac{4}{3}\pi R^3\right)}{r^3}$$

where R is the radius of the source as in *Figure 28*

If the measurement is made along the axis of the dipole (see *Figure 29*), then

$$T = \frac{2kF\left(\frac{4}{3}\pi R^3\right)}{r^3}$$

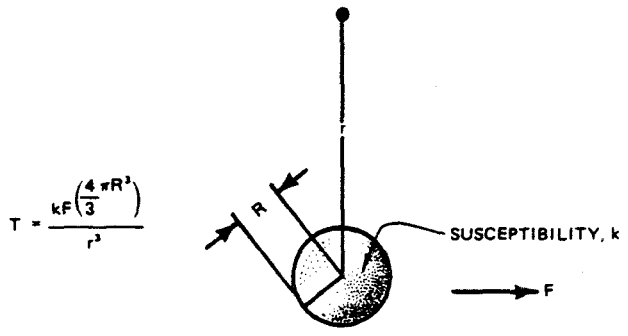


Figure 28. Anomaly of Sphere in Horizontal Field

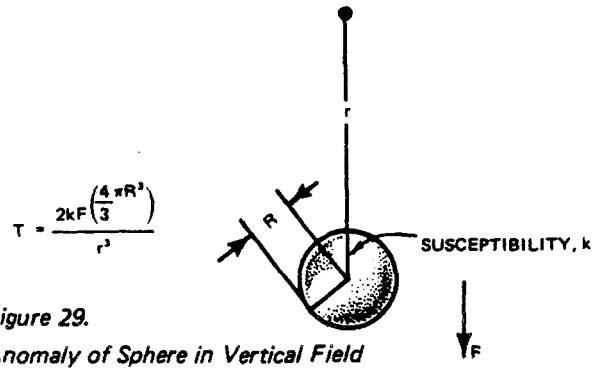


Figure 29.
Anomaly of Sphere in Vertical Field

As an example, consider an ore body 100 feet wide (R = 50), 500 feet deep comprised of 10% magnetite (k = 0.3), in a steeply dipping field (60° to 90° latitude) in a field of 60,000 gammas:

$$T = 2\,(0.10 \times 0.3) \times 6 \times 10^4 \left(\frac{4\pi}{3}\right)\left(\frac{50}{500}\right)^3 = 14.4 \text{ gammas}$$

For the same ore body in an equatorial field where F = 30,000 gammas and the induced dipole is now observed at a point on a line normal to the axis (no factor of 2)

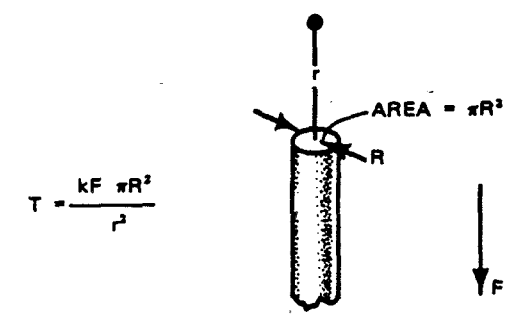
$$T = -3.6 \text{ gammas}$$

Thus a given dipolar source in an equatorial field will have only ¼ the maximum anomaly amplitude it would have in a polar region.

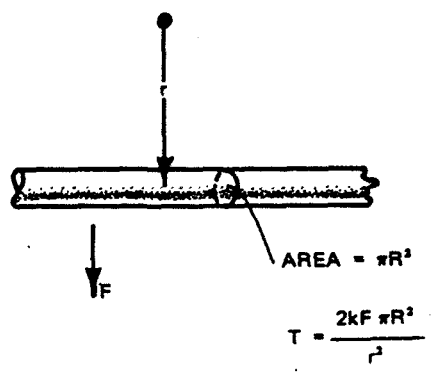
The above expressions are usually valid only for such sources as a small distant ore body (containing magnetite), small structure in deep basement, or most objects involved in search applications (see Chapter VII). The magnetization is expressed in gauss or gammas as desired. Since the anomalies are also expressed in terms of magnetic units, it follows that the units of dimension in the numerator must be of the same order as the denominator since they must cancel. Therefore, for a dipole whose anomaly varies as $\frac{1}{r^3}$ (said to have a fall-off of $\frac{1}{r^3}$), the volume, V, has dimensions of R^3. In the case of a monopole, which varies as $\frac{1}{r^2}$, the magnetic moment, M, is equal to IA where A is surface area and has dimensions of R^2. Consider for example, a vertical basement intrusive in a polar region with an upper surface 1000 feet in diameter at a depth of 5000 feet, with a susceptibility contrast of 10^{-2} in a field of 60,000 gammas. Thus,

$$T = \frac{kF\,\pi R^2}{r^2} = 10^{-2} \times 6 \times 10^4 \times \pi\left(\frac{50}{500}\right)^2 = 18 \text{ gammas.}$$

Horizontal prisms or cylinders also vary as $\frac{1}{r^2}$, with magnetic moment M equal to 2IA (IA for E-W horizontal prisms in equatorial regions) where A is the cross-sectional area of the prism *(see Figure 30)*. (NOTE: The long horizontal prism varies as $\frac{1}{R^2}$ not because it appears to be comprised of a monopole, but because it is a line of dipoles (in steeply dipping fields) and the effect of adjacent dipoles along an infinitely long line is 'seen' more by the magnetometer at a distant point of measurement than if all the magnetization were concentrated at a point as in an isolated dipole).



(NOTE: ALSO VALID FOR END OF N-S HORIZONTAL CYLINDER IN HORIZONTAL FIELD)



(NOTE: ALSO VALID FOR E-W HORIZONTAL CYLINDER IN HORIZONTAL FIELD)

Figure 30. Anomaly of Vertical and Horizontal Cylinders

A narrow, vertical dike in steep field or the edge of a horizontal sheet in a horizontal field can be considered as a line of monopoles varying as 1/r which is a lower rate of fall-off than a single monopole for the same reasons given above for a horizontal cylinder *(see Figure 31)*. The magnetic moment M = It where t = width of dike. Since the anomaly varies as 1/r, the dimensions of t are simply length. As an example, a vertical dike might be 100 feet wide, at a depth of 500 feet, with $k = 10^{-3}$ in a field of 50,000 gammas, or

$$T = \frac{kFt}{r} = \frac{10^{-1} \times 5 \times 10^{4} \times 10^{2}}{5 \times 10^{2}} = 10 \text{ gammas}$$

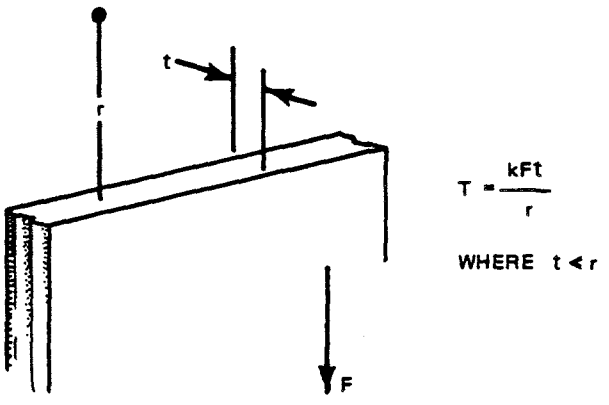


Figure 31. Anomaly of Narrow Vertical Dike

A common point of ambiguity arises with such simplified schemes as these in the case of a dike which is nearly as wide as it is deep. In this case, the anomaly is approximated as something between a line of monopoles as above and a sheet of monopoles as shown in the following. Moreover, as the dike is even wider than its depth, it can be approximated simply by 2 faulted contacts with 'no anomaly' in between.

For a semi-infinite slab of material such as a rock surface of great thickness and breadth in a non-horizontal field, the flux lines do not vary in direction or density above the slab, therefore the field does not vary at all with distance to its surface (similar to the limit of the spherical dipole above where R = r) so that

$$T = \frac{M}{r^0} = \frac{2\pi I}{1}, \text{ or } T = 2\pi\, kF$$

which is useful in estimating the magnitude of the anomaly at a vertical fault *(see Figure 32)*. For example, consider two rock types at a vertical contact of $k = 10^{-3}$ and $k = 10^{-5}$ for an effective susceptibility contrast of $k = 10^{-3}$ ($10^{-5} \approx 0$ relative to 10^{-3}) and where F = 50,000 gammas. Thus

$$T = 2\pi \times 10^{-3} \times 5 \times 10^{4} = 300 \text{ gammas}$$

If the rocks had $k = 10^{-4}$ and 10^{-3}, the effective susceptibility contrast would be

$$10^{-3} - 10^{-4} = 10 \times 10^{-4} - 10^{-4} = 9 \times 10^{-4} \text{ and}$$

$$T = 2\pi \times 9 \times 10^{-4} \times 5 \times 10^{4} = 270 \text{ gammas}$$

This simple example of two adjacent rock types is probably applicable in more instances in interpretation than any of the other geometries discussed above.

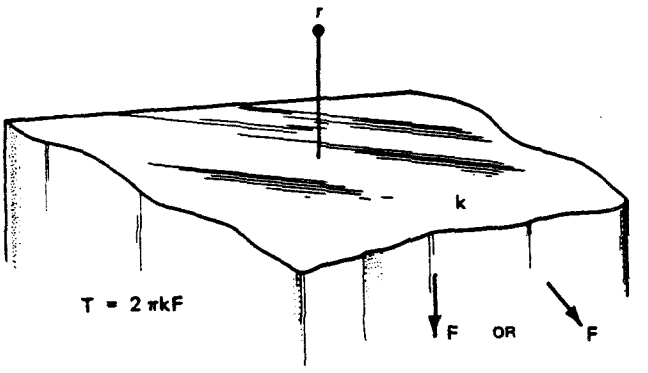


Figure 32. Anomaly of Semi-infinite Slab

Anomaly Depth Characteristics

In a very approximate fashion, the wavelength, or, effective width (or 'half-width' described in the following) of the anomaly and, with more accuracy, the width of certain characteristics of the anomaly such as slope, are measures of the depth to its source. However, recognition of the anomaly, the anomaly 'zero' and certain slopes would not only appear as different values as determined by different interpreters, but they also depend upon what is removed as the regional gradient. More objective criteria are used in some cases such as the nearly straight portions of a slope, and distances and angles between inflection points, peak values and other anomaly characteristics.

Anomaly Width

In general, the anomaly width as shown in *Figure 33* is on the order of 1 to perhaps 3 times the depth. Thus, when an anomaly appears to have a width as such of 100 feet, it is definitely not produced by a source at 1000 feet or at 10 feet, but more likely by a source between 30 and 100 feet deep (or distant). Such criteria, approximate as it is, is nevertheless useful for cursory interpretation of profiles and maps.

Anomaly Depth Estimation

Much is written on the variety and relative merit of methods for estimating the depth to the source of anomalies. Since the magnetometer is primarily a tool for subsurface mapping and detection, it follows that determination of the depth as well as edges of bodies is important in its application to geological exploration and search. The basis for depth determination is presented here in brief which, together with the foregoing background on anomaly behavior, should allow one to at least appreciate how a variation in depth affects an anomaly. In most cases, one needs only to apply this knowledge qualitatively through visual inspection of a profile. Whatever the requirement, depths may be estimated by visual inspection, several rules of thumb, modeling (i.e., calculation of assumed source and comparison with observed), measured gradient techniques (see Chapter VIII), or various computer-oriented procedures. As was demonstrated earlier, a given anomaly could have an infinite number of possible sources and source depths, but the realistic models that are assumed usually produce maximum depth estimates.

Knowledge of the depth of a particular formation or source may have considerable geological significance as it determines the nature or configuration of a forma-

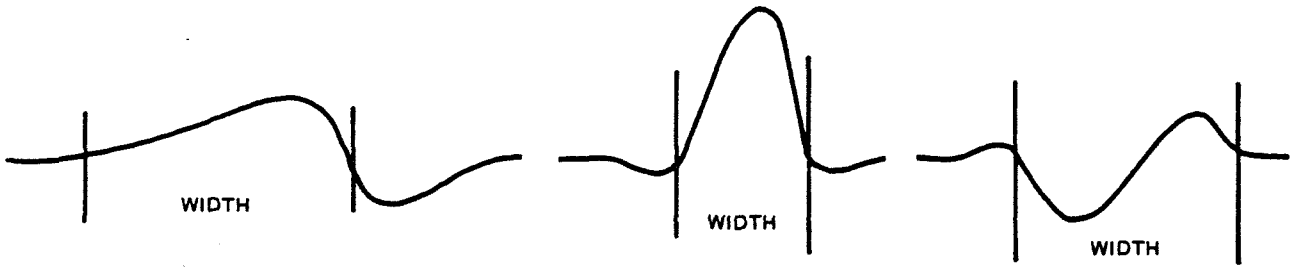


Figure 33. Anomaly 'Width'

tion, the slope of its surface and its discontinuities. The depth to various points on the surface of crystalline rock or magnetic basement allows one to map that surface and its topography and structures to depths exceeding 30,000 feet and to infer thickness of sediments or conformable sedimentary structures above it for exploration of petroleum, sedimentary ores, placer deposits or groundwater. Areas underlain by pediment or other sedimentary deposits may be ruled economic or non-economic according to depth. The depth to ore deposits associated with pyrrhotite, magnetite or ilmenite may be estimated as an aid to a drilling program or even for estimation of total tonnage of magnetic iron ore deposits. Black sand deposits of rutile, zircon, monazite, diamonds, gold, platinum, etc. are often associated with other high density, very resistant yet magnetic minerals, namely, magnetite or ilmenite. The depth to objects of search whether buried iron or man-made structures is invaluable in guiding the subsequent excavation efforts.

Identification of Anomaly

The anomaly of interest must be identified and discriminated against the obscuring effects of others. Recognition of the anomaly itself is usually the most difficult aspect of depth determination because of the composite effects of multiple sources, sources at various depths and at various distances in any direction from the magnetometer. Only the net effect of all anomalies are measured by the magnetometer since it has no inherent discrimination ability at the disposal of the operator. The anomaly should be inspected to ascertain the probable source and, if complex, the possible combination of sources. For example, a wide, shallow dike will appear as two anomalies which may or may not coalesce depending upon the relative width and depth. A very broad anomaly or regional gradient (described in Chapter IV). is usually caused by anomalies which are extremely deep or distant or by the normal variation in the earth's magnetic field. If one wishes to remove this gradient, it can be done either by drawing a straight line through the non-anomalous portions of the profile (away from the anomaly of interest) or by drawing a very smooth but broad wavelength curve through the data of much longer wavelength than any anomalies of interest. This regional gradient or background is then subtracted from the anomaly and the remaining, or residual anomaly, replotted. It is this anomaly which is then interpreted for either depth or for amplitude or general configuration of sources as described in Chapter IV.

Fall-Off Rate

The variation of anomaly amplitude with distance, or fall-off rate, is important in the interpretation of anomalies for it relates the anomaly to depth, it describes in a general way the configuration of the source, and it assists in determining susceptibility and mass of the causative magnetite. Recall that the anomaly from a dipole varies as $\frac{1}{r^3}$ and that of a monopole as $\frac{1}{r^2}$. The fall-off rate, in actual practice, does not involve precisely such factors or exponents but, in fact, is typically $\frac{1}{r^{2.5}}, \frac{1}{r^{0.6}}$, etc., or even $\frac{1}{r^0}$ as described above. In other words, various configurations of dipoles, monopoles, lines and sheet-like distributions of these poles constitute a continuous series of fall-off rates even in the vicinity of a single anomaly as one is much closer or further away from the source.

Representing various geologic sources as simple prismatic bodies, one may assume the following fall-off rates: a dipole will be produced by a source all of whose dimensions are small (less than $1/10$ compared to the distance between the source and magnetometer). Such a body is rarely seen in nature except as a very confined, usually magnetite-rich ore body. A monopole varying as $\frac{1}{r^2}$ will be produced by a long, thin, vertical prism, such as a narrow vertical intrusive in steeply dipping fields or a horizontal cylinder striking N-S in equatorial fields (e.g., a N-S anticlinal structure on the basement, one end of which is near the magnetometer). A line of dipoles is produced by a long, horizontal cylinder magnetized through its short dimension as in steeply dipping latitudes or striking E-W in equatorial regions. Such a cylinder will also vary as $\frac{1}{r^2}$. A line of monopoles would effectively be observed near one edge of a dike dipping in the direction of the field and would vary approximately as $\frac{1}{r}$. At a point above a horizontal semi-infinite sheet, the field would vary inversely as $\frac{1}{r^0} = 1$, which is another way of expressing the fact that the field does not vary at all with distance from a horizontal semi-infinite sheet of monopoles or dipoles. A wide vertical dike in a steep field or the edge of a fault might represent combinations between a line of dipoles or sheet-like distribution of monopoles and may thus vary as $\frac{1}{r^2}$ or $\frac{1}{r^{0.5}}$ or less. *Figure 34* indicates these variations.

Assumptions on Maximum Amplitude and Depth Estimates

Unless the remanent magnetization is actually measured, it is generally disregarded, and only the induced magnetization and susceptibility are utilized in these expressions. The magnetic anomaly calculated from these

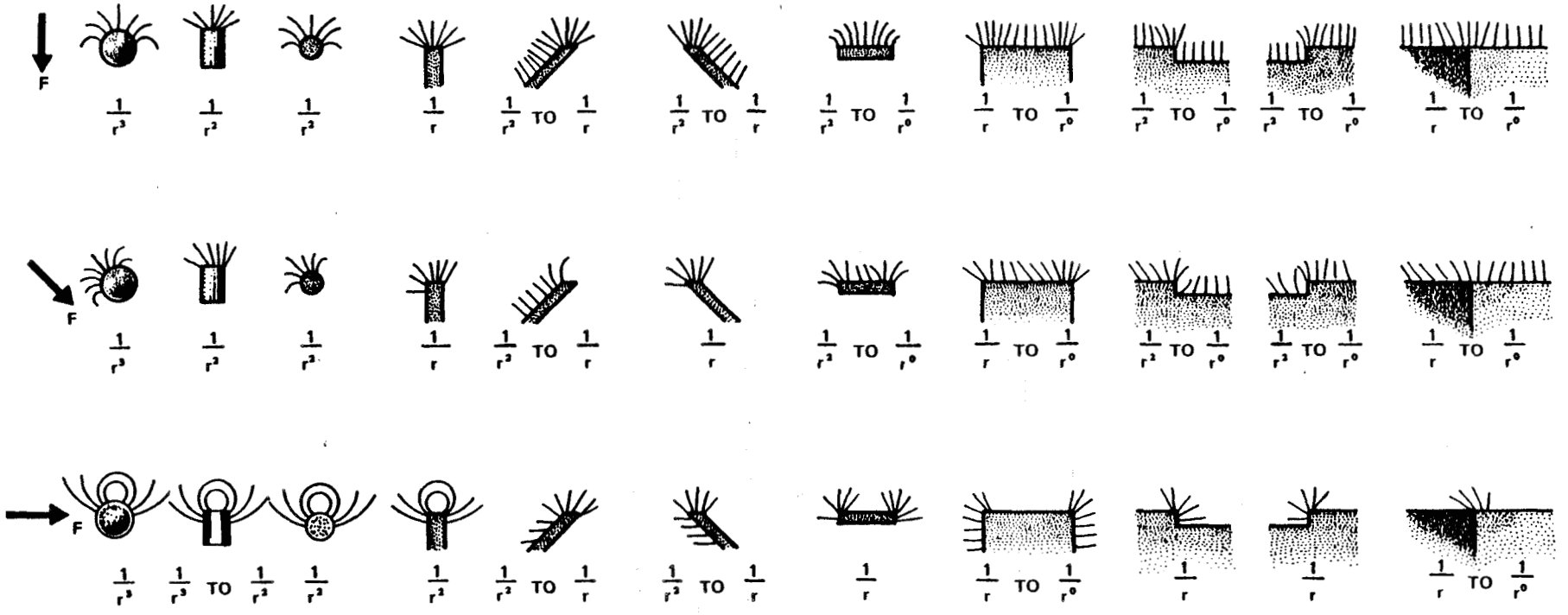
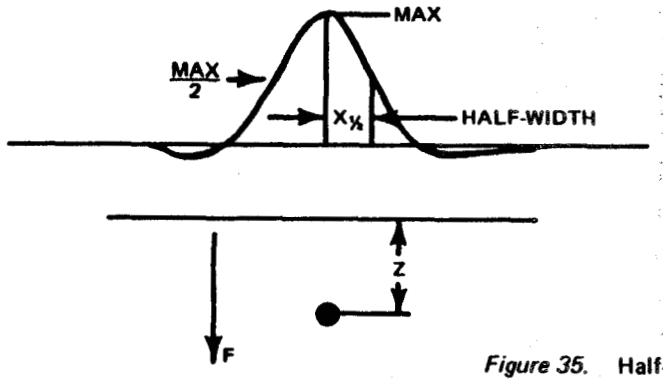


Figure 34. Field Lines and Fall-Off Rates of Various Geologic Models

(FLUX LINES SUPERIMPOSED ON REPRESENTATIVE GEOLOGIC MODELS FOR VARIOUS ORIENTATIONS OF INDUCING FIELD. ANOMALY AMPLITUDE PROPORTIONAL TO INDICATED TERM OF $1/r^n$.)



SPHERE (DIPOLE)	$Z = 2X_{1/2}$
VERTICAL CYLINDER (MONOPOLE)	$Z = 1.3X_{1/2}$
EDGE OF NARROW DIKE (LINE OF MONOPOLES)	$Z = X_{1/2}$
HORIZONTAL CYLINDER (LINE OF DIPOLES)	$Z = 2X_{1/2}$

Figure 35. Half-width Rules – Vertical Field

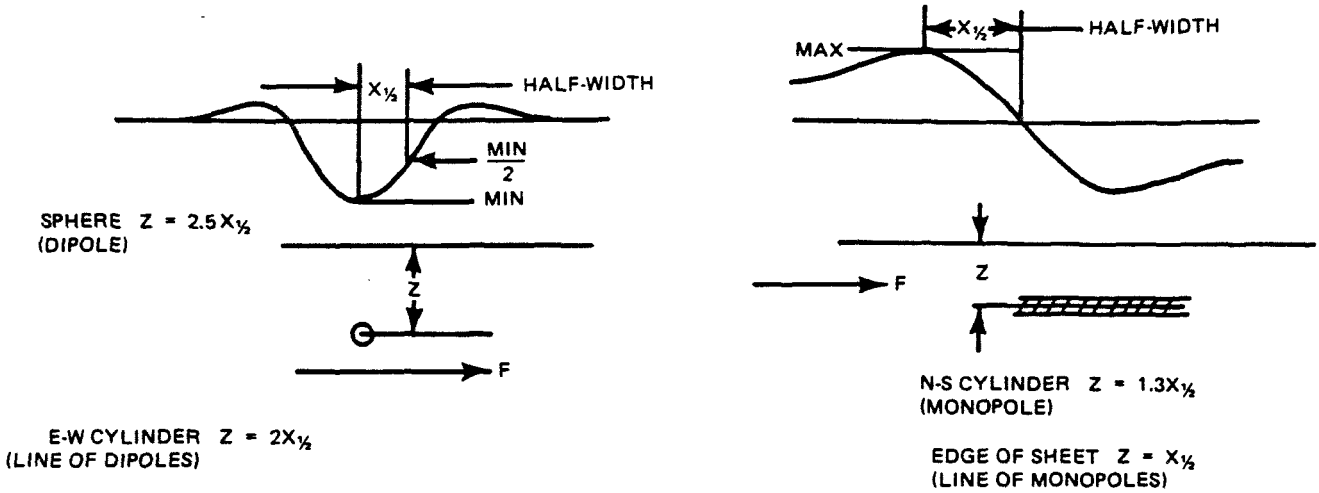


Figure 36. Half-width Rules – Horizontal Field (Equatorial)

highly simplified expressions represents the maximum amplitude from the local zero, non-anomalous field to the positive peak value in the northern and sourthern latitudes and to the minimum negative value in equatorial regions. It does not represent the peak-to-peak value which includes both positive and negative portions of the anomaly signature. The depth estimates derived from any of the techniques described are seldom more accurate than 10% of the actual depth and sometimes as poor as 50%. By theory most of the estimates are maximum estimates so that the actual source will actually be at a shallower depth. Moreover, the 'poles' or source described frequently throughout their chapter are within the geologic body or object of search and not simply on the surface; therefore, such depths are again maximum depths.

Half-Width Rules

In vertical or horizontal fields, it can be shown, from the previous expressions for dipoles and monopoles, that for simple forms of anomaly sources, the depth to their centers is related to the half-width of the anomaly. The half-width is the horizontal distance between the principal maximum (or minimum) of the anomaly (assumed to be over the center of the source) and the point where the value is exactly one-half the maximum value *(see Figure 35)*. This rule is only valid for simple-shaped forms such as a sphere (dipole), vertical cylinder (monopole), and the edge of a narrow, nearly vertical dike (line of monopoles) in the polar regions. At the magnetic equator, the half-width rules are somewhat different with the sphere remaining unchanged, an E-W horizontal cylinder being a line of dipoles, a N-S cylinder being a monopole, and the edge of an E-W striking horizontal sheet representing a line of monopoles. The rules presented in *Figure 36* apply according to the corresponding array of poles and in the case of the latter two, the half width being the horizontal distance between the point of maximum (or minimum) and zero anomaly. The half width rules are derived from formulae given above in "Dipole and Monopole Signatures in Vertical and Horizontal Fields".

Slope Techniques

Perhaps the most commonly used set of methods for estimating depth are those which utilize criteria involving the measurement of the horizontal gradient or slope at the inflection points of the anomaly. Based upon empirical observations utilizing computed models, these slopes are measured according to the horizontal extent of the 'straight' portion of the slope *(see Figure 37)* or the horizontal extent determined by different combinations of the tangent or slope at the inflection point, maximum of the anomaly and half slopes, etc. Each of these horizontal distance measurements when multiplied by an empirically-determined factor equals the depth to the top of the anomaly source. (The straight-slope, for example, is multiplied by a factor between 0.5 and 1.5). Detailed explanations of these methods are available in the references cited.

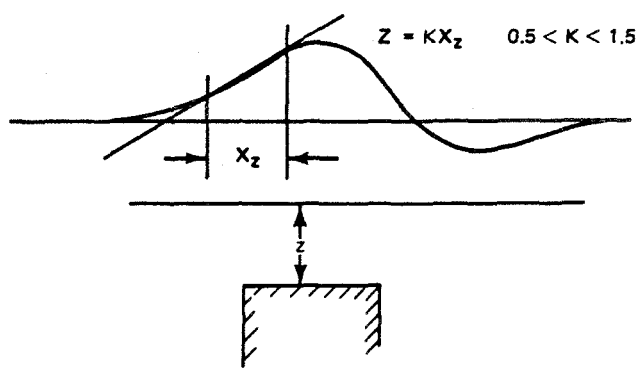


Figure 37.

Other Depth Estimating Methods

Modeling techniques require that one examine the observed anomaly for its likely source configuration. A model is assumed, the anomaly calculated, compared with the observed and repeatedly altered until a satisfactory fit to the observed data is finally achieved, with such work usually performed on a computer. Other computer-oriented depth estimating methods include programs utilizing Fourier and Hilbert transforms, convolution and other semi-automated programs which are usually applied to large volumes of data. Gradiometer measurements made with sensors at two points usually vertically arranged can also be used for depth estimates (see Chapter VIII).

Interpretation Summary

Interpretation is facilitated if one can thoroughly familiarize himself with how and why a given source produces an anomaly in the earth's field, the nature of total field measurements and the general behavior of an anomaly signature with increasing depth. What at first may have appeared complex in the interpretation of field profiles and maps is more readily understood when the above phenomena are examined one at a time.

The first procedure that should be followed in the interpretation of a given profile is to focus on the anomaly width and shape and attempt to construct at least a mental image of the source in realistic geologic terms (or object in the case of search) and its depth. Use the eye to discriminate against noise and the regional gradient or filter by one of the suggested techniques. Anomalous horizontal gradients should then be used, for lack of any other specific criteria, as an indicator of the edge of subsurface structures producing a magnetization contrast. Most anomalies on any given profile or map represent a simple contrast in magnetization or lithology, i.e., the edge of a body. Attempt to correlate such features on adjacent lines or interpret them as contacts on a total intensity contour map. The cessation, displacement or interruption of otherwise long or continuous features may also represent significant geologic structural information. However, one must realize also that a magnetic survey is only able to map a contact where there is a magnetization contrast so that, for example, different lithologies on either side of a long continuous fault will be mapped only in segments where such contrasts occur.

Changes in the character of the short wavelength anomalies (noise) may also represent mappable information if one is careful to evaluate their typical depth so as not to be mapping irrelevant soil anomalies. Negative anomalies arising from features of locally lower magnetization are as important geologically as the more common positive anomalies. Furthermore, the *most geologically significant anomalies on a given map are probably the more subtle ones and not necessarily the largest, most prominent anomalies.* Lastly, the total intensity profiles and maps are not an end in themselves, but are rendered usable only when expressed in terms of geology (or objects of a search). The more geological information one has (or size, magnetic or depth information for an object of search) the more valuable the total intensity data becomes and vice-versa.

VI.

MAGNETIC SUSCEPTIBILITY, MAGNETIZATION AND MAGNETIC MOMENT MEASUREMENTS

Introduction

Magnetic susceptibility and magnetization of rocks and the permanent and induced moment of objects can be measured in the field using the component measuring properties of the proton magnetometer. The procedure, at its simplest, involves rotating a sample about a point close to the magnetometer sensor on a line which is in the direction of the earth's total field and passes through the center of the sensor. Measurements of the maximum and minimum anomaly observed and the value of the field without the sample present is sufficient to allow reasonably accurate calculation of magnetic susceptibility and induced and remanent magnetization (and its direction) of all but the weakly magnetized rocks and the magnitude and direction of the magnetic moment of objects.

Applications

Knowledge of the magnetic susceptibility is useful in ground follow-up of aeromagnetic surveys to ascertain the source of observed anomalies, to determine possible magnetite-associated mineralization, and in mapping several rock units as a function of their susceptibility. Measurement of magnetization may also be useful in mapping certain members of volcanic formations, particularly where magnetization reversals are present. Measurement of the orientation of the permanent magnetization of rocks provides the basis for paleomagnetic measurements for the study of the changes and reversals of the earth's magnetic field. Although such studies require the precise direction of the remanence, it may nevertheless be useful to make more numerous measurements easily and in the field using a proton magnetometer if only to a few degrees accuracy. Additional objectives of such measurements for magnetic moment apply to search applications for buried or sunken ferromagnetic objects as described in the following section (VII) where such measurements can determine the estimated anomaly from certain objects of interest and thereby aid in the planning for such a survey. Magnetic compensation of objects is also facilitated by measuring the moments of both the magnetic object and the proper compensating magnet to avoid laborious cut-and-try techniques. As yet another application of such measurements, it is possible to classify or identify certain types of objects or rock types or their specific identity within a class of magnetic objects merely by unique combinations of permanent magnetization, induced magnetization, the ratio of these, the relative direction of these magnetizations, their variability, etc.

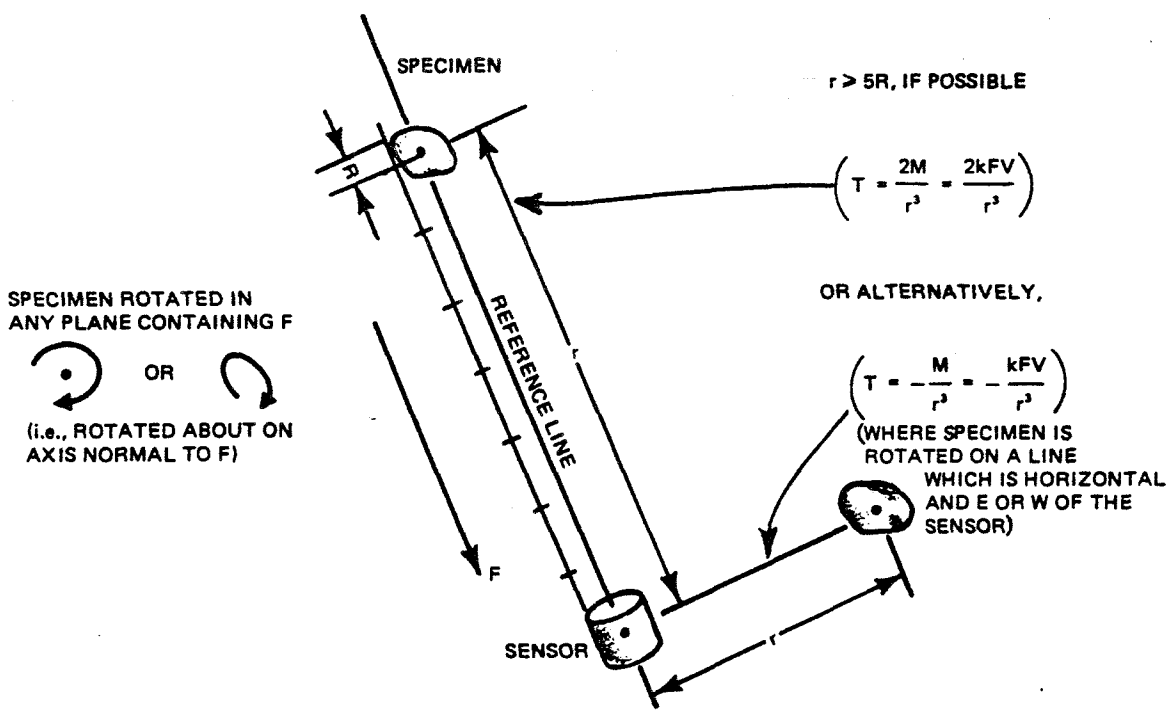


Figure 38. Schematic of Rotation of Specimen for Measurement of Magnetic Properties

Procedures

The first step in making such measurements requires that the sensor be placed in a fixed position in a magnetically clean area. A string, rod, or other non-magnetic line is then placed adjacent to the sensor such that it is aligned with the earth's magnetic field vector and allows rotation of a fist-size or larger rock specimen, about a point at a known distance from the center of the magnetometer sensor and along a line, to be called the *reference line*, containing the sensor, specimen and the earth's field vector. (NOTE: The specimen can be on either side of the sensor along this line; the measurements and procedures are unchanged.) Such an arrangement is shown in *Figure 38*. Marks should be placed along this reference line at perhaps distances of 10, 25, 50 and 100 centimeters from the center of the sensor. (Centimeters must be the units employed as the measurement objectives of magnetization, susceptibility, magnetic moment, etc. are always expressed in cgs.)

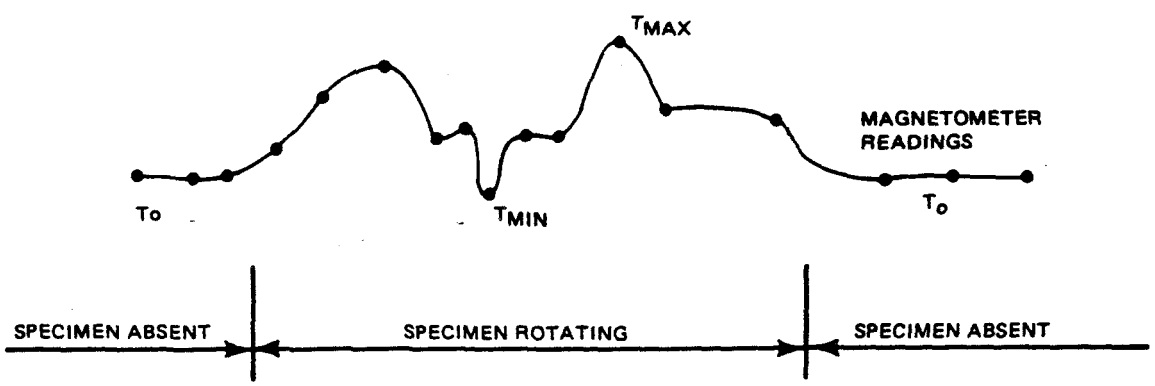
The earth's field direction can be determined from a table of inclination such as appears in *Figure 3* in Chapter II. The earth's field direction is oriented as the angle of inclination measured downwards from the horizontal in a north direction and within a vertical magnetic north-south meridional plane. A dip needle can also be used to determine this direction. An alternative way of determining the precise direction of the earth's field vector using the magnetometer itself would be as follows: affix a non-magnetic rod to the sensor in such a way that it passes through the center of the sensor (usually the magnetometer staff is such a rod). At a point perhaps 30 to 50 centimeters away from the sensor, place a needle or other very long but thin ferromagnetic (steel) object (it does not necessarily have to be permanently magnetized) along the axis of the rod. Take this rigid arrangement of staff, sensor and needle (small dipole) and slowly re-orient the staff until a maximum or minimum total field intensity reading is obtained. The orientation of the staff at the maximum or minimum will be precisely along the earth's field vector. (NOTE: for a soft iron needle with no permanent magnetization there will also be a minimum at right angles to the field, but it is presumed that at least the general direction of the field is known)

Ideally, the sample should be as equi-dimensional as possible and should be at a distance of 5 times the diameter or greater if the approximation of a dipole is to remain valid. However, the size of the sample, distance from the sensor, and the maximum possible anomaly at the magnetometer are all compromises and for low susceptibility samples, a useful measurement can still be obtained when the sample is nearly in contact with the sensor.

Random Sample Rotation for Magnitude Only

After assuring that anything moving is magnetically clean, obtain a hand specimen and hold it at arm's length away or more (at least 3 times further than the measurement distance, r) from the magnetometer sensor and obtain the reading, T_0, with the sample thus absent. Then bring in the sample to a point perhaps 15 centimeters or at some other known distance from the sensor in order to cause a change of at least several times greater than the basic resolution of the magnetometer. Obtain readings from numerous random orientations (say, every 45° of rotation) of the specimen if only susceptibility and magnitude of remanent magnetization is desired. As a more systematic procedure, orient the sample every 45 degrees about an axis normal to the reference line. Then rotate the sample 90 degrees about the reference line and rotate it again every 45 degrees. Note the maximum value, T_{max} and the minimum value, T_{min}, then remove the sample and once again check to see that the same reading, T_0, is obtained as observed at the start of the test. If the same reading is not obtained (or within 2 gammas), conduct the measurements over. If one were to plot such measurements, they would appear as in *Figure 39*.

Next, measure the diameter of the sample which should be as equi-dimensional or spherical as possible and which can be made so by taking a geology pick and hammering off the portions of the rock to produce an approximately equi-dimensional sample. Measure the average diameter, D, of the specimen and the distance, r, between the center of the specimen when rotated and the center of the sensor. *These five parameters, T_0, T_{max}, T_{min}, D, and r, are all that is needed* in the following formulae to calculate both magnetic *susceptibility* and magnetization or the induced and permanent *magnetic moments* of a small object.



$$\frac{T_{max} - T_{min}}{2} = T_r \qquad \frac{T_{max} + T_{min}}{2} - T_o = T_i$$

Figure 39. Typical Readings Obtained During Rotation of Specimen Near Sensor

For the remanent magnetization information

$$T_r = \frac{T_{max} - T_{min}}{2} = \frac{2 M_r}{r^3} = \frac{2 I_r \, {}^4/_3 \, \pi \left(\frac{D}{2}\right)^3}{r^3}$$

expressed in centimeter-gram-second (cgs) units and noting that F, T_r, T_{min}, and T_{max} are to be expressed in gauss (1 gamma = 10^{-5} gauss). M_r is the permanent or remanent magnetic moment in cgs units. All other terms are previously defined. Therefore

$$I_r = \frac{3}{2\pi}\left(\frac{r}{D}\right)^3 (T_{max} - T_{min})$$

and

$$M_r = \frac{r^3}{4}(T_{max} - T_{min})$$

where I_r and M_r are the remanent magnetization per unit volume and permanent dipole magnetic moment respectively.

For the induced parameters,

$$T_i = \frac{T_{max} + T_{min}}{2} - T_0 = \frac{2 M_i}{r^3} = \frac{2 I_i \frac{4}{3}\pi\left(\frac{D}{2}\right)^3}{r^3}$$

and $I_i = kF$

Thus

$$k = \frac{3}{2\pi F}\left(\frac{r}{D}\right)^3 (T_{max} + T_{min} - 2 T_0)$$

and $M_i = \frac{r^3}{4}(T_{max} + T_{min} - 2 T_0)$

where the susceptibility per unit volume and the induced dipole moment respectively. If the specimen is not equi-dimensional or nearly so, there will be a small error in both k and M_i.

For magnetometers with a sensitivity of 1 gamma or 0.25 gamma, the smallest magnetic susceptibility that can be measured using such techniques is on the order of 2×10^{-5} or 5×10^{-6} cgs units, respectively, for a large specimen adjacent to the magnetometer sensor. Attention should be paid not to bring very high magnetic susceptibility (10^{-3} cgs or greater) samples close to the magnetometer sensor for it would degrade the signal. High magnetic susceptibility specimens or ferromagnetic objects can be rotated at greater distances, anyway, perhaps 100 centimeters from the sensor and low susceptibility specimens at 15 centimeters or even closer. If only approximate susceptibility is required in the field, it is even possible to rotate the sample, estimating the distance of rotation from the sensor, estimating the direction of the earth's field after knowing this value from maps (the direction does not change appreciably over hundreds of miles), and then estimating the diameter of the specimen. Such a measurement should not require more than one minute to obtain a value within a factor of 2 or better for both the susceptibility and remanent magnetization.

Systematic Rotation for Magnitude and Direction

In contrast to this highly simplified and approximate method for measuring susceptibility and remanent magnetization using the random orientation procedures outlined above, one may wish to obtain the values more systematically, more precisely and most important, to obtain directional information describing particularly the remanent magnetization and permanent moment. If such is desired, the object is rotated in all three orthogonal planes to obtain the components and to separate the effects of the induced and permanent magnetizations. The magnitude of the induced perturbations for the orthogonal directions would be T_i, as before, since ${}_xT_i = {}_yT_i = {}_zT_i = T_i$, the object is assumed to be spherical and with isotropic susceptibility; and ${}_xT_r$, ${}_yT_r$ and ${}_zT_r$ for the orthogonal components of the remanent perturbations.

These components would be obtained as follows: first rotate the object through 360° about any line normal to the reference line, i.e., earth's field. Note, T_0, the value of the field with no object present and the values at rotation positions 90° apart, namely, T_{90}, T_{180}, T_{270} and T_{360}. For these measurements one has

$${}_xT_r = \frac{T_{180} - T_{360}}{2}, \quad {}_yT_r = \frac{T_{90} - T_{270}}{2},$$

and

$$T_i = \frac{T_{360} + T_{180}}{2} - T_0 = \frac{T_{90} + T_{270}}{2} - T_0$$

The object is then removed and reinserted on the reference line so that the former axis of rotation (in this case, the z axis) is now parallel to the field. Measure this field value and one at 180° from this position to get

$${}_zT_r = \frac{T_{z=360} - T_{z=180}}{2}$$ and if one wishes, the

redundant value $T_i = \frac{T_{z=360} + T_{z=180}}{2} - T_0$

The calculations of k, M_i and I_i are performed as described above. The magnitude of the remanent moments, however, would then be

$${}_xM_r = \frac{r^3}{2}\,{}_xT_r, \quad {}_yM_r = \frac{r^3}{2}\,{}_yT_r \text{ and } {}_zM_r = \frac{r^3}{2}\,{}_zT_r$$

and the total moment, $M_r = ({}_xM_r^2 + {}_yM_r^2 + {}_zM_r^2)^{1/2}$

The direction of the remanent moments would be given by the direction cosines $\cos\alpha$, $\cos\beta$, and $\cos\gamma$ where

$$\frac{{}_xM_r}{M_r} = \cos\alpha, \quad \frac{{}_yM_r}{M_r} = \cos\beta \text{ and } \frac{{}_zM_r}{M_r} = \cos\gamma.$$

The remanent magnetizations, ${}_xI_r$, ${}_yI_r$ and ${}_zI_r$, also defined as dipole moment per unit volume, are in the same direction as their respective moments and are given by

$${}_xI_r = \frac{{}_xM_r}{V}, \quad {}_yI_r = \frac{{}_yM_r}{V} \text{ and } {}_zI_r = \frac{{}_zM_r}{V}$$

Therefore $I_r = ({}_xI_r^2 + {}_yI_r^2 + {}_zI_r^2)^{1/2}$

For shapes other than spheres other formulae must be used for the geometric factors. If the magnetization is larger than, say, 0.1 cgs, demagnetization factors must also be considered which are usually available in tables expressed in terms of the length-to-diameter ratio and direction of magnetization. Demagnetization arises from the fact that the object itself creates an induced field, which as pointed out earlier, opposes the ambient field

in the region to the side of the object (with respect to the field direction). The inducing field is thus smaller and the magnetization less than would be predicted without accounting for the effects of this demagnetization.

Dipole in Earth's Field

For measurements which are not precisely along the "reference" line or normal to it, it may be instructive to examine the properties of the dipole and properties of a permanent or induced dipole located within the vicinity of a total field magnetometer (see also Chapter V).

The field of a magnetic dipole can be expressed in terms of its tangential and radial components, T_θ and T_r where

$$T_\theta = \frac{M}{r^3} \sin\theta$$

and

$$T_r = \frac{2M}{r^3} \cos\theta$$

and where θ is the angle between the dipole axis and r the line between the dipole and point of measurement as in *Figure 40*. The magnitude of the field intensity of the dipole can thus be expressed as

$$T = (T_\theta^2 + T_r^2)^{1/2}$$
$$= \frac{M}{r^3} (1 + 3\cos^2\theta)^{1/2}$$

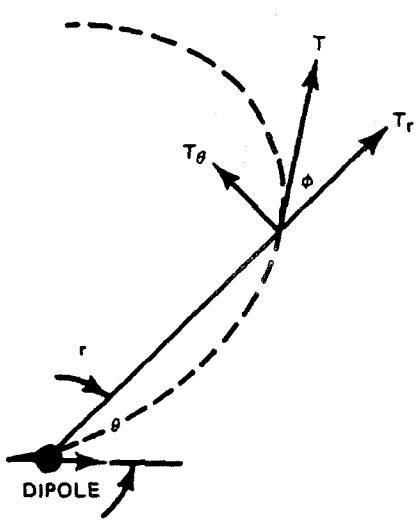


Figure 40. Terms Used in Calculating Effect of Dipole on Earth's Field.

The total field perturbation T_F due to a magnetic dipole at an angle β to the earth's field as shown in *Figure 41* is simply the component of the dipole field in the direction of the total field or

$$T_F = \text{comp}_F T = T\cos(\phi + \theta + \beta)$$

and from the above geometry of a dipole

$$T_F = \frac{M}{r^3} (1 + 3\cos^2\theta)^{1/2} \cos\left[\tan^{-1}\left(\frac{\tan\theta}{2}\right) + \theta + \beta\right]$$

Non-Spherical Object Rotation

An entirely different situation occurs when the object is not equi-dimensional but possesses a high length-to-diameter ratio as in the case of a long, narrow cylinder.

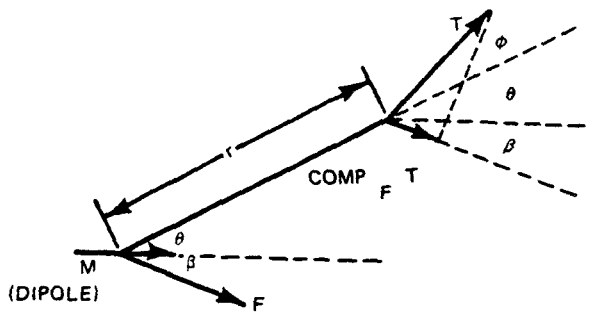


Figure 41. Reference Diagram for Estimating Effect of Dipole in the Plane of the Earth's Field

In this case, the induced field tends to align itself with the long dimensions of the object in a positive sense 90° or less in the direction of the ambient field for ferromagnetic objects. Such an object, if rotated end-over-end in a plane containing the ambient field, will produce a dipole moment which is nearly parallel to the axis of the object which is always positive and which varies in magnitude from the maximum parallel to the field to a minimum at right angle to the field. In an object which possesses both permanent and induced magnetic moments and in addition has a high length-to-diameter ratio, the effects are algebraically additive, but at any one orientation, nevertheless, appears as a dipole whose direction is the vector sum of the induced and permanent dipole moments.

The nature of the variation of intensity with respect to the rotations described will differ considerably depending upon the relative magnitude of the induced and permanent magnetization and upon the shape of the sample. Typical situations are expressed diagramatically in *Figure 42*. All rotations are shown as they would appear if they were rotated about one point on the reference line containing the earth's field except as noted for the last example.

In the above procedures for measuring moment, one may note that all measurements are made along the line containing the earth's field. It is also possible to make such measurements magnetically east or west in a horizontal line from the sensor *(see Figure 38)*. However, as it may be noted from the expression for the dipole moment and from the properties of the dipole outline in Chapter V, the total field perturbation will be only one-half that which would be observed as suggested above on a line containing the sample, sensor and earth's field. Furthermore, a positive magnetization or increase in magnetization from a sample rotated east or west of the sensor will cause an inverse effect or decrease in the field at the sensor as may be noted by the direction of the field lines at a point on a line normal to the axis of an induced or permanent dipole.

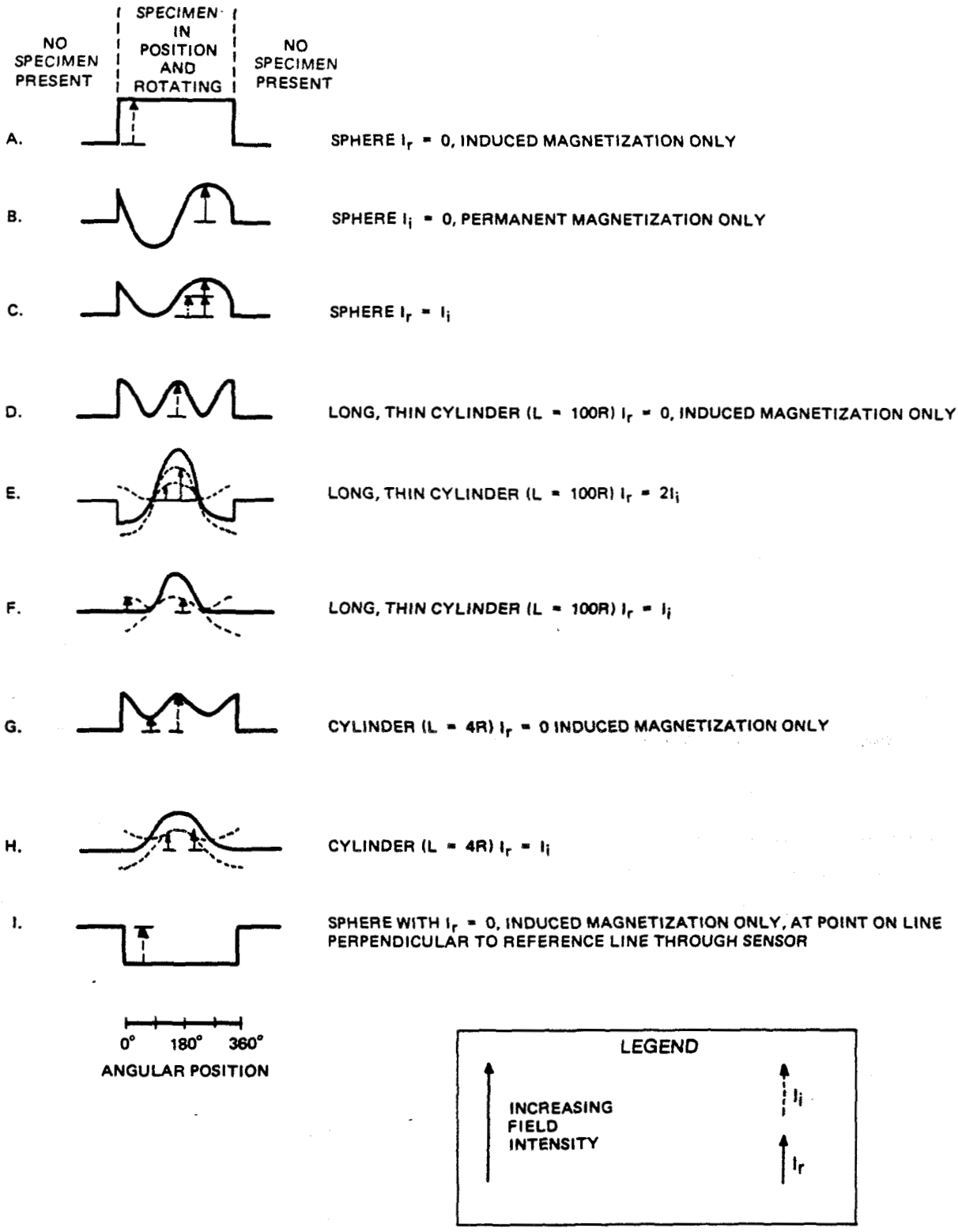


Figure 42 Total Field Variations Due to Rotation of Specimen Near Sensor

VII.

MAGNETIC SEARCH

Introduction

Portable magnetometers can be very usefully applied to the task of finding objects which are buried, submerged, or otherwise hidden from view. An object can be found directly where it is itself magnetic, or where it may displace material which is otherwise uniformly magnetic. An object may, in some instances, be found indirectly when it produces a magnetic anomaly as a consequence of it being buried or emplaced. The object of a search may involve a man-made iron or steel object, an archaeological feature such as a brick, pottery, or tomb, or an intentionally buried magnet used for relocation purposes. In fact, among the diverse buried or sunken objects for which magnetometers have been used for their search are: culverts, pipelines, buried magnets, survey benchmarks, ships, vehicles, weapons, boat and aircraft engines, flight recorder, skiis, buried skier with affixed magnets, rails, wellheads, machine tools, chain and anchors, tunnels, and the numerous items listed under Archaeological Prospecting below. In each of these cases, the objects could be found and their depth and mass estimated—but only if several conditions exist favorable to magnetic search procedures.

The techniques outlined here are primarily for portable magnetometer search applications on land except as noted. Marine search techniques involve other specific tactics, magnetometer sensors and cables designed for underwater use, and continuous recording displays.

Determination of Object Magnetism

In assessing whether a magnetometer would be useful in a search, *it must first be determined whether the object* (direct or indirect) of the search *is truly magnetic.* Iron and steel, for the purposes discussed here, are the only metals which are ferromagnetic and, among these, stainless steel (300 series) can usually be considered non-magnetic. All naturally-occurring rocks and soils are weakly magnetic as a consequence of the amount of naturally-occurring magnetite present. Moreover, when such materials are heated, they attain a much higher magnetism upon cooling from a high temperature as would occur naturally in igneous rocks or artificially in kiln-baked clay. Magnets and coils carrying direct current are also detectable with a magnetometer. Buried chambers, tombs, some caverns, lava tubes and other subsurface voids are also detectable if they occur at a shallow depth in an otherwise uniformly magnetic material.

Detectability

The most important single factor affecting detectability with a magnetometer is the distance between the magnetometer and the object; for, most anomalies in a search vary inversely as the cube of this distance, i.e., $T = M/r^3$. Thus, any effort made towards reducing this distance greatly increases the likelihood and one's ability in finding the object of search. The next most important consideration is the amount of ferromagnetic material associated with the object in contrast with the surrounding material. The effective magnetic mass (magnetic moment) of the object can be considered to be the degree of magnetism of the material times the volume of such material (e.g., a small magnet can be as magnetic as an automobile or a very large cavern).

The last significant criterion for detectability is the expected background magnetic noise arising from such sources as geology or man-made materials and electric current. In general, volcanic or dark-colored igneous rocks and soils derived from such rocks are very magnetic and render it difficult to detect a small, subtle anomaly. Common artificial sources of noise include power lines, direct current electric cables and trains (see Chapter IX), iron and steel debris and major cultural features including buildings, roads, fences, pipelines, reinforcing steel in concrete, etc. By and large, most sedimentary rocks (sandstone, shale, limestone, chert) and their metamorphic equivalents, salt or fresh water or air do not alter the magnetic anomaly in any way; it is then simply the distance between the sensor and object that is important when buried in such materials.

Magnetic Anomaly Signatures

The typical object of search is relatively small with respect to the distance between it and the magnetometer. Irrespective of its shape, *the object would* then *behave as a magnetic dipole* with all the characteristics described in Chapters V and VI. Typical dipole anomaly signatures (anomalies) expressed as profiles and contour maps at various orientations of the magnetic moment of the object and at various inclinations of the field appear in *Figure 43.* The anomaly shape expressed in *Figure 43* is primarily a function of the magnetic latitude and the direction of the permanent (remanent) magnetic moment. For example, given a magnetic profile or map over any dipole and some familiarity with total field magnetics, one should be able to recognize the inclination of the field and perhaps also the orientation of the object as a dipole.

Depth/Amplitude Behavior

As described in Chapter V, the anomaly will appear broader proportionately as the object is deeper or more distant (NOTE: the object is not always beneath a given traverse, but more than likely is at a distance to one side of the traverse. The distance between magnetometer and object herein referred to as depth may, in fact, only represent the 'closest approach' requiring perhaps another traverse to be truly 'over' the object). This anomaly width/depth characteristic of magnetic anomaly behavior serves as a means for determining the depth to the source which can be used to one's advantage in a search (see Chapter V). The amplitude of the anomaly will, as stated, also decrease inversely as the cube of this distance. An example of anomaly depth and amplitude behavior is shown in *Figure 44* which can be extrapolated to the other signatures which appear in *Figure 43.*

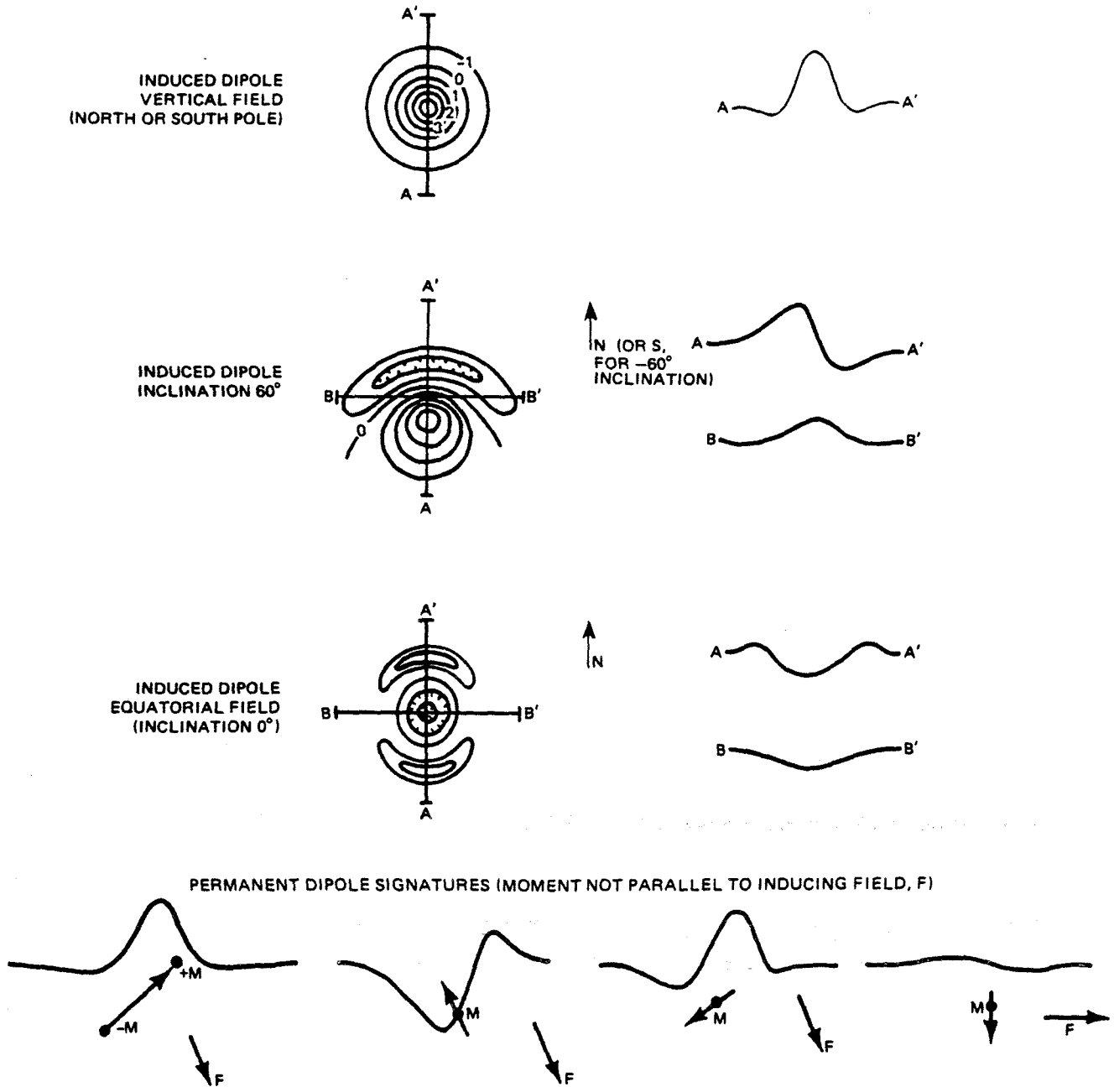


Figure 43. Total Intensity Signatures at Various Inclinations of the Field and for Induced or Permanent Magnetic Moments

Figure 44. Depth/Amplitude Behavior of Dipole Anomalies

Search Procedures

Determination of Magnetic Moment vs. Search Grid vs. Resolution

The first consideration in conducting a search is to determine as much as possible what is magnetic, if anything, in the object or related to the object. Frequently, a similar object can be obtained and measured in the presence of a magnetometer at varying distances and orientations according to the methods outlined in the previous chapter. Remember that it is only the mass of ferromagnetic material and not the mass of the entire object that is of importance in magnetic search. Once the ferromagnetic mass is estimated, it is possible, using the simplified formulae below, to determine the maximum probable anomaly at various distances. Estimation of this maximum anomaly is important to determine whether the object is even detectable at the surface and, if so, how close the readings should be spaced on a traverse and the distance between adjacent traverses (spacing of the grid) if such a plan is considered. Ideally, one should lay out a regular grid covering the area such that the anomaly is readily detectable on any two adjacent traverses, i.e., there be some overlap in the detectability distance. To be sure, there are situations where very little is known about the object, whether it is even detectable at all magnetically, and the area in which it lies cannot for various reasons be covered at the proper grid interval.

It is important to realize that in order to recognize an anomaly, it must be several times larger than the sensitivity (resolution) of the magnetometer and the effective 'noise level' of the profile. If one has, say, a magnetometer of 0.25 gamma sensitivity and anomalies of 0.5 gamma due to the effects of surface soil, then the object would have to exhibit an anomaly of perhaps 1 gamma or more in order to be readily identified. This is even more important when the object is very deep for the anomaly is then very broad and may be confused with broad background changes due to deeper-seated geology or more distant anomaly sources. Therefore, a given object buried at 3 feet may have an anomaly width of 5 to 10 feet and may be detected if the anomaly is only 2 or 3 gammas in amplitude. Another object buried at 30 feet would correspondingly have an anomaly width of 50 to 100 feet, but may have to be 10 gammas in amplitude in order to be discernible in the presence of the normal background magnetic gradients.

Traverses

Several theoretically-derived search procedures have been devised which use spiral paths, statistically determined grids and search sequences to cover a given area under investigation. The method suggested here is merely a simple set of parallel traverses with readings obtained to cover the area by a square grid of readings.

If no other constraints dictate the direction of the principal traverses, they should be made in a north-south direction, for in any latitude there will be a greater peak-to-peak magnetic anomaly in this direction. As may be observed on the contour map of *Figure 43*, the maximum and minimum of an anomaly will be adjacent on such a line thereby creating a larger effective peak-to-peak anomaly and a maximum rate of change or slope, both of which enhance its detectability. In the case of long horizontal pipelines, traverses should be made perpendicular to the probable direction of the pipelines (except for north-south pipelines at the magnetic equator where there is no anomaly over the mid-portions of the pipeline except for perhaps small permanent magnetization anomalies at pipe-section junctions).

The sensor should be held within several feet of the ground for small objects buried at shallow depths. There are occasions, however, when the sensor should be carried higher at perhaps 6 feet or more above the ground such as a situation where surface magnetic noise exists and where the anomaly depth is greater than perhaps 15 or 20 feet. In this case, the surface anomalies may be decreased by a factor of 20 or 30 while the anomaly of the object may only be decreased by a third greatly improving the visibility of the anomaly. If the situation allows, it is always recommended that a regular grid indeed be established and followed using local reference points, perhaps walking along a long string which is moved for each traverse, or possibly moving by a combination of dead reckoning and pacing, marking the lines already covered by pouring a visible powder such as lime or flour on the ground.

It is important to cover the area objectively and to know where one has already mapped and has yet to map. If a large area is to be covered, it is usually best not to be deterred from completing the measurements for an entire grid before returning to possible anomalies for more detailed measurements. It is indeed frustrating to those involved with the search not to 'follow-up' immediately any preliminary indications of an anomaly, but the net result is poor coverage of the grid, missed areas, lack of time to complete the grid, and disappointment in uncovering the wrong objectives. Where the area is large, the target of sufficient importance, and time of the essence, two or more magnetometers should be employed using one simply to pinpoint and follow-up each anomaly location and depth while the other continues to map the area under investigation.

Detailed Mapping for Pinpointing Location

After locating a given anomaly on a traverse, its location on the traverse should be so noted. As stated above, whatever the grid dimension, *it is likely that the object is not precisely under the original traverse, but rather to one side.* Therefore, the next traverse should be perpendicular to the original traverse at a point on the latter where the maximum horizontal rate-of-change (gradient) is observed. On this second or perpendicular traverse, the anomaly is usually of much greater amplitude and larger rate of change with distance indicating, of course, that one is closer to the object of search. A third traverse perpendicular to this second traverse and parallel to the original might be required if the exact location of the object is desired. Typical profiles, from a sequence of three such traverses are shown in *Figure 45* (the horizontal location cannot usually be determined to a precision greater than approximately 10% of the depth to the center of the dipole).

One then may wish to qualitatively compare the observed signature with those in *Figure 43* to determine the location in plan view of the object. Alternatively, one may use as a rule of thumb, the criterion that for locations in the magnetic polar or equatorial regions of the earth, the object is probably located at the greatest maximum or minimum and for regions elsewhere the object is nearest the point on the anomaly where there is maximum horizontal gradient or rate-of-change. The variability of the orientation of the usually unknown perma-

nent moment and any very large or extended shape of the object may create complexity of anomaly shape in the 'near field' of an object. (NOTE: the magnetometer signal may also disappear which itself indicates a high gradient and therefore the near presence of an object.)

It may be important during this detailed mapping phase of a search to be able to recognize an anomaly of interest quickly so as to minimize the efforts involved in this localized remapping of what appears to be an anomaly of interest, but after the fact turns out to be something much too small, much too deep, or much too shallow had one been able to recognize certain anomaly characteristics. Approximate depth estimation is useful when also used, in turn, for estimation of the size of the object according to the order of magnitude methods described in the following. (See Chapter VIII for accurate depth determination using readings at two sensor positions.)

Special Search Topics

Iron and Steel

The maximum anomaly amplitude for a variety of objects can be estimated given their size, weight and description by using the formulae presented in Chapters V and VI. For typical man-made iron or steel objects, the magnetic moment, M, is between 10^5 and 10^6 cgs units per ton (either 1000 kg or 2000 lbs.), where

$$T = \frac{M}{r^3}\left(\text{for latitudes greater than } 60^\circ\text{, use } T = \frac{2M}{r^3}\right) \text{and}$$

T is the anomaly in gauss, M is the dipole moment in cgs and r the distance in centimeters. Thus the maximum anomaly for 0.1 ton of iron at a distance of 1000 centimeters would be between

$$T = \frac{10^5}{(10^3)^3} \times 0.1 = 10^{-5} \text{ gauss}$$

$$\text{and } T = \frac{10^6 \times 0.1}{(10^3)^3} = 10^{-4} \text{ gauss}$$

$$\text{or} \qquad 1 \text{ gamma} < T < 10 \text{ gammas}$$

This same formulae for a magnetic anomaly can be expressed directly in terms of gammas, pounds, and feet, if desired, for

$$1.75 \times 10^2 < M_{fps} < 1.75 \times 10^3$$

and

$$T = \frac{M_{fps}}{r^3}$$

where T is the anomaly in gammas, M the magnetic moment per pound or iron, and r the distance in feet between the object and the magnetometer. A ton of iron is therefore between 0.35 and 3.5 gammas at 100 feet or as a rule of thumb, can best be remembered as 1 ton of iron is 1 gamma at 100 feet. *Figure 46* is drawn as a nomogram or guide in estimating anomaly amplitude for a dipole comprised of common iron or steel.

Permanent vs. Induced Anomaly Sources

In general, iron objects exhibit both permanent and induced magnetization which have a net magnetization producing a single magnetic anomaly in the earth's field as measured by the magnetometer. All rules herein

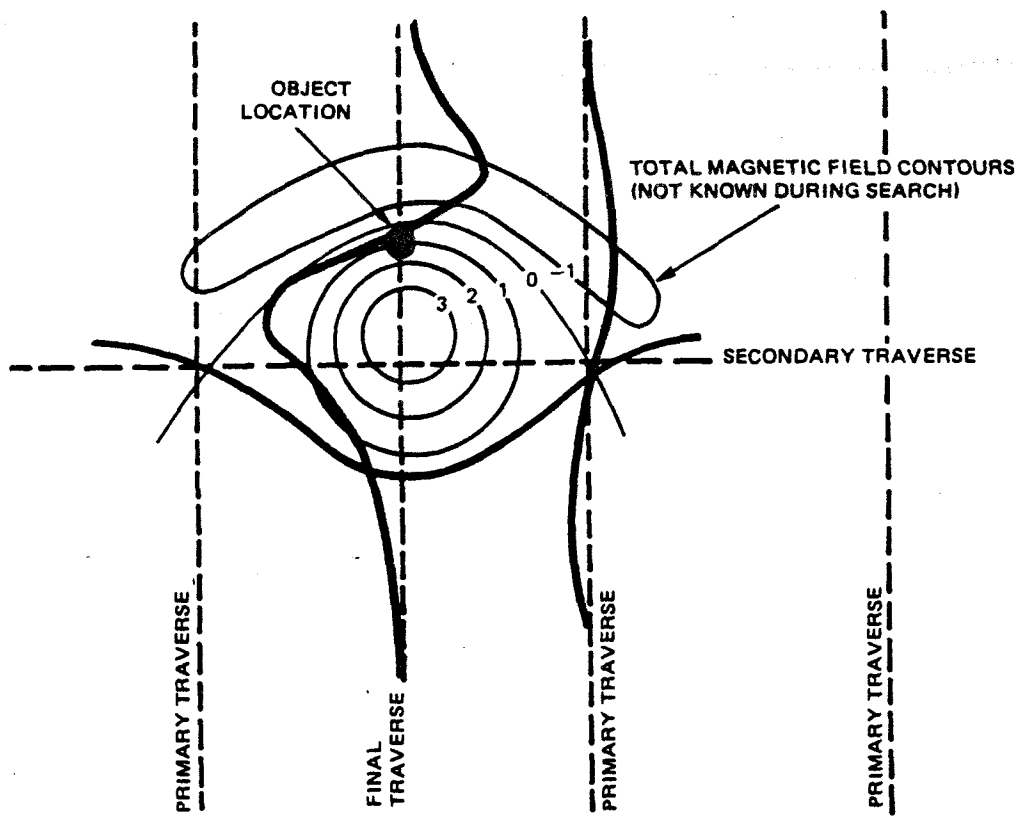
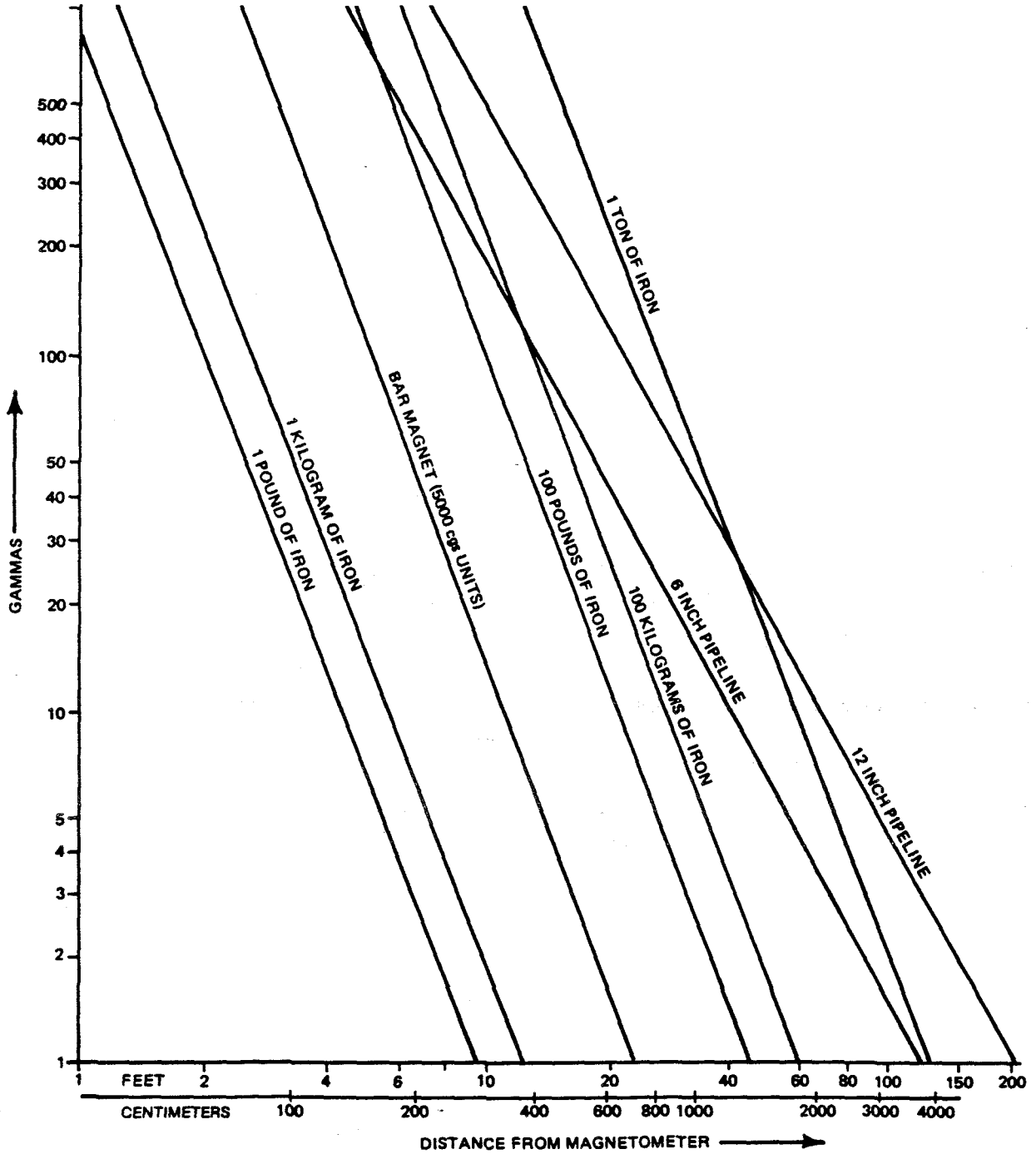


Figure 45. Typical Sequence of Traverses During Search Procedures (Profiles drawn on respective traverse lines)

Figure 46. Nomogram for Estimating Anomalies from Typical Objects (assuming dipole moment M = 5 X 10^5 cgs/ton, i.e., k = 8 cgs. Estimates valid only within order of magnitude)



INSTRUCTIONS FOR USE:

To use the nomogram, select a given weight or type of object from among the diagonal labeled lines. Then choose a distance along the bottom line (abscissa) of the graph and follow a vertical line upwards from that distance until it intersects the diagonal line of the selected object. At that point, move horizontally to the left to a value on the vertical axis (ordinate) of the graph and read the intensity in gammas.

At a given distance, the intensity is proportional to the weight of the object. Therefore, for an object whose weight is not precisely that of the labeled lines, simply multiply the intensity in gammas by the ratio of the desired weight to the labeled weight on the graph. If the distance desired does not appear on the graph, remember that for a typical object the intensity is inversely proportional to the cube of the distance and for a long pipeline the intensity is inversely proportional to the square of the distance between magnetometer sensor and object. Due to the many uncertainties described herein, the estimates derived from this nomogram may be larger or smaller by a factor of 2 to 5 or perhaps more.

assume for simplicity, that the anomaly is produced by the induced moment only. Nevertheless, the harder the steel, the more permanent magnetization it possesses, which at times may be 10 times or more than the induced magnetization. Although one cannot usually predict the orientation of the permanent moment of a buried object, it can be assumed that the larger the permanent magnetization, the larger the anomaly and the susceptibility, k, used in the formulae herein is really an effective k intended to include such increased magnetization. A single large part, such as a single pipe or an engine, etc., may exhibit one single anomaly due largely to the permanent moment. Conversely, the more component parts an object has, the more these individual permanent magnetic moments tend to cancel, leaving only the induced magnetization. When the permanent and induced moments are of the same order of magnitude (see revolvers, for example, in table of anomalies on page 46), and the permanent moment happens by chance to be oriented in an opposite direction to the earth's field, the observed anomaly would be very small, but almost never zero. Whether or not an object has a large or small permanent moment is not consequential except in explaining the unusual shape of the anomalies one might observe as compared to the anomaly signatures shown in *Figure 43*. (Note: Stainless steel, type 300, particularly Stainless 310, is practically non-magnetic. Similarly, manganese steel is only weakly magnetic.)

If one is able to measure the susceptibility, permeability or the magnetic moments by the procedures in Chapter VI, the following expression (also presented in Chapter VI) could be used to estimate the maximum anomaly amplitude

$$M = kFV$$

where M is the dipole magnetic moment in cgs units, k the susceptibility which is between 1 and 10 cgs units for most iron and steel objects, F the ambient field in gauss, and V the volume in cubic centimeters. If permeability, μ, is to be used, recall that $\mu = 1 + 4\pi k$, numerically. Attention should be paid to the effects of demagnetization (Chapter VI under "Systematic Rotation for Magnitude and Direction") which describes the fact that an anomaly from a more-or-less spherical iron object may not be as large as predicted from consideration of μ or k alone.

Pipelines (horizontal)

Most pipelines have very high permanent magnetization and show separate anomalies for each length of pipe, i.e., anomalies at each joint due to their independent thermal and mechanical histories. Valves and other attachments to pipelines show separate anomalies as well. A horizontal pipeline in steeply dipping fields or E-W at the equator varies inversely as the square of the distance between its center and the magnetometer and behaves as a line of dipoles as described in Chapter V. Thus, the maximum anomaly amplitude from a pipeline can be estimated as follows:

$$T = \frac{M}{r^2} = \frac{kFA}{r^2} = \frac{kF\pi Dt}{r^2}$$

where A is the approximate cross-sectional area of iron, and D and t are the pipe diameter and wall thickness respectively in the same dimensional units as the distance, r, and the other factors as used above. For most pipes, the steel is 'hard' and k (effective) is therefore high, perhaps, 10 to 50 cgs or higher. For example, consider a horizontal pipeline diameter 6 inches, wall thickness ¼ inch in a field of 50,000 gammas buried at a depth of 20 feet beneath the magnetometer,

$$T = \frac{10 \times 5 \times 10^4 \times \pi \times 6 \times \frac{1}{4}}{(20 \times 12)^2} = 40 \text{ gammas}$$

The expression, πDt, represents the approximate cross sectional area of the thin wall of the pipe. A more precise but more complicated expression for this area might be $(\pi R_o^2 - \pi R_i^2)$ where R_o and R_i are the outside and inside diameters of the pipe respectively.

For solid pipes, rods, or steel cable, a similar expression is used,

$$T = \frac{kFA}{r^2} = \frac{kF\pi R^2}{r^2}$$

where R is the radius of the rod.

The anomaly signature for pipelines in various directions and field inclinations would appear as in *Figure 47*. (Note the difficulties in detecting N-S pipelines in equatorial regions described above under "Traverses" and Chapter V.) The permanent magnetic moment is often predominant in a pipeline and may commonly exhibit a signature as shown in *Figure 47* with the maxima and minima reversed and a very large amplitude. A pipeline is generally easy to detect because its great length often assures one of actually crossing it. Also, the signature varies inversely as the square of the distance instead of the cube of the distance as in the case of a dipole (pipelines are lines of dipoles) and the anomaly amplitude thus remains large. If one has access to both ends of a hidden pipeline, it is also possible to pass a large DC current through it to aid in its detection by enhancing its magnetic field selectively in space or time. For example, to find one pipeline out of many possible interfering pipelines, pass a current through it for one reading and reverse the current for the next, taking two such readings at each point. The location of the one anomaly can be so mapped as the difference in these values becomes larger as one is closer to the pipe. (1 ampere of current through an infinitely long pipe would produce 10 gammas at 60 feet and would in this case produce 20 gammas peak-to-peak and vary inversely as the distance to the pipe. However, observe the geometry noted in Chapter IX.)

Magnetic Markers

It is often of interest to be able to relocate oneself or an object over a long period of time. The purpose may be to locate a survey benchmark, an important junction in a pipeline, or a point in shallow marine waters. In lieu of a radio transmitter or other active source, it is possible to bury a magnet which should keep most of its magnetic moment for many years or longer and at a depth sufficiently below any level that is likely to be disturbed. In some cases, it may be reasonable to bury several magnets oriented to produce maxima or minima or in a pattern to assure easy relocation or to differentiate one magnetic marker from another. Given a specialized requirement, a solenoid coil or single long wire with an applied direct current may also serve such a relocation purpose.

A magnet of convenient size and made of Alnico V is available in the form of a thumb-size 'cow-magnet', a

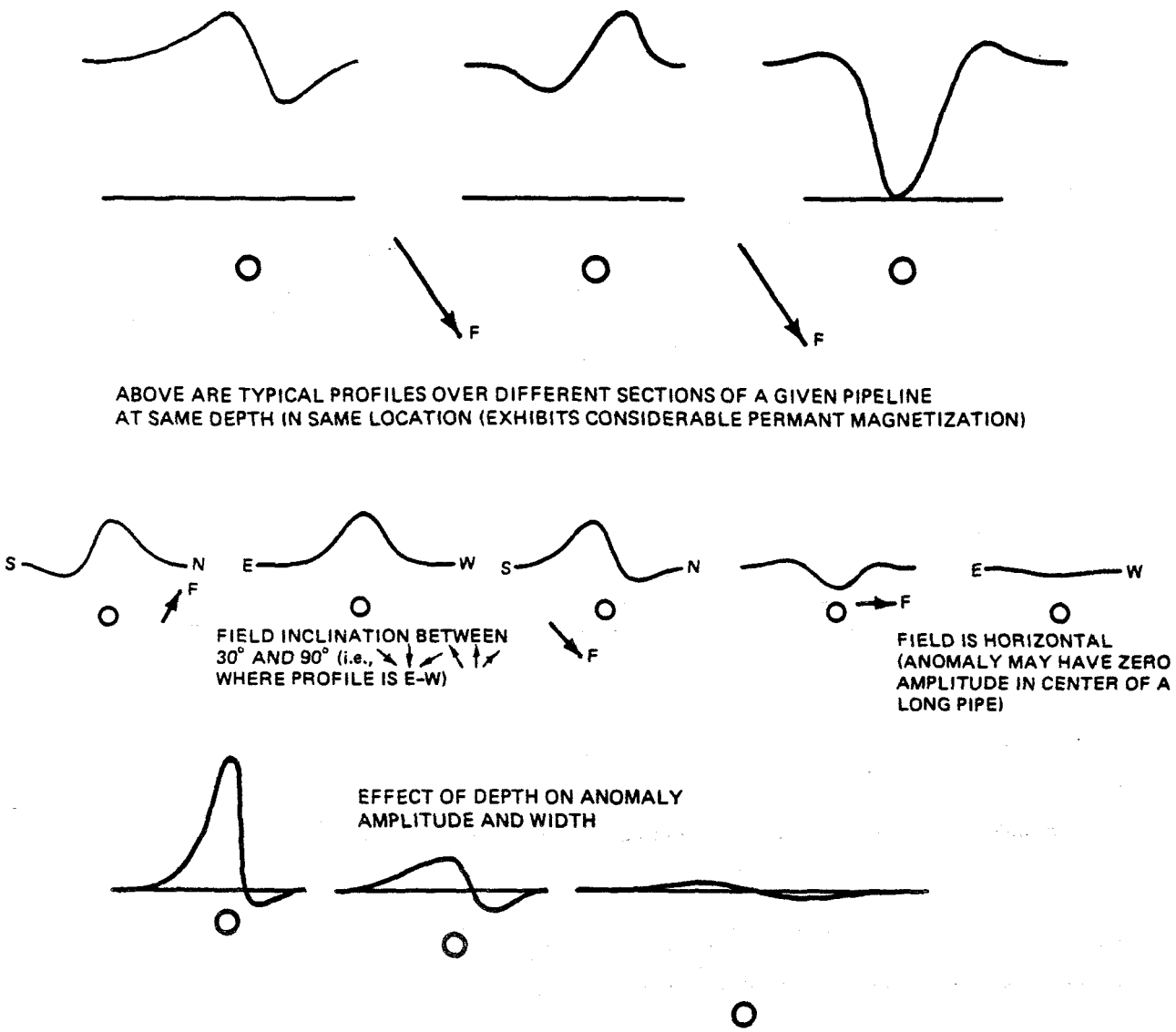


Figure 47. Pipeline Signatures

cylinder ½" in diameter by 2¾" long, which will produce a magnetic moment of 5000 cgs units, or an anomaly of approximately 20 gammas at 10 feet. (Such magnets are available through the 'Farm' catalog of several large mail-order firms.) For comparison, a cylindrical Alnico V magnet 2" in diameter by 10" long will produce an anomaly of 1 gamma at 100 feet. Both anomalies will vary inversely as the cube of the distance and directly with the number of magnets laid end-to-end with opposing poles in contact with each other. Expressed in the terms above for calculating moments, such magnets would usually have an intensity of magnetization or magnetic moment per unit volume, I, of approximately 500 gauss per cubic centimeter.

The following table is illustrative of the magnitude of the anomalies which may be produced by several common objects. The values are merely typical and may easily by larger by a factor of 5 or smaller by a factor of 10 depending upon the actual size of the object, its metallurgy, orientation, permanent magnetization, number and relative size of component parts, position of the magnetometer relative to the object and to the field and other parameters discussed in Chapters V and VI.

Archaeological Exploration

Introduction

Magnetometers have been used for exploration at numerous archaeological sites around the world to detect such features as buried walls and structures, pottery, bricks, roof tiles, fire pits, buried pathways, tombs, buried entrances, monuments, inhabited sites, and numerous objects submerged in water such as ships, ballast stones, iron, cannon, amphora, various potsherds, etc. Most of these objects were detected and mapped as a result of their being more magnetic than the surrounding or covering material. A few features such as certain buried walls and tombs were not, themselves, magnetic, but displaced a uniformly magnetic soil which presently covers them. Still other sites both historical and archaeological have iron objects which are easily detectable according to the methods described in the preceding section.

Magnetic Anomalies of Archaeological Origin

Anomalies exist at archaeological sites as a consequence of the contrast in magnetic properties between the cultural features of interest and the surrounding medium,

Table of Anomalies of Common Objects

Typical Maximum Anomaly

Object	Near Distance	Far Distance
Automobile (1 ton)	30 feet 40 gammas	100 feet 1 gamma
Ship (1000 tons)	100 feet 300 to 700 gammas	1000 feet 0.3 to 0.7 gammas
Light Aircraft	20 feet 10 to 30 gammas	50 feet 0.5 to 2 gammas
File (10 inch)	5 feet 50 to 100 gammas	10 feet 5 to 10 gammas
Screwdriver (5 inch)	5 feet 5 to 10 gammas	10 feet 0.5 to 1 gamma
Revolver (38 special or 45 automatic) (induced approximately equal to permanent, see text)	5 feet 10 to 20 gammas	10 feet 1 to 2 gammas
Rifle	5 feet 10 to 50 gammas	10 feet 2 to 10 gammas
Ball Bearing (2mm)	3 inches 4 gammas	6 inches (0.5 feet) 0.5 gamma
Fenceline	10 feet 15 gammas	25 feet 1 to 2 gammas
Pipeline (12 inch diameter)	25 feet 50 to 200 gammas	50 feet 12 to 50 gammas
DC Train	500 feet 5 to 200 gammas	1000 feet 1 to 50 gammas
'Cow' magnet (½" W, 3" L)	10 feet 20 gammas	20 feet 2 gammas
Well casing and wellhead	50 feet 200 to 500 gammas	500 feet 2 to 5 gammas

(Note: anomalies are only representative and may vary by a factor of 5 or even 10 depending upon the many factors described herein)

both of which are usually composed of material of natural origin such as rocks or soil or even empty space. This magnetic contrast is a function of the concentration and thermal and mechanical history of magnetite present in either the cultural feature or its burying medium. The amount of magnetite determines the magnetic susceptibility and therefore the induced magnetization as described in Chapter III for various configurations and for a variety of natural materials. Remanent magnetization, commonly present in materials which have undergone heating, is responsible for the most prominent anomalies arising from cultural features (with the exception of iron).

Remanent Magnetization

The remanent magnetization of archaeological objects is particularly significant not only because of its large relative intensity, but because it is intimately associated with many enduring objects of ancient habitation, namely, baked clay which comprises bricks, tiles, pottery, kilns, hearths and similar features. This remanent magnetization otherwise called thermoremanent magnetization (see Chapter III) is created when the magnetite-bearing clay is heated to a relatively high temperature and cooled in the presence of the earth's magnetic field. Magnetic domains within each magnetite crystal are at first randomly oriented then move about during heating. Upon cooling, many domains align themselves with the ambient or earth's field and thus parallel to each other creating a net magnetization fixed with respect to the object and parallel to the earth's total field at the time of cooling.

Archaeomagnetism

Such objects are not only easier to find than most other objects at archaeological sites, but in certain cases, where their kiln-baked position with respect to the vertical is known, they can also be used to estimate the age of the object. The age can be determined by measuring the inclination of the remanent magnetization (by methods described in Chapter VI) which occurred at the time it was baked. This magnetic inclination can then be compared with the history of the variation of the earth's magnetic inclination known through historical records and other fire-baked clay objects already dated by other methods.

Magnetization and Susceptibility of Soils

Soils exhibit a magnetic susceptibility related in general to the susceptibility of the rocks from which they were derived, i.e., soils from volcanic or other igneous rocks have a higher susceptibility than soils weathered from sandstone, limestone or shale. However, magnetite being among the most resistant minerals appears to be present in the soils in higher proportion than other, more soluble minerals. In addition, organic action particularly in high-humus soils, is thought to be responsible for the formation of the magnetic mineral, maghemite, from other non-magnetic forms of iron oxide—a phenomenon of importance in mapping features associated with habita-

tion. Therefore, soils may have a somewhat higher susceptibility than would be indicated by the parent rock susceptibility, soils of 10^{-4} cgs being common. This surface magnetite is also a source of magnetic noise in precision magnetic surveys performed very close to the surface of the ground when the magnetite, by the action of surface waters and gravity, collects into small pockets of placer magnetite common almost everywhere in the microtopography of the ground surface.

Remanent Magnetization of Soils

Of additional significance to archaeological exploration is the presence in surface soils of remanent magnetization often with twice the intensity of induced magnetization. This magnetization is due sometimes to heating, but more probably to 'viscous' magnetization attained slowly in place (during tens to thousands of years) and the formation in situ of maghemite by the organic processes cited above. This remanent magnetization is most common in the upper layers of soil and if disturbed by cultivating, by digging graves, by foot or animal traffic, or by other physical disruption of the integrity of the soil, is destroyed creating a locally negative anomaly, often mappable with a portable magnetometer.

Magnetic Anomaly Complexity

The anomalies observed at archaeological sites are in most cases very complex as a consequence of several factors. The sources which produce the anomalies are relatively shallow and therefore close to the magnetometer which emphasizes the extremely complex nature of the 'near field' of any magnetic object. Also, the various sources of magnetic anomalies from soils, near surface rocks and the clutter of ancient or modern human habitation, including the very objects of interest, is often very pronounced. The nature of the measurements one obtains in archaeological exploration—closely spaced and near to the ground surface—makes the data seem more noisy than they appear on the usual mineral exploration survey. An archaeological survey properly conducted, planned and interpreted, however, can often make sense of this complexity and produce meaningful interpretations from individually resolvable, magnetic archaeological features.

Archaeological Survey Planning and Feasibility

Successful application of a magnetometer to archaeological prospecting can assist an archaeological program in several ways. Most obviously, the specific site and features which are hidden from view can be located, depths estimated and excavations conducted efficiently, rapidly and more economically than if the locations were not known with any confidence. In some instances, excavations need not be performed at least initially, where boundaries of structures and the extent of the site can be mapped through magnetic surveys, e.g., salvage archaeology, extending known sites, etc.

Although it may be tempting to assume that a magnetic survey may be useful in mapping and detecting features at a given site, *it may be fair to state that most sites, a priori, are not amenable to this method.* Features may not present a detectable magnetic contrast, the magnetic background noise may be excessive or the site may be better mapped through less sophisticated means such as visually or other tried and true techniques.

The known features should first be considered or measured by the techniques outlined in Chapter VI to determine if there is, in fact, a measureable magnetization contrast (estimated by methods of Chapter V). Representative samples of both the buried features as well as the burying material should be measured with special attention to such items as: fist-size samples of structures, fire-baked large objects, soil, soil intact (to preserve remanent magnetization), humus-rich material, cultural material present in appreciable amounts, rocks which are thought to underlie the site (which may create insurmountable noise as from volcanic rocks or laterite) and other material which may be present in any significant way at the site.

Having measured the induced and remanent magnetization (not important to measure the directions), having estimated the amplitude of the anomalies and having determined the background magnetic noise, one may be able to predict whether a magnetic survey would be of significance. *One can never really be certain of its feasibility, to be sure, until a survey is attempted.*

The depth and amplitude can then be used as criteria to determine the grid, or density of individual measurements. Commonly, the area is divided into manageable quadrangles perhaps one or two hundred feet on a side and a rope, marked by colors, alternating at the grid points, is laid along one traverse line (or perhaps a rope grid is constructed). Measurements are taken at each point on the rope and the rope moved away one grid distance away from its first position, etc. Sometimes careful pacing between known grid points at the edge of the quadrangle is sufficient for the measurements. A spring-wound reel fixed to the ground at one side of the quadrangle with a distance-marked cord attached to the magnetometer-bearer is a very rapid means for measuring distance. Care should be taken to make sure a magnetic heading error does not occur when the operator faces the other direction upon returning on alternating traverses. The measured or empirically-determined offset, however, can be applied to correct for such an offset. Time variations may be removed, if small or deep anomalies are sought, by methods in Chapter IV using either a recording base station, tie lines (two or more lines which cross the traverse lines), or re-occupied stations.

The data should then be contoured (see Chapter IV) and interpreted in light of what is known about the site. After and during excavations, it may be useful to follow up the survey by mapping select areas once again after some sources are removed and if the depth to features of interest is thus markedly decreased (by access to deep and wide holes and if the soil is not too magnetic or magnetically disturbed).

Archaeological Anomaly Amplitude and Signatures

In order to estimate the maximum anomaly from an archaeological object, consider the anomaly from a single cube of rock representing perhaps a buried monument.

$$T = \frac{kF\,D^3}{r^3}$$

where T = the anomaly in gammas, k the susceptibility contrast per unit volume, F the earth's field intensity in gammas, D the dimension of one side of the cube in the same units as r, r the distance between the magnetometer and center of the cube of rock in any distance

units whatever. As an example, consider a monument of volcanic rock, $k = 10^{-2}$ in a soil of $k = 10^{-4}$, in a field of 50,000 gammas formed of a cube 2 feet on a side at a distance of 5 feet. The $k = 10^{-4}$ is so small as to be negligible in comparison with 10^{-2} and the susceptibility contrast is therefore 10^{-2}. Thus

$$T = 10^{-2} \times 5 \times 10^{4} \times \left(\frac{2}{5}\right)^{3} = 32 \text{ gammas}$$

On the other hand, a void or tomb of the same geometry and in the same soil would have a negative anomaly of

$$T = -10^{-4} \times 5 \times 10^{4} \times \left(\frac{2}{5}\right)^{3} = -0.32 \text{ gammas}$$

Note that the amplitude for the void is negative for it is opposite to what one would expect for a magnetized material since the void is simply the absence of material.

Generally speaking, a void cannot easily be detected when the distance between the magnetometer sensor and the center of the void is much greater than the diameter of the void. This arises from the fact that in order to detect the void, the soil or rock must itself have an appreciable magnetization, the higher the contrast, the larger the anomaly. Large magnetizations, however, are intimately associated with non-uniform or inhomogeneous magnetization which is a significant source of magnetic noise obscuring the subtle anomaly signature of the void at the empirically-determined limit noted above.

Other anomalies can be computed by the methods presented in Chapter V and the susceptibilities of Chapter III. *Figure 48* portrays several types of anomaly signatures at different latitudes for various possible situations of archaeological features.

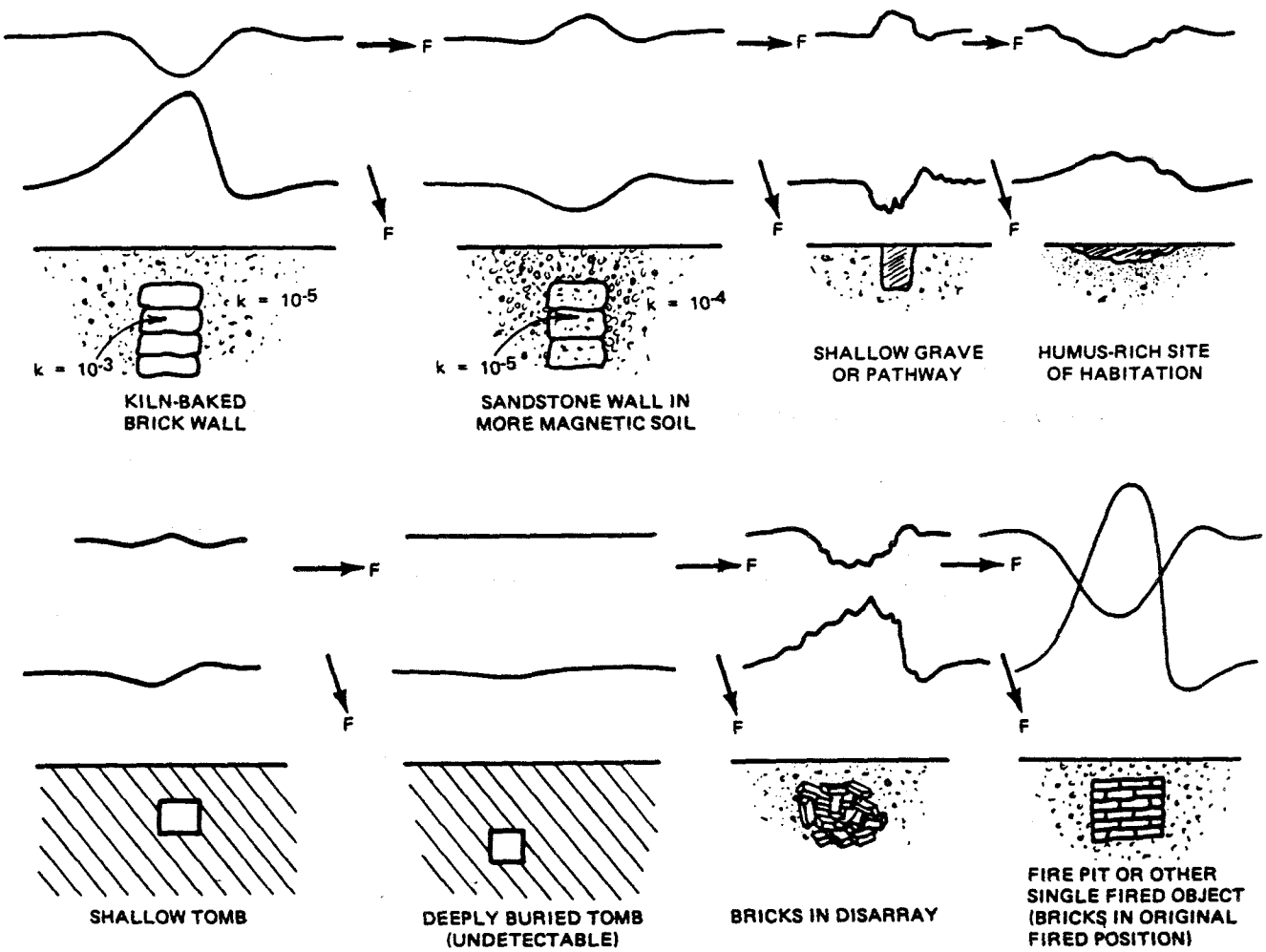


Figure 48. Typical Magnetic Anomalies of Common Archaeological Features

VIII.

GRADIOMETERS AND GRADIENT TECHNIQUES

Introduction

It is of some interest in exploration to measure various gradients, particularly the vertical gradient using a portable magnetometer. The average horizontal gradient along the traverse can easily be computed from the profile, whereas the vertical gradient from typical, widely-spaced ground traverses cannot be accurately computed. A gradiometer is so named because it measures the gradient and in the context of the Manual, the gradient of the total field. In order to meet all the requirements and applications suggested in this chapter, *the gradiometer is here defined as a differential magnetometer where the spacing between sensors is fixed and small with respect to the distance to sources whose gradients are to be measured. The difference in intensity divided by the distance between sensors is then the gradient measured at the midpoint of the sensor spacing.* A quasi-differential magnetometer using a single instrument with successive measurements with the sensor at two or more positions is suggested as more practical for most uses than a two sensor configuration.

Generally, it is more desirable for gradient measurements to have higher sensitivity on the order perhaps of 0.25 gammas for reasons that will become obvious, but 1 gamma sensitivity is adequate when the anomalies and their gradients are relatively large. As an additional condition, *it is relatively important in any ground gradient applications that there be no significant surface magnetic noise,* for gradient anomalies tend to greatly enhance such shallow noise sources which would be detrimental for most objectives.

Applications of the Gradiometer

The vertical gradient or any gradient for that matter has several properties of interest in exploration. First, gradient anomalies tend to resolve composite or complex anomalies into their individual constituents and on the same basis automatically remove the regional magnetic gradient to better define the shallower anomalies assumed to be of interest. Also, the magnetic time variations including the effects of magnetic storms are effectively removed. The measurements which comprise the gradient are made almost simultaneously and very closely spaced compared to the source of magnetic storm effects and diurnal variations so that such effects on the two readings are essentially identical and therefore removed on the differential. A third useful attribute of the gradients is that they can be used very quantitatively or for their vector properties (gradient of the scalar) in ascertaining anomaly depth, magnetic moment, shape and location. These vector properties also allow use of the vector diagram techniques formerly requiring the more cumbersome horizontal and vertical component magnetometers or modified dip needles.

Use of a protable magnetometer as a gradiometer also involves several difficulties over use of the instrument as a simple single-reading magnetometer. Some of the applications require not just two but three or even four separate readings per station and the attendant additional data reduction efforts. The usual advantages of an orientation-insensitive scalar instrument represented by a proton magnetometer are partially defeated in the directional requirements inherent in the two readings of a gradiometer, albeit they are only on the order of ± several degrees. Lastly, considerably more care must be taken in obtaining the data (e.g., magnetic cleanliness of operator, positioning of sensors, etc.) for a gradiometer implies and utilizes higher resolution total intensity measurements. The proper application of the gradiometer techniques outlined in this Chapter, however, may easily justify such extra effort for many geological, search and other objectives.

Conditions for Gradient Measurement

As defined above, a gradiometer is first a *differential* magnetometer, i.e., a difference, ΔT, is measured or computed between two readings at different locations. For many if not most applications, the conventional total field at one of the positions (in practice, either one) is also utilized. The word *fixed* is in the definition to denote the difference between a gradiometer as used here, and a differential magnetometer where one sensor is fixed, the other traversing, connected so as to remove time variations.

The most significant requirement expressed in the definition is that which requires that the spacing between sensors, i.e., their positions of measurement, Δr, be *small* with respect to the distance, r, to the sources of the anomalies under investigation. If one considers a dipole, for example, one sensor at r would measure an anomaly T. A second sensor at 2 r would only measure $1/8$ of T, i.e., the second sensor is essentially not sensing the anomaly at all and may as well be at infinity. The differential measurement in this case is, for all practical purposes, the same as the usual single sensor total field measurement. More specifically, the gradient can be expressed as

$$\frac{\Delta T}{\Delta r} \approx \lim_{\Delta r \to 0} \frac{T_r - T_{r+\Delta r}}{\Delta r} = \frac{dT}{dr}$$

where $\Delta T = T_r - T_{r+\Delta r}$ is the total field differential between two sensor positions spaced Δr apart and $\frac{dT}{dr}$ is the derivative or gradient of T in the direction of r. The expression, $\Delta r \to o$ expresses the mathematical condition that Δr should be small with respect to r (in theory Δr should be zero). *If Δr is less than $1/10$ r or even $1/5$ r, the condition is well satisfied* in the context of all suggested applications. Usually there is no point in making Δr smaller than $1/10$ r, for the gradiometer sensitivity (as expressed in the following) will be unjustifiably degraded. Practical considerations as well limit both maximum and minimum Δr.

(Note: as explained in Chapter II, a total field magnetometer measures only the vector component of any local anomaly in the undisturbed direction of the field. For a local anomaly T, then, the magnetometer will measure the component, T_F, in the direction of F as previously presented. The gradiometer will then effectively measure $\frac{dT_F}{dr}$, i.e., the gradient in the direction r of the component in the total field direction of the anomaly T.)

Gradiometer Sensitivity

The expression $\frac{\Delta T}{\Delta r}$ or $\frac{dT}{dr}$ is the measurement observed with the gradiometer (after proper data reduction). The gradiometer thus measures a gradient expressed in gammas per foot or gammas per meter, etc. in the direction of r (or the vertical gradient, $\frac{dT}{dz}$, in the direction of z) which may be contrasted with the basic magnetometer measurement of T (actually total field, F), which is a scalar and inherently specifies no direction. (NOTE: the total field anomaly T is used herein instead of total field F to simplify and be more consistent in the expressions for the anomalies themselves).

The smaller the value of $\frac{\Delta T}{\Delta r}$ that the gradiometer can measure, the more sensitive is the gradiometer. This value can, in turn, be made smaller by minimizing ΔT or maximizing Δr. Thus, for a magnetometer with a sensitivity of 1 gamma and spacing of 3 feet between sensor positions, the gradient sensitivity would be $\frac{1}{3}$ = 0.3 gamma per foot. For a magnetometer with 0.25 gamma sensitivity and sensor spacing of 3 feet, the gradient sensitivity is $\frac{0.25}{3}$ = 0.08 gamma per foot. Increasing the sensor spacing to 8 feet and using 0.25 gamma magnetometer sensitivity provides $\frac{0.25}{8}$ = 0.03 gamma per foot sensitivity—adequate for many petroleum exploration applications.

Gradiometer Readings in the Field

The gradiometer measurements incorporated in some of these applications are the vertical gradient $\frac{dT}{dz}$ and the two horizontal gradients, $\frac{dT}{dx}$ and $\frac{dT}{dy}$, z being the vertical coordinate, x along the profile and y normal to the profile. When these three gradients are used together, the symbolism for partial derivatives, $\frac{\partial T}{\partial x}$, $\frac{\partial T}{\partial y}$ and $\frac{\partial T}{\partial z}$ will be used, but they are the same numerically as their corresponding expressions above.

A vertical differential reading can be obtained by using a single magnetometer with the sensor placed first at one elevation and then another over the same point on the traverse. Typical elevations are 4 feet and 8 feet for very large gradients (mineral exploration or search) or 4 feet and 12 feet for smaller gradients, the larger the separation the more sensitive the gradiometer. It is important in the vertical gradiometer observations that the sensor occupy the same horizontal position when making each measurement. One possible arrangement is to place the sensor on a long staff and to place an additional support or staff, at right angles to the principal staff near the sensor. Thus, readings could then be taken on each of these staffs so long as adequate signals are obtained for these orientations. *(See Figure 49.)*

Horizontal gradients can be computed from the total field data as the slope of the total field profile at any point of interest which is one example of the necessity for total field, not simply vertical gradient alone. Adequate horizontal gradients can only be computed in this manner when the anomalies are extremely broad, i.e., the sources deep, relative to the station density, as might be true for many petroleum surveys. In the case of shallow anomaly sources as in mineral exploration where the total field variations and their gradients are large and rapidly changing, the individual total field measurements may be spaced too far apart to allow for accurate slope measurements at the points where the vertical gradient is observed. In such surveys, the horizontal gradient can be measured in any of several ways with increasing accuracy, but also increasing time and effort.

In theory, a gradiometer measures the gradient at the midpoint of the sensor spacing. Ideally therefore, one may wish to measure the vertical gradient with two measurements above and below a point P and the horizontal gradient (or gradients) from two additional measurements in front and back of the same point for a total of 4 measurements. A purist may also recommend that where total field is required, it, too, should be measured at P as a fifth measurement and if the other horizontal gradient is desired as well, it would involve 2 additional observations for a grand total of 7 readings.

In practice, however, particularly for sources deeper than, say, 100 feet, what is recommended is simply three readings, two spaced perhaps 8 feet apart at the higher elevation of 12 feet, and one beneath either of the first two at an elevation of 4 feet. The assumption would be made that all measurements were centered about the same point *(see Figure 49)*, as the ideal case above.

The lower reading of any vertical gradiometer pair of measurements should seldom be made much closer than several feet to the ground surface due to possible effects of surface noise from the microtopography, placer magnetite, etc. On the other hand, it is desirable to maximize the separation between sensors to increase the sensitvitiy of the gradiometer without making the higher sensor unwieldly and impractically high. The two sensors in any configuration should not in general be off a vertical or horizontal line by more than 5 or 10 degrees if at all possible, for one is making a vector (angular-dependent) measurement.

Gradiometer as a Filter

For reasons detailed in the following section below, the gradiometer automatically removes the regional gradient, and increases the resolution of even local anomalies *(see Figure 50)*. Each anomaly is portrayed as a more resolved anomaly, separating, for example, the anomaly from different edges of a source into two or more discrete anomalies *(see Figure 51)*. This increased resolving power is exhibited by horizontal or vertical gradiometers equally well. The same property, however, precludes useful application of a gradiometer in areas of surface noise, i.e., very local anomaly sources.

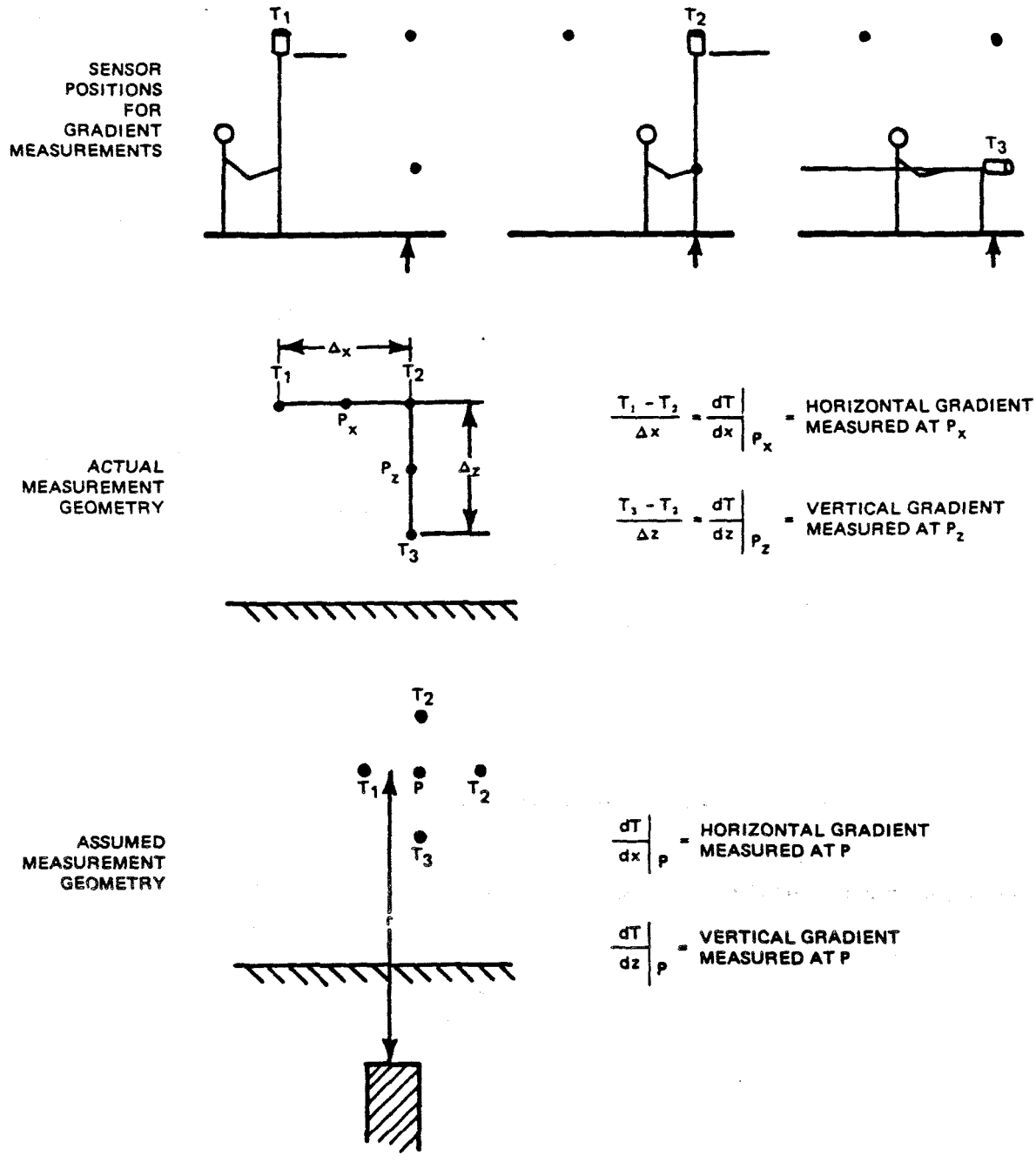


Figure 49. Gradiometer Measurement Procedures

Calculation of Vertical Gradient

For a dipole, the vertical gradient is expressed by taking the derivative of the simplified expression of the dipole (see Chapter V for other orientations of a dipole):

$$T = \frac{M}{z^3}$$

and

$$\frac{dT}{dz} = \frac{-3M}{z^4} = \frac{-3}{z}\,\frac{M}{z^3} = \frac{-3T}{z}$$

Note that the gradiometer anomaly from a dipole varies as $\frac{1}{z^4}$ which explains why the gradiometer automatically removes non-local anomalies, such as the regional gradient. In other words, the gradient varies much more with distance than the total field, or expressed in other terms the difference in intensity between two nearby sensors from distant sources is so small that it is negligible compared to the difference in intensity from nearby sources.

The above expression, $\frac{3T}{z}$, is a convenient form for rapidly estimating the gradient from a dipole given only the total field anomaly and the distance to the source. For example, the earth's field itself thus has a vertical gradient of 0.004 and 0.008 gammas per foot at the equator and at the poles respectively.

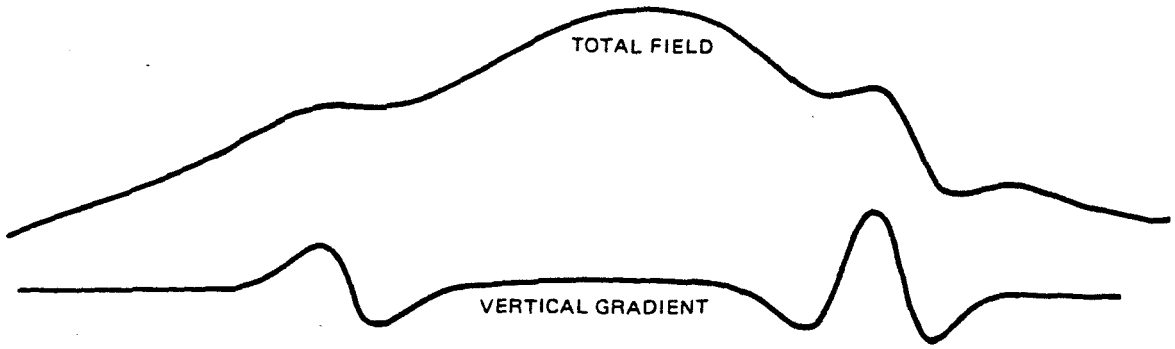


Figure 50. Gradiometer as a Filter for Removal of Regional Gradient

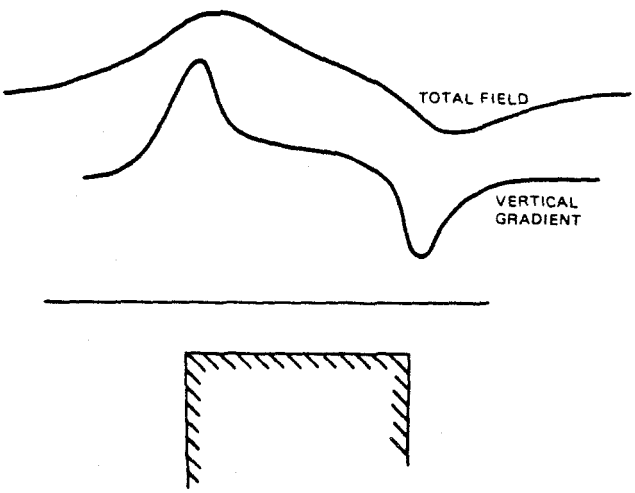


Figure 51. Gradiometer for Resolving Local Anomalies

For a monopolar source,

$$T = \frac{M}{z^2}$$

and

$$\frac{dT}{dz} = \frac{-2M}{z^3} = \frac{-2}{z}\frac{M}{z^2} = \frac{-2T}{z}$$

The gradiometer anomaly from a monopole source is seen to vary as $\frac{1}{z^3}$. In fact, for any generalized source which has a total field expression,

$$T = \frac{M}{r^n},$$

the gradiometer anomaly is

$$\frac{dT}{dr} = \frac{-nM}{r^{n+1}}$$

and any gradiometer anomaly therefore varies at a higher rate or fall-off than its corresponding total field anomaly.

Depth Estimates from Vertical Gradients

If one assumes that a given source is a dipole as would be true for most objects of search and thus has a fall-off factor n = 3 (see above), then by measuring the gradient, $\frac{dT}{dz}$, and the total field anomaly, T, *over the anomaly*, one can determine the depth z, for

$$z = \frac{-3T}{\frac{dT}{dz}}$$

Thus, it is possible in this case to determine the depth without requiring knowledge of the magnetic moment or of what it is comprised—other than that it behaves as a dipole. Furthermore, these values can then be re-inserted in the basic expression for the dipole to compute M which is the product of k, F, and V which, in turn, may be helpful in determining the susceptibility or volume for ore reserves, rock type, etc.

Whether or not, the dipole anomaly involves M or 2M for the magnetic moment is not important, for if

$$T = \frac{2M}{z^3},$$

then

$$\frac{dT}{dz} = \frac{-6M}{z^4} = \frac{-3T}{z}$$

and

$$z = \frac{-3T}{\frac{dT}{dz}}$$

which is the same as given above for $T = \frac{M}{z^3}$. Therefore, the depth may still be calculated, for, as stated, this method removes the dependence on the knowledge of the magnetic moment M and its factors.

For a monopole,

$$z = \frac{-2T}{\frac{dT}{dz}}$$

and for a horizontal cylinder, $$z = \frac{-2T}{\frac{dT}{dz}}$$

for the edge of a narrow vertical dike, $$z = \frac{-T}{\frac{dT}{dz}}$$

and for any generalized anomaly, $$z = \frac{-nT}{\frac{dT}{dz}}$$

(Note: Refer to Chapter V for a summary of 'n', the fall-off factor.)

Alternatively, one may wish to calculate depths by using the two total field measurements separately instead of their use in the gradient calculation particularly when the sensor spacing is greater than ⅕ of the distance to the source which invalidates the gradient measurement. As an example, consider again the dipole

$$T_z = \frac{M}{z^3} \text{ at elevation } z$$

and

$$T_{z+\Delta z} = \frac{M}{(z+\Delta z)^3} \text{ at elevation } z+\Delta z.$$

Then, by dividing the two expressions,

$$\frac{T_z}{T_{z+\Delta z}} = \left(\frac{z+\Delta z}{z}\right)^3$$

and

$$z = \frac{\Delta z}{\left(\frac{T_z}{T_{z+\Delta z}}\right)^{1/3} - 1}$$

General Expression Involving Gradients and Coordinates

The above expressions for depth estimates involving the vertical gradient and z are merely a special case of the following general expression (known as Euler's expression for homogeneous equations):

$$x\frac{\partial T}{\partial x} + y\frac{\partial T}{\partial y} + z\frac{\partial T}{\partial z} = -nT$$

where n is the fall-off factor (e.g., n = 3 for a dipole, n = 2 for a monopole, etc., see Chapter V). Thus, over the anomaly where x = o and y = o, $z = \frac{-nT}{\frac{\partial T}{\partial z}}$, as above.

Such an expression is only applicable for simplified sources having a single effective value of n (i.e., mathematically homogeneous to degree n). It is possible to utilize the measured values of the gradient at various points on a profile to solve for the depth, z (and the fall-off factor, n). Assuming that the profile is, for example, over the anomaly source and in a magnetic north direction (x—direction), $\frac{\partial T}{\partial y}$ and y would be small and the term, $y\frac{\partial T}{\partial y} \approx$ o. Where the horizontal gradient(s) is zero, $\frac{\partial T}{\partial x} = 0$ and $z = \frac{-nT}{\frac{\partial T}{\partial z}}$, similarly where x = 0, again $z = \frac{-nT}{\frac{\partial T}{\partial z}}$

Thus, z and n have the same relative value or ratio at these two points on the profile, one noted by observation of the $\frac{\partial T}{\partial x} = 0$ which would be at a peak (maximum or minimum) of the anomaly and the other at x = 0, i.e., the point immediately over the anomaly source. Thus, the point x = 0 can be determined. Plotting values of z as a function of n for various values of $\frac{\partial T}{\partial x}$, $\frac{\partial T}{\partial z}$ and x will thus produce a series of straight lines intersecting at the solution of z and n as shown in *Figure 52*.

An expression similar to Euler's equation can be derived which does not involve the magnitude of the anomaly itself, but only the gradient and can be used for solving for anomaly location and depth. The algebraic scalar (or dot) product of the radius vector, $\vec{r}$, and the gradient vector, $\overrightarrow{\nabla T}$, taken at any point along the profile is

$$x\frac{\partial T}{\partial x} + y\frac{\partial T}{\partial y} + z\frac{\partial T}{\partial z} = |\overrightarrow{\nabla T}|\,|\vec{r}|\cos\theta$$

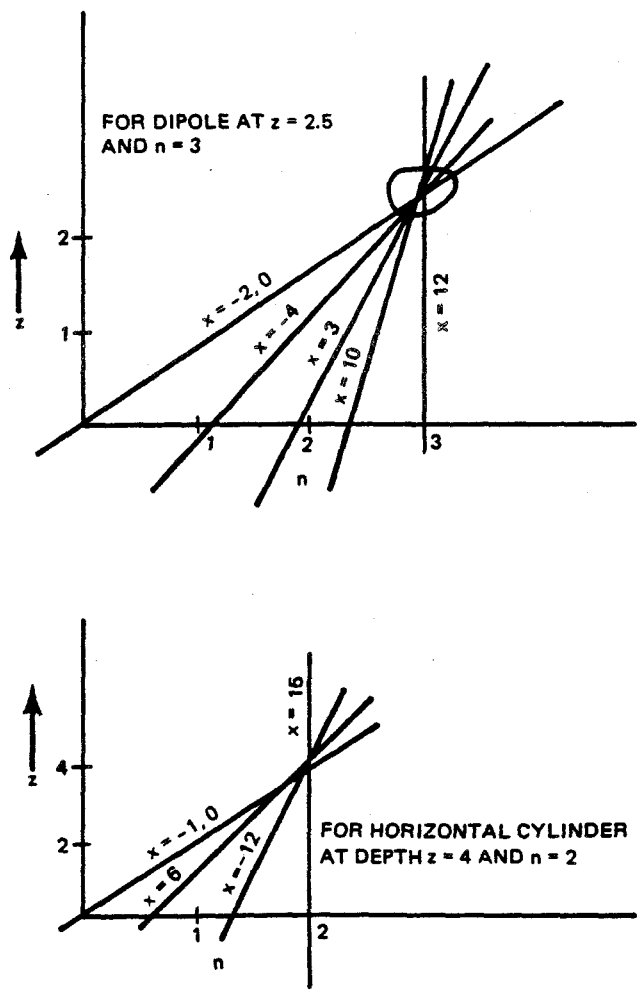


Figure 52. Graphical Solution to Euler's Equation for Depth and Fall-off Rate for Typical Case

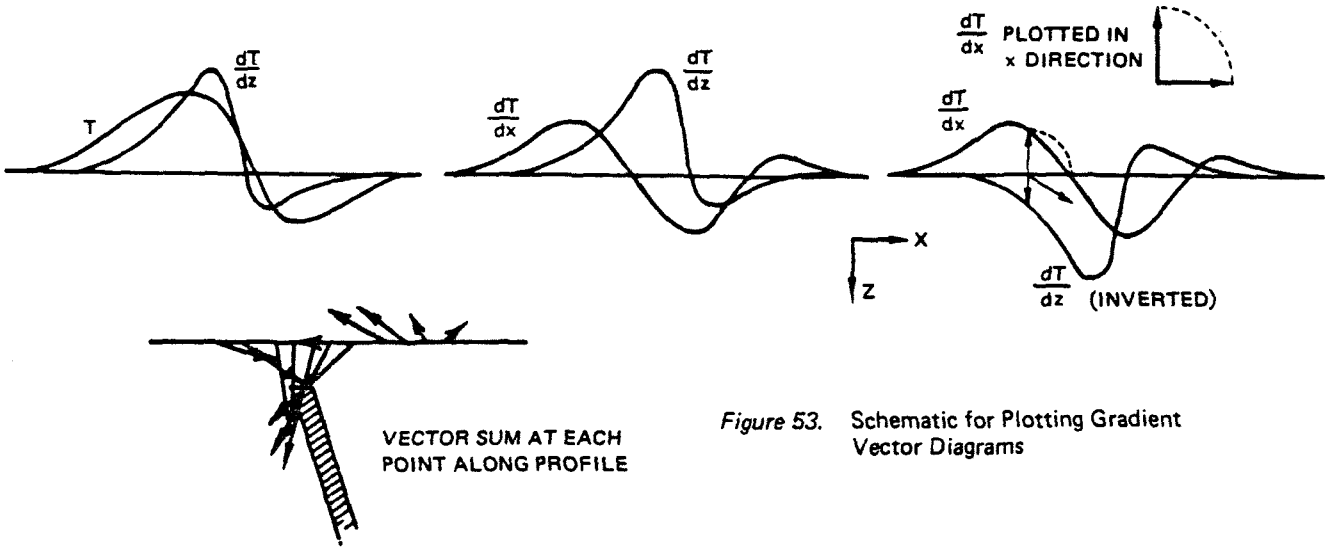


Figure 53. Schematic for Plotting Gradient Vector Diagrams

where

$$|\overrightarrow{\nabla T}| = \left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2\right]^{1/2}, \quad |\vec{r}| = (x^2 + y^2 + z^2)^{1/2}$$

and θ is the angle between these vectors. The angle θ is usually 0° when a radial line to the effective source is parallel to the earth's field (for induced sources). This expression can be used by itself expressing θ in terms of the coordinates and gradients or by equating

$$|\Delta T|\ |r| \cos\theta = -nT$$

and, as before, solving for x, z and n.

Gradient Vector Diagrams and Vector Information from Total Field

Of interest to those who prefer graphical methods for expressing magnetic profile data, consider again the expressions above, but only with respect to the magnitudes. If one assumes either a two-dimensional (infinitely long) anomaly or a traverse over a 3-dimensional source, where in either case $\frac{\partial F}{\partial y} = 0$ and/or y = 0, then the profiles for $\frac{\partial T}{\partial z}$ and $\frac{\partial T}{\partial x}$ would appear as in *Figure 53*. Inverting $\frac{\partial T}{\partial z}$ and plotting in their respective directions, the relative magnitudes of each gradient taken directly from each curve, a set of gradient vectors and their vector sum can be obtained which is very analagous but not identical to, the component fields of an anomaly as are often observed using a vertical and horizontal intensity magnetometer or dip needle. In the case of the total field magnetometer, however, the basic measurement is a scalar which, by itself, is easily and rapidly derived. The directional, or vector, requirements of the gradiometer are derived as the gradient of the scalar with orientation requirements in terms of only several degrees. Conversely, the basic measurement of any component magnetometer involves slow, careful measurements to accuracies on the order of minutes of arc. Such vector diagrams, which are common in the literature over the last 3 decades, can be very usefully applied for a graphic (both literally and figuratively) presentation of a number of common geologic structures as sketched in *Figure 54* which many exploration personnel find very useful.

An interesting alternative method for obtaining vector or directional information from the inherently scalar total field magnetization is described in Chapter VI as a method for determining the direction of the field. The method employs simply the sensor, staff and a small (hard steel, slightly magnetized) needle all rigidly joined. As this arrangement is positioned at various directions, a maximum or minimum is observed precisely at the local earth's field direction. Realizing the difficulties, one may wish to affix a level bubble to such an arrangement to observe and plot the small change in dip of the earth's field in the vicinity of local anomalies particularly the larger anomalies. More sophisticated modifications to such a scheme would require audio display of the reading for rapid determination of a maximum or minimum reading or a coil system to modulate the field in a parallel or perpendicular direction.

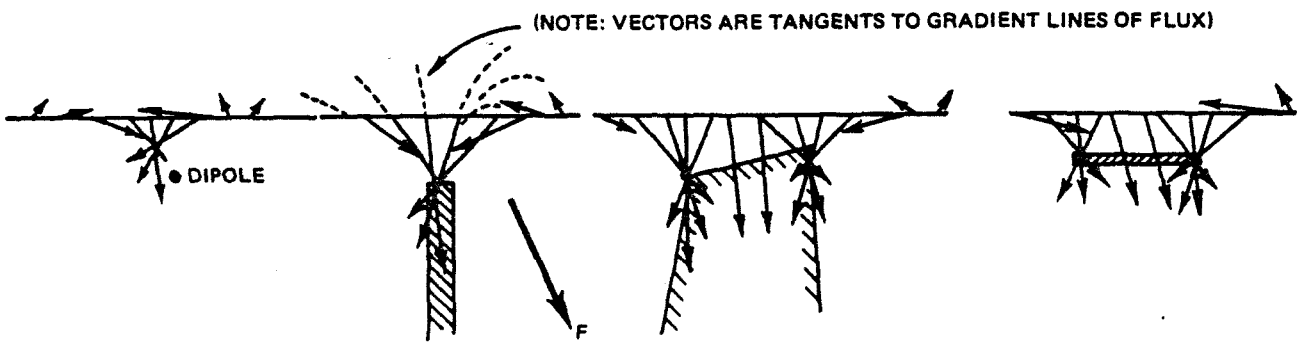


Figure 54. Gradient Vector Diagrams

IX.

MAGNETIC MEASUREMENTS OF ELECTRIC CURRENT DISTRIBUTIONS

Introduction

The magnetic measurements described in Chapters I through VIII, by and large, concern anomalies due to various distributions of magnetite. The principal exceptions to this source of anomalies were certain sources of noise including the time variations of the field, electric trains and AC and DC power lines. It may therefore be obvious that electric currents, too, produce magnetic field perturbations measurable with a portable magnetometer. Such effects are important to consider from a standpoint of evaluating possible noise sources, establishing certain magnetic bias fields, object location using active currents and several other applications.

Among the current sources to be considered for these applications will be those due to a long wire, pair of parallel wires, conducting sheet, solenoid (or loop) and Helmholtz bias coil. In all cases in this chapter, it is only direct current (DC) that is considered in producing magnetic fields measurable with the magnetometer. Alternating current (AC) sources are not easily measured with the ordinary portable magnetometer and are only considered in light of their degrading effects on the proton precession signal.

Applications

The estimation of the field produced by a given pair of parallel line sources may be used to estimate the effect of a nearby (or distant) DC train, tram, subway, or the newer extra-high-voltage DC power lines. A single line source can be used to locate buried pipelines or other conductors by applying the current to externally available points and following the suggestions given in Chapter VII. A sheet of current and its field is useful as an active method for mineral exploration. A solenoid or any other concentrated set of more-or-less circular windings is normally used to create a uniform field within the solenoid itself (as it is used, for example, in the proton magnetometer itself in the form of a solenoid or toroid, which is a solenoid whose ends are joined). A single solenoidal coil, however, produces an external field as well and produces a dipole magnetic moment identical to that created by a magnet except that the solenoid field can be varied at will in amplitude, sense and turned off as desired. Such a solenoid may be used for relocation under soil, rock or shallow water as previously described. Similarly, a solenoid can be placed in shafts, adits or boreholes and detected, regardless of conductivity, in adjacent holes when it is desired to obtain the approximate direction, distance and location of the former. Requirements for such location may arise in connection with the location of air shafts, connecting portions of a mine, access to mine workings, caves, lava tubes, or in the solution of other more esoteric problems.

Various configurations of coils can be constructed to produce a uniformly magnetic bias field for magnetic observatory use, measurement of magnetic properties of materials, cancelling or changing the direction of the earth's magnetic field or a variety of other purposes. Such coils are often in the shape of a large cube, sphere or different coaxial and orthogonal configurations, the simplest being the Helmholtz coil comprised of two identical coaxial coils spaced apart on their common axis at a distance equal to their radius. At the center of this arrangement is a relatively uniform field whose intensity is governed by the current in the coil.

A Helmholtz coil can be used with a total field magnetometer to obtain an accurate component measurement of the earth's field. If, for example, the coil is aligned with its axis vertical, the vertical component of the earth's field within the coil can be cancelled by generating an equal but opposite vertical field leaving only the horizontal component of the earth's field. A total field sensor within the coil then measures only the total field (now horizontal), and changes along this direction, i.e., it measures the horizontal component of the earth's field. Vertical components can be measured in a similar manner by switching coils and current appropriately.

As another application of the effect of electric currents on the earth's field, consider the measurement of the conductivity of the subsurface that would be of interest in geological exploration. As in many electrical methods for mineral exploration, electrodes of various configurations at spacings of hundreds of feet can be used to apply direct current into the ground for a period which overlaps the measurement time of the magnetometer. The magnetic field of the resulting current distribution can be measured and mapped with a portable total field magnetometer as an indirect means for mapping the subsurface conductivity (resistivity). Thus, a magnetometer, particularly one with higher sensitivity, say, 0.25 gamma, can be used for such a conductivity survey, rapidly, without orientation restrictions and without requiring contact with the ground surface. (NOTE: The current should be switched in polarity during consecutive readings at one location using the difference in readings as a measure of current density; the electrode array should be set up with consideration for the earth's field direction and the magnetometer can be used as well for conventional field measurements when the current is removed.)

Configuration of Magnetic Field of Electric Current Sources

It will be assumed, as before, that the field of any current source is much smaller than the ambient field (except in the case of the Helmholtz bias field above)

and the total field magnetometer therefore measures only components of any current-produced field in the direction of the ambient field. The magnetic field of a single, long wire appears as in *Figure 55* in the form of concentric circles about the wire in a direction following the 'right-hand-rule', i.e., the field will be in the direction of the curled fingers of the right hand when the current is in the direction of the thumb. Observe, for example, that a total field magnetometer will see no effect of the current in a wire parallel to the earth's field. Two long, straight, parallel wires with current flowing in opposite directions (the usual case) will produce fields which almost, but not quite, cancel at distances large compared to the separation of the wires. The configuration of the field, however small, will appear as a line of dipoles whose axes are at right angles to the plane of the two wired (see *Figure 55*).

A solenoid produces an external field identical to that from a small bar magnet in the same direction. The field lines of a solenoid and the approximate field of the Helmholtz bias coil are shown in *Figure 55*.

Amplitude of Fields of Current Sources

The field of a single long wire is given by

$$T = \frac{0.2\,i}{r}$$

where T is the anomaly in the direction of the earth's field in gauss (10^5 gammas = 1 gauss = 1 oersted), i is the current in amperes and r is the distance in centimeters between the wire and the point of measurement. The anomaly, T , as measured by a total field magnetometer would, again, be the component of T in the direction of the total field, F, paying special attention also to the configuration of the field of the wire.

A pair of infinitely long wires with current in opposite directions is

$$T_n = \frac{0.8\,di}{4r^2 + d^2}$$

at a point on a line from the midpoint between the wires where T_n is the anomaly in gauss, d, the separation of the wires in centimeters, r, the distance to the midpoint of the wires and, i, the current. The field at a point in the plane of the wires is

$$T_\theta = \frac{0.2\,di}{r^2 + rd}$$

In the case where r>>d, the field is the same for a given distance, r, in any direction from the wires and behaves as though it were a line of dipoles with amplitude

$$T = \frac{0.2\,di}{r^2}$$

As an example, consider an electric train at the magnetic equator in an E-W section of track, with several locomotives drawing current from the circuit using a total of 2000 amperes, with the distance, d, between the overhead wire and its ground-rail-return of 500 centimeters and with a magnetometer at 1 kilometer (10^5 centimeters):

$$T_F = T = \frac{0.2 \times 5 \times 10^2 \times 2 \times 10^3}{(10^5)^2} = 2 \times 10^{-5} \text{ gauss}$$

= 2 gammas

From the configuration of this field as shown in *Figure 55*, the effect of this train with a track in an N-S direction at the equator or in any direction at the north magnetic pole would be $T_F = 0$, i.e., it would produce no effect on a total field magnetometer.

A conducting sheet carrying a current of density, i amperes per centimeter would produce a field, T, at right angles to the current flow above the sheet with the sense determined by the right hand rule. The current is

$$T = 0.2\pi i$$

where the intensity does not vary with distance from the sheet.

The external field of a solenoid can be expressed by

$$T = \frac{0.2\,\pi\,a^2\,Ni}{r^3}$$

where T is the field in gauss along the axis of the solenoid (one-half this value at the same distance at a point on a line normal to the axis of the solenoid), a, the radius of the solenoid, N, the number of turns, and the other terms as described. The field behaves as a dipole with all of the geometric characteristics described in Chapter V. For such a solenoid of an average radius of 2 centimeters with 500 turns carrying 0.1 ampere with its axis parallel to the field, the field at 50 centimeters E or W of the solenoid would be

$$T = \left(\frac{1}{2}\right)\frac{0.2 \times \pi \times 2^2 \times 5 \times 10^2 \times 0.1}{(50)^3} = 5\text{X}10^{-4} \text{ gauss}$$

= 50 gammas

in a sense opposite to that of the solenoid itself.

A Helmholtz coil produces a field, T, at its center given by

$$T = \frac{0.899\,Ni}{a}$$

where T is the field in gauss produced by the coil independent of the direction of the earth's field, a, the radius of the coils and the other terms as described above. More detailed information on the fields of coil systems, their homogeneity, etc., is available in publications of magnetic observatories.

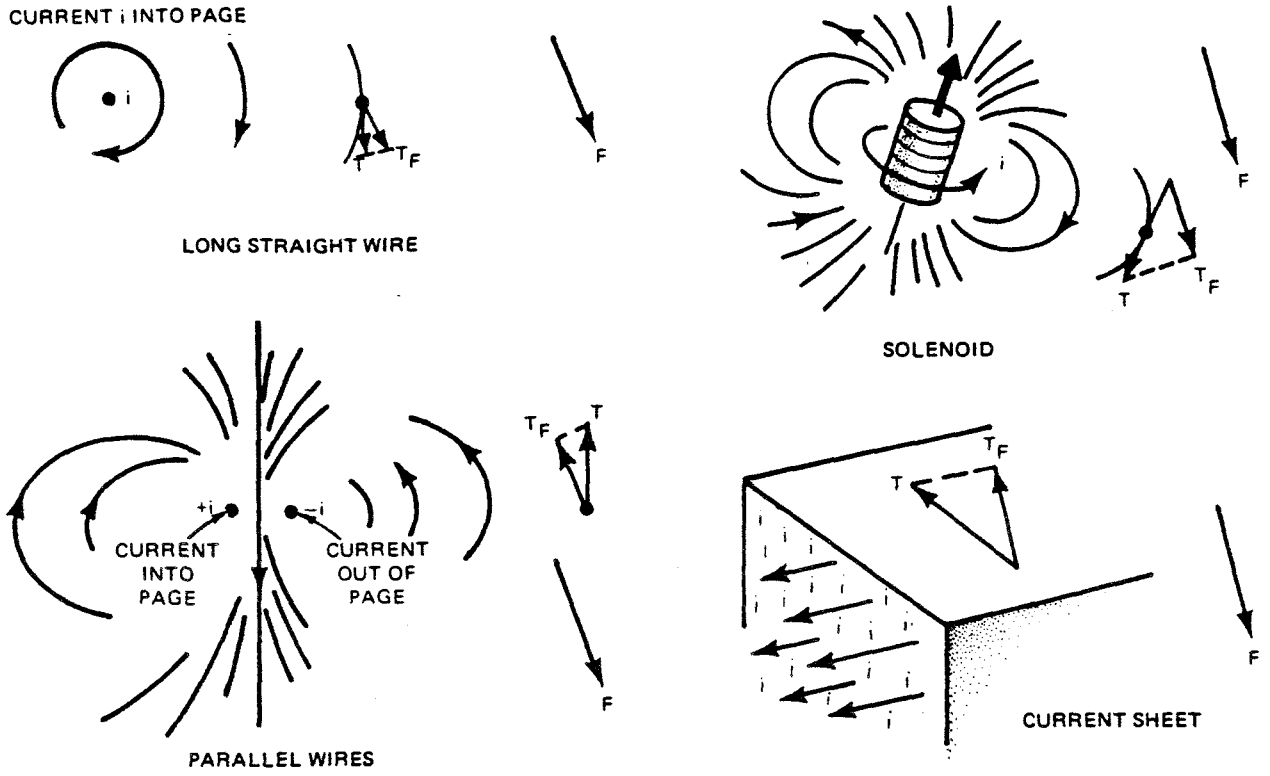


Figure 55. Configuration of Magnetic Field of Various Electric Current Sources

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INSTRUCTION MANUAL

BISON INSTRUMENTS OFFSET SOUNDING SYSTEM MODEL 2365

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I. PURPOSE AND GOALS

The Bison Offset Resistivity Sounding Cable System provides a means to conduct Wenner-type resistivity soundings. Several important benefits are incorporated into the system as follows:

(1) The system employs an "Offset Sounding Method" which greatly reduces the troublesome interpretation problems arising from local, near-surface lateral resistivity variations.
(2) The system produces a much more detailed resistivity sounding curve for improved subsurface interpretations.
(3) The system greatly reduces the field time required to obtain a resistivity sounding, yet achieves this with a smaller number of personnel. After the Bison Offset Sounding Cable has been laid out, the complete sounding is carried out using only the switch-box arrangement, with no further movements of the electrodes required.

In consequence of these benefits, the "Offset Wenner" electrode configuration becomes superior rather than inferior to the Schlumberger configuration, with respect to sensitivity to errors from lateral resistivity variations.

The essence of the Offset Wenner arrangement is to exploit the redundancies and cross-checks inherent in a five electrode array. Only four electrodes are used for each measurement, but these electrodes may be selected in several different ways from the total of five. In addition, any electrode can be used either as a current electrode or as a potential electrode.

The theory behind this development has been set forth by Dr. R. D. Barker from the University of Brimingham, England. A description of this theory and references to Dr. Barker's papers are available in a separate document, supplied upon request.

The various combinations used in the Bison Offset Sounding System are shown in Figure 1:

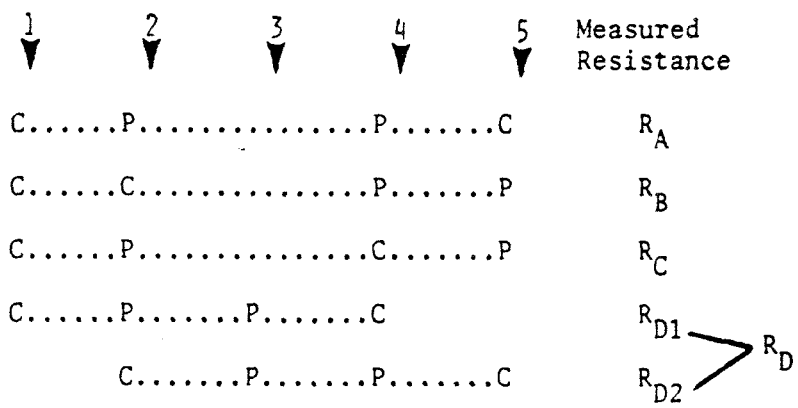

FIGURE 1: The various resistances measured with the five-electrode array.

A second feature of the system lies in choosing the succession of electrode spacings ("A-values") to produce the maximum redundanc in electrode positions. For example, the current electrodes foı A = 10 meters occupy the same physical position as the potential electrodes for A = 30 meters. Thus the same electrodes can be used in these positions for both readings, and possibly others as well. The electrical connections to the electrodes can be accomplished simply by a switching arrangement.

With a five-electrode system, this redundancy becomes even greater. As shown in Figure 2, the sequence of measurements is accomplished by doubling the spacing for every group of five electrodes:

Spacing is increased by doubling:

Figure 2: The principle of offset sounding in the Bison Offset Sounding System.

Specifically, data are taken at A-spacings of 0.5, 1, 2, 4, 8, 16, 32, 64, and 128 meters for the BOSS System.

For each of these spacings, however, several readings are taken as shown in Figure 1, by means of switching arrangements. Certain combinations of these readings are equivalent to the Wenner resistances that would be measured with spacings of 1.5, 3, 6, 12, 24, 48, 96, 128 and 256 meters, although these spacings are never actually used in the field.

All of this can be achieved with only one center electrode plus 9 electrodes in each direction, or 19 electrode positions total, yet the arrangement produces a 16-point Wenner sounding curve. An equivalent Schlumberger sounding would require occupancy of 34 electrode positions, and a conventional Wenner sounding would require a minimum of 38 electrode positions.

These features produce a very detailed Wenner sounding curve which can result in superior subsurface interpretations. Furthermore, all standard resistivity interpretation procedures can be used, with no special transformations or data corrections such as required for Schlumberger data.

The most significant benefit of all from the Bison Offset Sounding System remains to be described, namely the minimization of errors from unknown lateral resistivity variations in the subsurface.

The spurious effect of local, near-surface, lateral resistivity variations is one of the most troublesome problems encountered in resistivity sounding. The effects can seriously distort the sounding curve which, it is hoped, represents a horizontally layered structure. Numerical filtering techniques cannot be employed to remove lateral effects without distorting the observed sounding curve in other ways. These effects can be reduced and often almost removed by employing the Offset Sounding method.

Figure 3 shows a section through the four electrodes of a Schlumberger array.

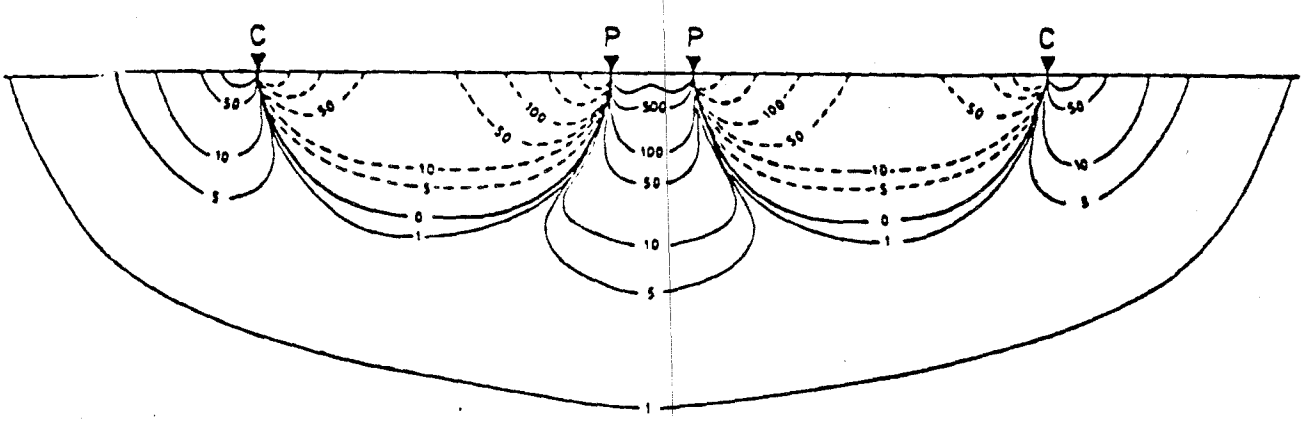

FIGURE 3: The signal contribution section for a Schlumberger electrode configuration. Negative contributions are shown by broken lines.

The contours show the relative contribution to the measured resistance given by a unit volume of earth at any point in the section. A near-surface body of high resistivity located in a positive zone in an otherwise homogeneous earth, will produce a measurement of resistivity which is too high, i.e. higher than would have been measured in the absence of the body. If the body were located in negative region, the measured resistivty would be too low.

The effect of a body of anomalous resistivity located in a positive zone could be removed by offsetting the electrodes along the electrode line by a distance such that the body now lies in a negative region. An average of the two resistance measurements will cancel the spurious positive contribution in the first measurement with the negative contribution in the second. In this way the effect of the body will be removed.

In practice the Wenner electrode arrangement must be used. Figure 4 shows the signal contribution section for the Wenner array.

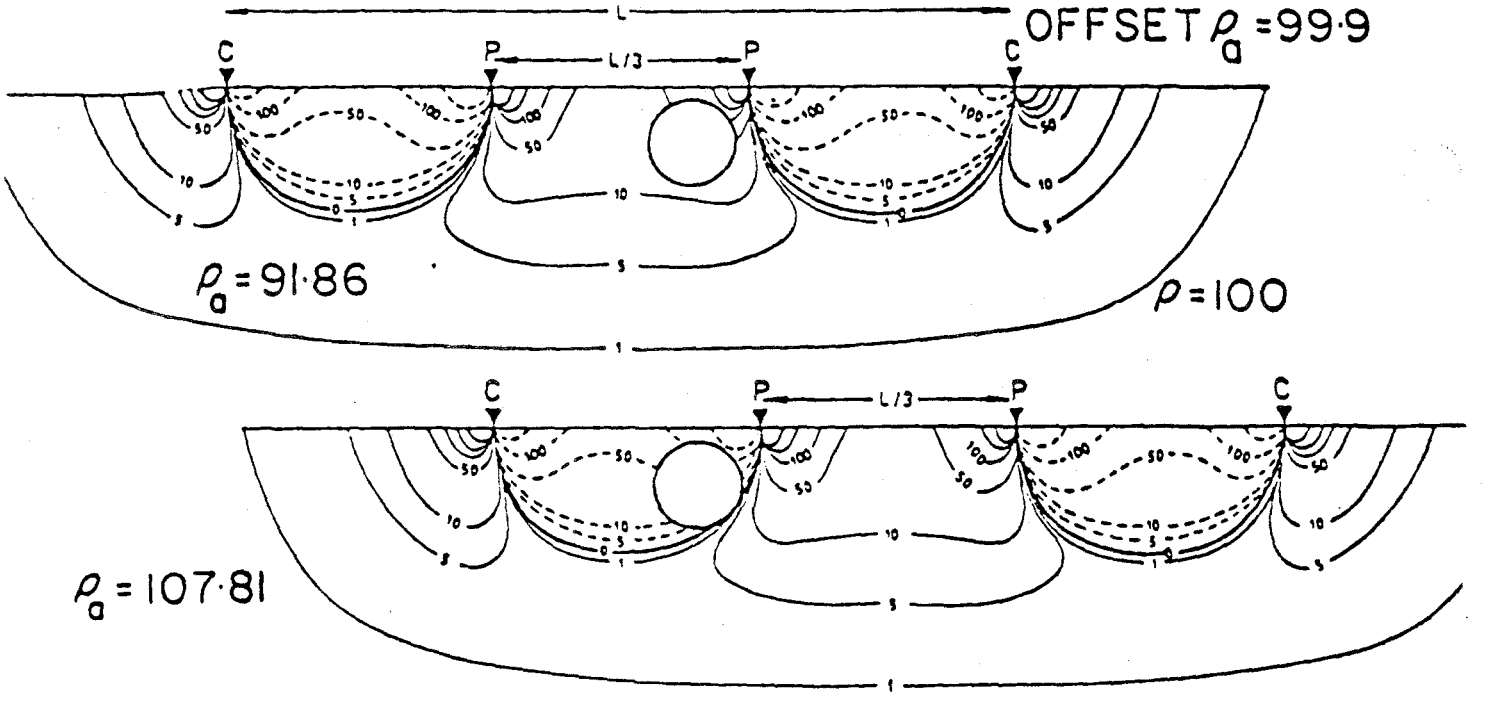

FIGURE 4: A signal contribution section for Wenner array, illustrating the offset principle. The apparant resistivity are those which would be measured with a highly-conductive sphere in the position shown.

It comprises positive and negative regions of approximately equal extent. The effect of a body of anomalous resistivity lying within one of these zones can be strongly reduced by offsetting the whole array by a distance equal to the spacing. Except for the regions at each end of the electrode line, negative zones now fall where positive regions fell previously and vice versa. The resistance measurement is repeated and an average of the two measurements made.

In the particular case illustrated in Figure 4 in which a buried conducting sphere is located in an otherwise homogeneous medium of resistivity 100 ohm-m, the measured resistances would be 91.9 and 107.8 ohm-m. An average of these is 99.9 ohm-m. In this way an 8% error is reduced to an error of only 0.1%.

Comparisons of this type depend on the position of the anomalous body relative to the electrodes. A better analysis can be made by comparing complete profiles across the body. Figure 5 compares Wenner and Offset Wenner horizontal profiles across a buried conducting sphere.

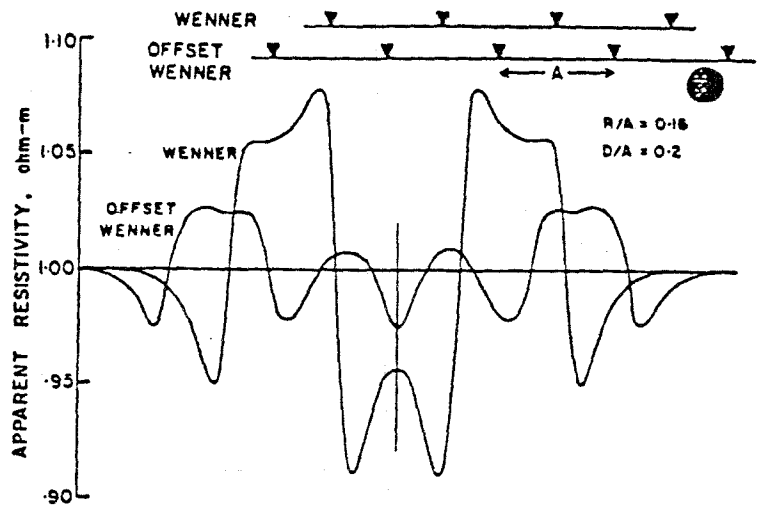

FIGURE 5: A comparison of conventional Wenner and Offset Wenner profiles across a conducting sphere.

In this case the effect of the sphere is reduced by at least a factor of three whatever its position relative to the electrodes. The reduction increases for bodies nearer the surface and decreases with deeper sources.

Figure 6 compares a sounding curve obtained using the conventional Wenner technique with a curve obtained using an Offset Wenner five-electrode expanding array. The curves were obtained in a resistivity tank in which bodies of anomalous resistivity were modelled. Each curve is compared with the curve obtained in the complete absence of the lateral effects. The improvement obtained by using the Offset technique is clear.

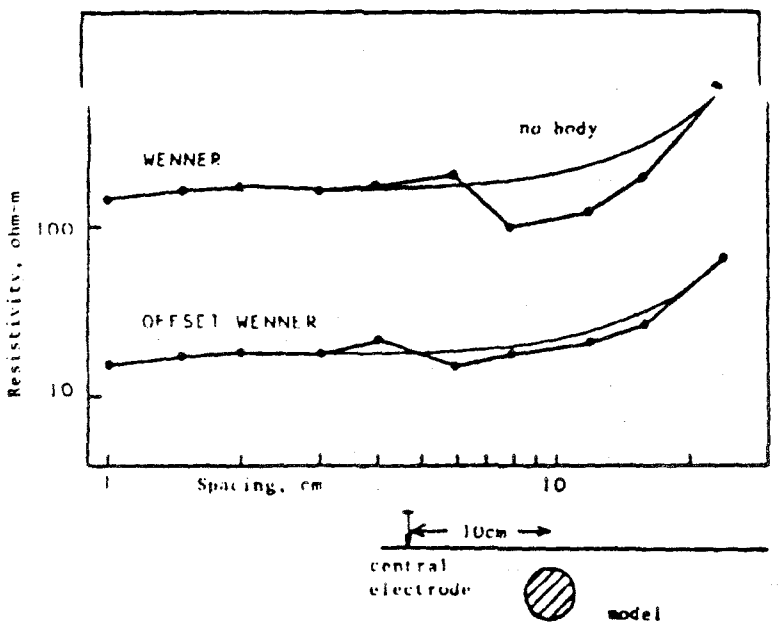

FIGURE 6: Tank model study in a layered medium, to show reduction in error produced by an anomalous resistive body.

II. EQUIPMENT DESCRIPTION

The Bison Offset Sounding System comes with two sets of cables, the standard Boss-128 multi-conductor cable and the extension-256 cables. The BOSS-128 provides readings to a maximum spacing of 64 meters, permitting computed readings to a maximum of 128 meters. The extension cables provide one additional factor of two in the spacings. Since the principles of operation are identical, the following description will be directed to the BOSS-128 system.

The system components consist of:

a) Two multi-conductor cables with multiple takeout connections.

b) 21 steel electrodes.

c) Switch Box.

d) Central electrode cable.

e) Four extension cables.

f) Instruction Manual, including computer program to expedite data reduction.

The cable configuration is shown in Figure 7 for the BOSS System.

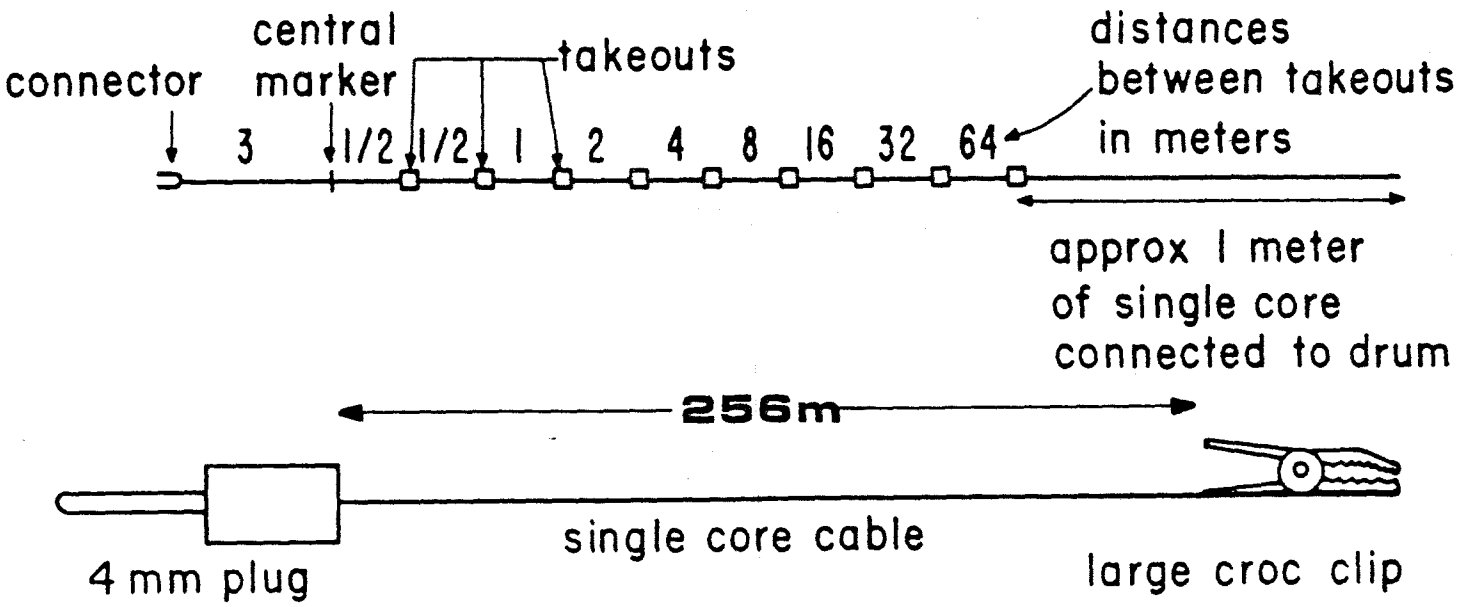

FIGURE 7: Cable configuration for the BOSS System.

The electrodes and their connections to the cable are shown in Figures 8 and 9.

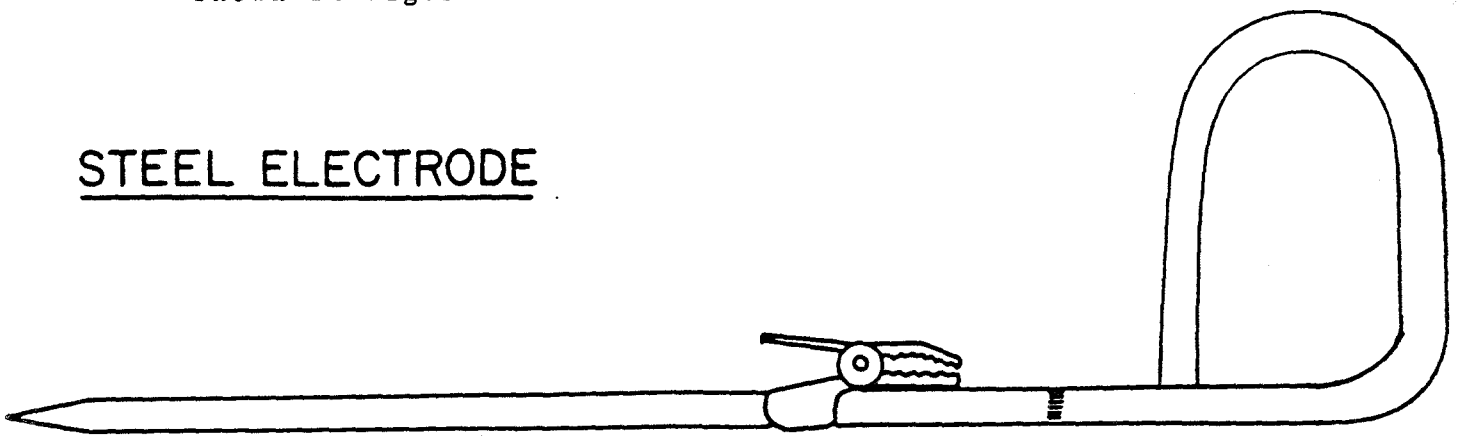

FIGURE 8: Steel electrodes for use with BOSS systems.

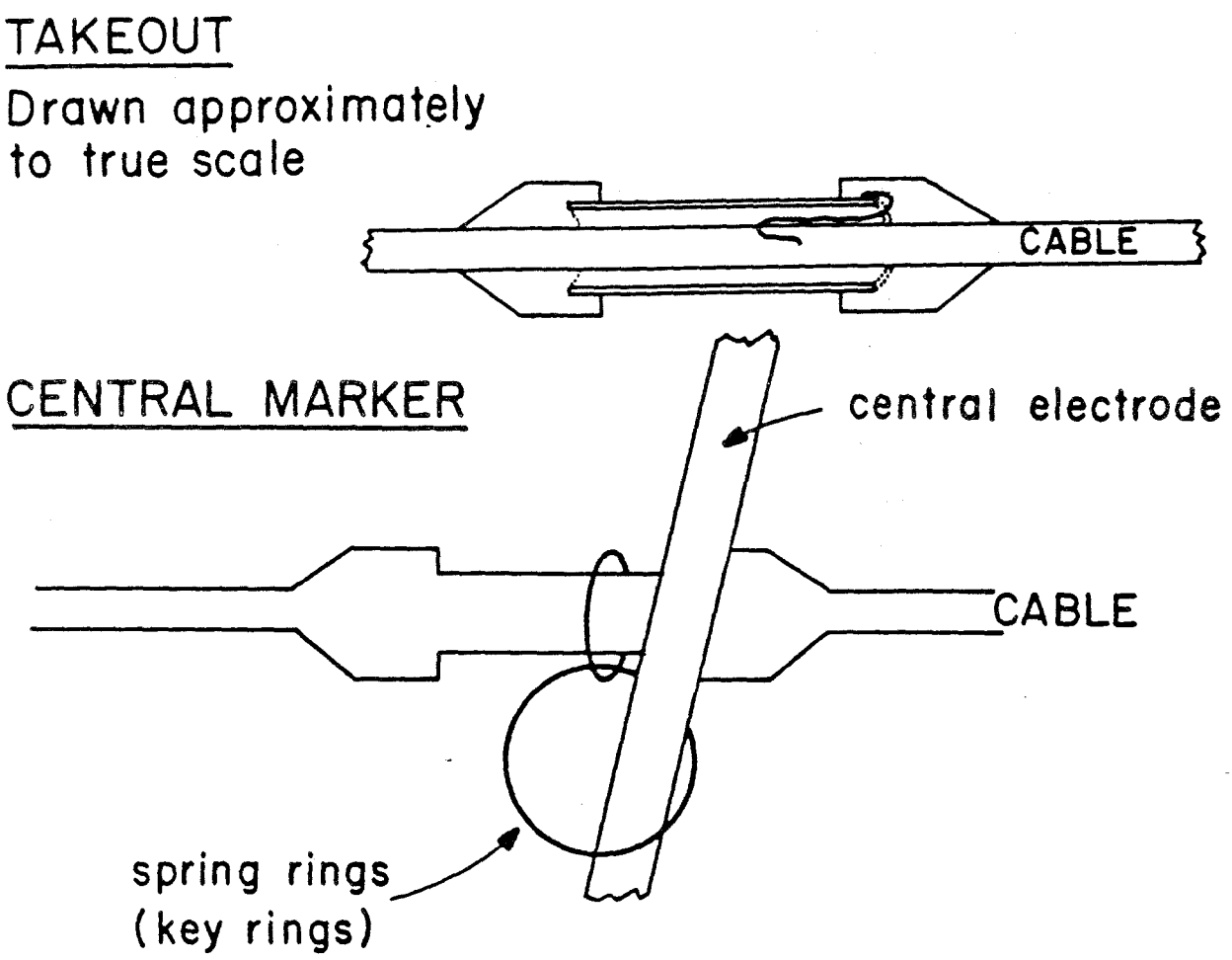

FIGURE 9: Electrode connection to cable.

Figure 10 shows the external appearance of the Switch Box, whose use is described below. Figure 11 shows the interconnections contained within the Switch Box.

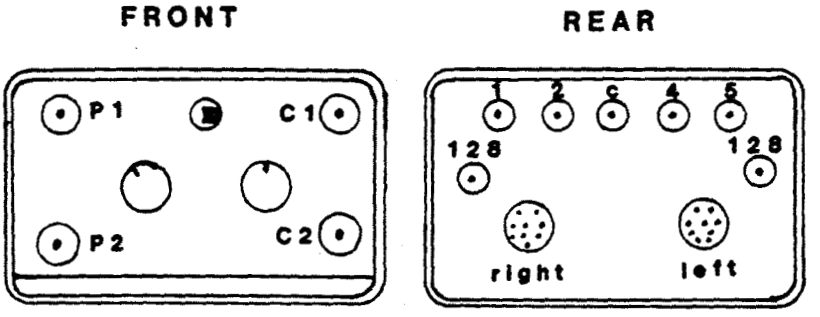

FIGURE 10: Switch Box, external view.

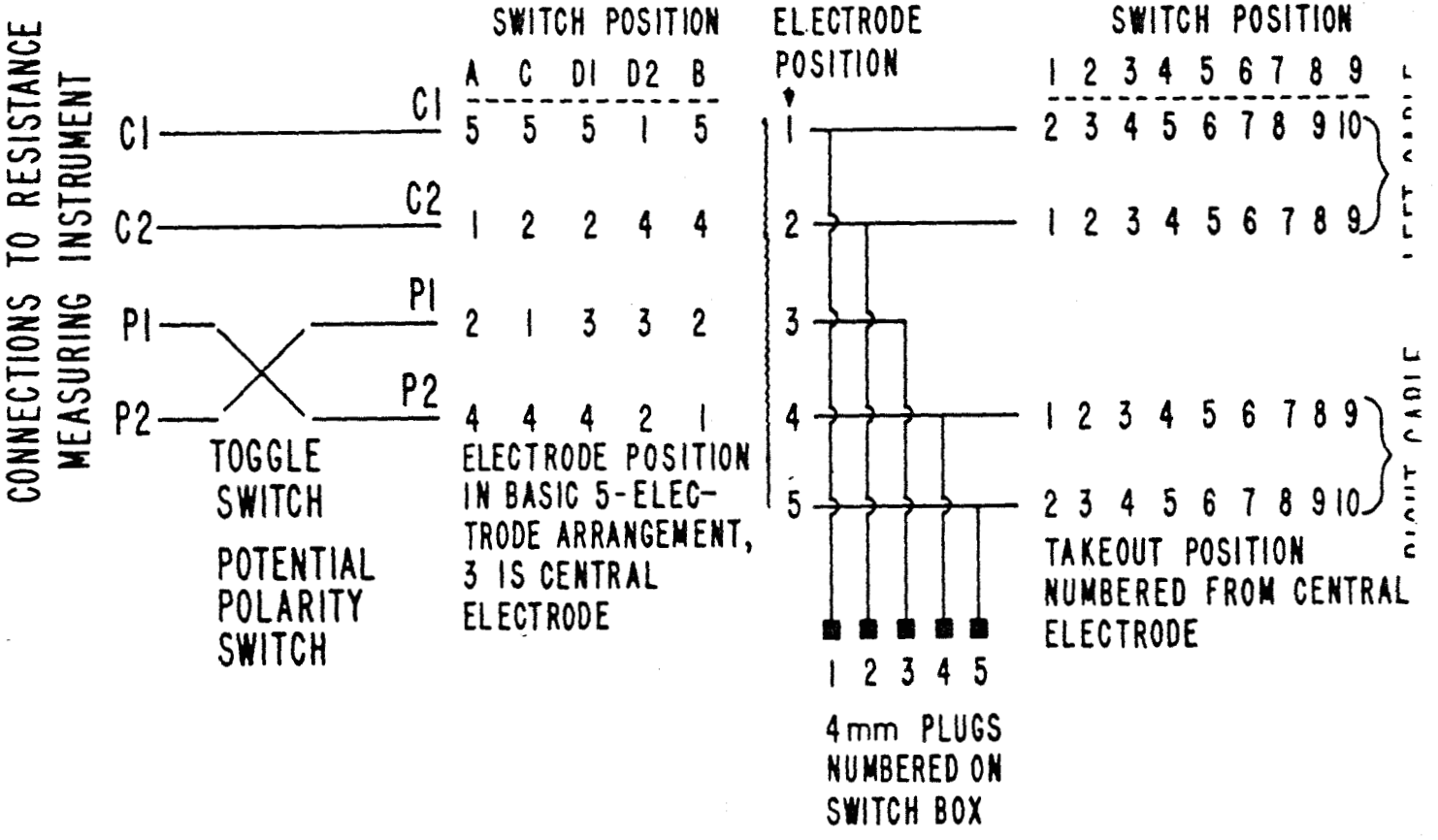

FIGURE 11: Switch Box, internal connections.

Figure 12 shows the extension cables, whose use is described below.

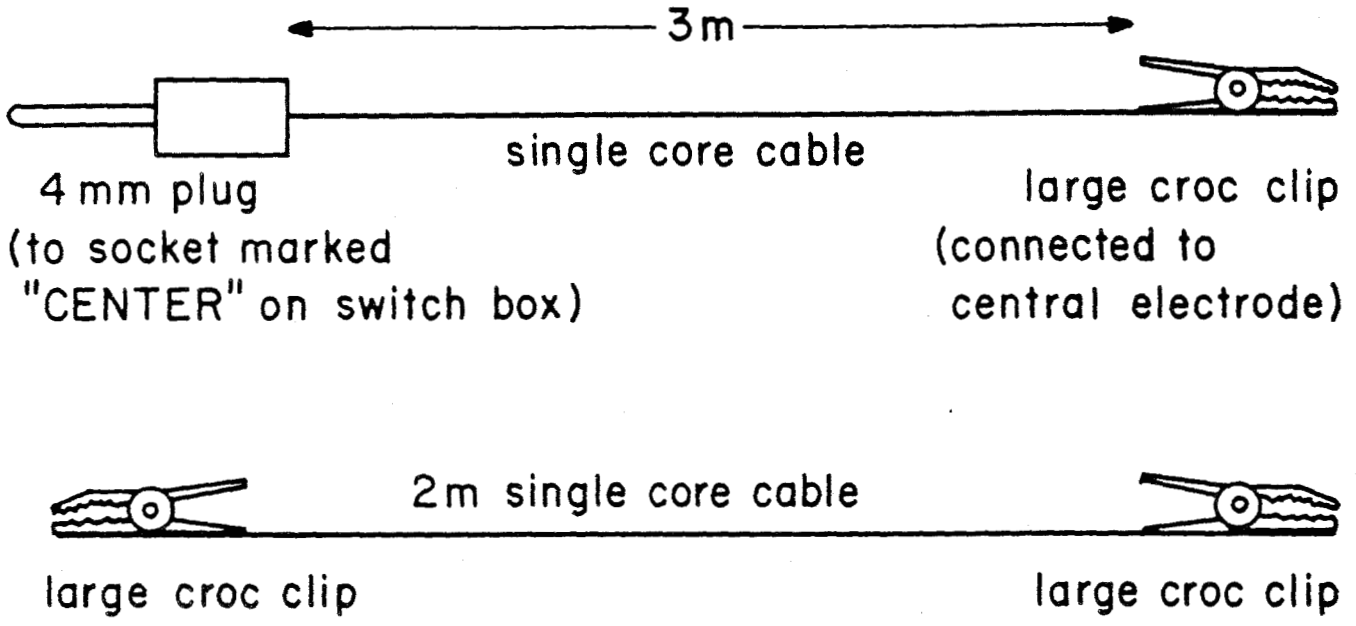

FIGURE 12: Extension cables.

III. FIELD PROCEDURES

1. Field Check List
   --2 BOSS-128 multicore cables and 2 extention cables.
   --2 sets of 10 electrodes plus center electrode.
   --Switch Box.
   --Connecting Cable, Switch Box to center electrode.
   --4 extension leads.
   --Measuring instrument, accessories, and connection to Switch Box (not supplied).

2. Place one electrode through the two rings which are found one on each cable about 3 meters from the connectors. This electrode will mark the center of the line of electrodes.

3. Walk away from the spread center carrying one set of electrodes and unreeling one cable at the same time. Continue walking in a straight line until the end of the cable is reached or until sufficient electrode positions have been passed.

4. Place the outermost electrode into the ground and connect it to the cable. Return to the center of the spread connecting the remaining electrodes to the cable. If it is not possible to position an electrode exactly at the cable takeout, it can be positioned nearby and connected to the cable using one of the extension leads provided.

5. Lay out the second cable in the opposite direction in the same way.

6. Connect the two BOSS-128 cables and resistance measuring instrument to the switch box.

7. Connect the center electrode to the switch box using the connecting cable provided.

8. Record the resistance measurements as described below.

9. On completion of the measurements disconnect the electrodes and wind in the cable. Do NOT drag the cable along the ground but WIND AS YOU WALK.

CARE OF THE CABLE

The multiconductor resistivity cable does not have a strain bearing core and for this reason should not be subjected to high stress. To increase the life of the cable, it should not be dragged along the ground but should be wound onto the drum while walking.

CABLE DAMAGE

If one of the cores breaks during a survey a spare single core cable may be connected between the unconnected electrode and the appropriate socket on the switch box for that position of the SPACING switch. For example, if number 5 of the five electrodes in use at switch position 2 is unconnected, a separate single core cable is run from socket number 5 to the appropriate electrode and the measurements made. When the SPACING switch is changed to 3, the cable should then be connected to socket 4 as the unconnected electrode will now have changed roles and be fourth in order. The spare cable should be disconnected for all other positions of the SPACING switch.

EXTENDING THE ELECTRODE LINE

Further measurements may be obtained by placing electrodes at a distance of 256m from the center along the line of electrodes. Using spare single core cable these are then connected to sockets labled 128m on the switch box. The SPACING switch is changed to position 9 and the resistances measured. Points on the Wenner apparent resistivity curve may then be computed out to a spacing of 256m.

IV. MEASUREMENT PROCEDURES AND CALCULATIONS

Offset Wenner sounding is conveniently conducted using a five-electrode array (Figure 13).

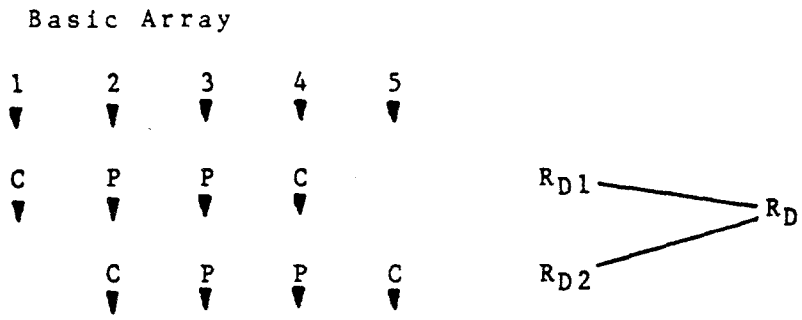

FIGURE 13: The two basic Wenner measurements, R_{D1} and R_{D2}, from the five-electrode array.

In practice this is no more difficult than normal sounding, for the additional electrode remains fixed at the center of the spread. A switching device is used to change from one adjacent set of 4 electrodes to the other. Two resistances are obtained which are averaged to provide the Offset Wenner resistance, R_D. If the spacing is increased according to the series A = 1/2, 1, 2, 4, 8, 16, 32, and 64m, so that the potential electrode always falls on the position previously occupied by a current electrode, 8 high quality resistance measurements are obtained.

Additional points on the apparent resistivity curve are obtained by measuring resistances with various arrangements of the five electrodes while still using the 2^n spacing series. The electrode arrangements which allow the measurement of R_A, R_B and R_C are shown in Figure 1.

There are various ways in which intermediate Wenner points may be computed but one of the most satisfactory is found to be by use of the relationship

$$R_W(3A) = 1/2R_D(2A) + R_B(2A) - R_B(A) + 1/2R_D(4A)$$

Using this equation, Wenner resistances are computed for spacings 1.5, 3, 6, 12, 24, 48, and 96m. A further resistance on the Wenner apparent resistivity curve may be obtained from the relationship

$$R_W(2A) = 2[(R_C(A) - R_D(A)]$$

This enables a Wenner resistance at 128m to be computed from resistances measured at a spacing of 64m. It is then possible, by occupying only spacings 1/2, 1, 2, 4, 8, 16, 32 and 64m, to measure sufficient resistances to enable the construction of a 16 point Wenner apparent resistivity curve.

The basic electrode arrangement consists of five equally spaced electrodes as shown in Figure 13, the third electrode being at the center of the array. The spacing, A, between electrodes is determined by the SPACING switch as follows:

SPACING switch position	1	2	3	4	5	6	7	8
electrode spacing in meters	1/2	1	2	4	8	16	32	64

The CONFIGURATION switch determines the arrangement of the four electrodes used in any one measurement as follows:

CONFIGURATION switch	electrodes 1	2	3	4	5	measured resistance
A	C	P	-	P	C	R_A
C	C	P	-	C	P	R_C
D1	C	P	P	C	-	R_{D1}
D2	-	C	P	P	C	R_{D2}
B	C	C	-	P	P	R_B

The POTENTIAL REVERSE switch enables the roles of the potential electrodes to be reversed if this is necessary for the correct functioning of the resistance measuring apparatus.

For each position of the SPACING switch resistance measurements are made with each of the CONFIGURATION switch positions A, C, D1, D2, B. A check on the reliability of the results is given by the relationship:

$$R_A = R_B + R_C$$

which must be satisfied within observational error (say 3 - 5%) for any subsurface geology and any spacing. High observed errors will indicate a fault in the system (e.g. instrument fault, high contact resistance at electrodes, damaged cables, etc.,) and the source of error should be sought if differences of more than 5% are recorded. This 'tripotential' field check is described in more detail by Carpenter and Habberjam (Geophysics V. 24, 1956, p. 455).

Under most conditions the observed resistances will have magnitudes varying in the following way:

$$R_A > R_C > R_{D1} = R_{D2} \gg R_B$$

The speed at which readings are taken can be increased by conducting the measurements in this order. Alternatively, to avoid unnecessary instrument scale changes, all measurements of R_B could be left until the measurement of the other resistances has been completed for all spacings.

If an instrument of such low power is used that the smaller resistance of R_B is impossible to measure, these values may be obtained from the difference between R_A and R_C.

CALCULATION OF THE WENNER RESISTANCES

It can be seen that only positions D1 and D2 of the CONFIGURATION switch enable the measurement of true Wenner resistances. An average of R_{D1} and R_{D2} PROVIDES A Wenner resistance (Offset Wenner resistance) in which the effects of near surface lateral resistivity variations are greatly reduced. Offset Wenner resistances are measured at spacings 1/2, 1, 2, 4, 8, 16, 32, and 64m. A smooth apparent resistivity curve may be quickly plotted in the field if these resistances only are used. This curve is often of such high quality that further resistances need not be computed.

However, Wenner resistances at spacings 1 1/2, 3, 6, 12, 24, 48 and 96 m may be obtained with the following equation:

$$R_{W(3A)} = 1/2R_D(2A) + R_B(2A) - R_B(A) + 1/2R_D(4A)$$

where $R_B(A)$ is the resistance measured with CONFIGURATION B at spacing A. $R_D(A)$ is the Offset Wenner resistance measured at spacing, A.

These Wenner resistances are influenced by near-surface lateral resistivity variations to a slightly greater degree than the Offset Wenner resistances and in some cases where this effect is particularly strong, points may sometimes lie off the smooth curve that is characteristic of the Offset Wenner apparent resistivity plot.

V. ERROR CALCULATION

The system of resistance measurements employed with the BOSS Offset multicore cables enables the calculation of errors of observation and an estimation of the effects of lateral resistivity variations.

OBSERVATIONAL ERROR

The error of observation, E_o is calculated for each spacing from the expression:

$$E_o = \frac{R_A - (R_B + R_G)}{R_A} .100\%$$

This error includes all the small random effects such as observer error and instrument error. Expressed as a percentage, E_o will normally vary betwen +5 and -5. If E_o is consistently outside these limits, the source of the error should be sought. Instrument malfunction, leakage of current from damaged cables and high contact resistances at the electrodes will often cause high observed errors.

OFFSET ERROR

The offset error, E_a is purely a measure of the effects of subsurface lateral resistvity variations. It may be computed from the expression:

$$E_a = \frac{R_{D1} - R_{D2}}{R_D} .100\%$$

Values of E_a greater than 20% indicate the presence of strong lateral resistivity variations.

LATERAL ERROR

The lateral error, E_l is another measure of the effect of lateral resistivity variations but which employs in its calculation resistances measured at two different spacings.

$$E_1 = \frac{R_D\ (2a) - 2.(R_C\ (a) - R_D\ (a))}{R_D\ (2a)} .100\%$$

In the absence of strong lateral resistivity effects, the magnitude of E_1 will normally be less than 50%.

R.M.S. ERRORS

A single root-mean-square (R.M.S.) value for each of the errors may be calculated for each sounding curve in the following way:

$$E_{RMS} = \frac{1}{N} \sqrt{\sum_{1}^{N} E^2}$$

R.M.S. values of E_a and E_1 greater than 25% and 50% respectively will indicate that the sounding curve is strongly influenced by lateral resistivity effects. The interpretations from these sounding curves should be viewed with some care.

VI. FORMULAS FOR HAND CALCULATIONS AND FOR COMPUTER PROGRAMMING

NOMENCLATURE

To distinquish between the raw field data and the corrected or adjusted data, we will use the nomenclature:

Field readings, resistance	Adjusted readings, resistance
PA	RA
PC	RC
PD1	RD1
PD2	RD2
PB	RB

The symbol "RW" will designate the Wenner resistance. When multiplied by the spacing factor, $2\pi A$, it yields the Wenner apparent resistivity, "RWA".

REDUCTION OF FIELD READINGS TO RESISTANCES

For every pair of readings of voltage V and current I, we convert to resistance using:

$$P = \frac{V(\text{millivolts})}{I(\text{milliamperes})} \quad \text{or} = \quad \frac{V(\text{volts})}{I(\text{amperes})}$$

For example, if V = 410 mv and I = 10 ma for electrode configuration "C" at spacing A = 1 meter, then:

PC = 41.0 ohms

for this A value.

Some resistivity instruments such as the Bison Model 2350 give a direct dial reading of the quantity:

$2\pi\ (V/I)$.

The simplest approach is to divide every reading by 2π, which is easily programmed into the computer.

Alternatively, the computations can be carried through using the dial readings, in which case (see final formula in Section VI) the conversion to apparent resistivity will require multiplication only by A rater than by $2\pi A$. (The computed errors will be proportionately too high by a factor of 2π.)

INCOMPLETE OR QUESTIONABLE DATA

Data may be incomplete or questionable from several causes. Each must be handled differently.

1. The field readings may have been terminated with fewer than the full sequence of 8 A-spacings.

   Computations must then be carried out for only as many readings as are available. In the computer program, the input value N will be a number smaller than 8. For example, if the readings were terminated at A = 16 meters, then N = 6 and the readings will be available for:

   A = 1/2, 1, 2, 4, 8, 16 meters

2. In general, if a reading is questionable, the safest approach is to run through the calculations twice and compare results.

   The first run will include the questionable reading. The second run will omit the questionable reading, as if it were unavailable.

   It will be noted from the computation formulas that the interpolated values for spacing "3A" require field readings for spacing "A", "2A", and "4A". Thus an error or uncertainly in any one of these will be propagated into the interpolated values.

3. One or more field readings of PB (the resistance value taken with electrode configuration "B") may be unavailable.

   This will sometimes happen because PB is usually a small quantity.

   PB can be calculated from readings taken with electrode configurations "A" and "C", using:

   PB = PA - PC,

   but this will eliminate the cross check which is normally available from independent measurements. The "error of observation" will be misleading computed as 0.0 for this electrode spacing.

4. A field reading of either PD1 or PD2 may be unavailable.

   In the absence of lateral resistivity variations, these two quantities should be equal. Thus we can set the missing value equal to the available value. For example, if PD1 is unavailable, set:

   PD1 = PD2.

   The "offset error" will be misleadingly computed as 0.0 for this electrode spacing.

5. A field reading of PA or PC may be unavailable.

   This should not be permitted to happen during the field work, since the readings tend to be large and easy to measure.

   If it does happen, then the computation sequence should be terminated at the previous electrode spacing. For example, if PA is unavailable for A = 32 meters, the computations should be carried out only for N = 6 using:

   A = 1/2, 1, 2, 3, 8, 16

   The reminaing values of Wenner resistance can be calculated manually using:

   RW(A) = 1/2 (PD1 (A) + PD2 (A))

   for (in the present example)

   A = 32, 64 meters

6. In the computer program which follows, the existence of an unavailable reading is indicated by entering some negative number, for example -1.0.

REDISTRIBUTION OF ERRORS

For perfect data, the following condition would be satisfield:

$$PB = PA - PC.$$

A failure to satisfy this condition leads to an "error of observation."

The error can be redistributed amoung the three readings by the following steps:

$$E = PA - PB - PC$$

$$EE = PA + PB + PC$$

$$RA = PA \times (1 - E/EE)$$

$$RB = PB \times (1 + E/EE)$$

$$RC = PC \times (1 + E/EE)$$

COMPUTATION FORMULAS FOR WENNER RESISTANCE

We compute Wenner resistance by the following formulas:

$$RW(A) = 1/2\ (PD1(A) + PD2(A))$$

for A = 1/2, 1, 2, 4, 8, 16, 32, 64*

$$RW(2A) = 2\ (RC(A) - RW(A))$$

for A = 64*

or 2A = 128

$$RW(3A) = 1/2RW(2A) + RB(2A) - RB(A) + 1/2RW(4A)$$

for A = 1/2, 1, 2, 4, 8, 16, 32**

or 3A = 1 1/2, 3, 6, 12, 24, 48, 96

*If the number of readings, N, is different from 8, the final value is 2^{N-2}.

**The final value is 2^{N-3}.

COMPUTATION FORMULAS FOR ERRORS

Observational error

$$E = \frac{PA - PB - PC}{PA} \times 100 \text{ percent}$$

Offset error

$$H = 2 \frac{PD1 - PD2}{PD1 + PD2} \times 100 \text{ percent}$$

Lateral error

$$EL(A) = \frac{RW(2A) - 2\ RC(A) - 2\ RW(A)}{RW(2A)} \times 100 \text{ percent}$$

RMS error over all readings, for any of the above

$$ERMS = \frac{1}{N} \left(\sum_{1}^{N} E^2 \right)^{1/2}$$

COMPUTATION OF APPARENT RESISTIVITY

$$RWA\ (A) = 2\pi A \quad RW(A)$$

VII. COMPUTER PROGRAM FOR RESISTIVITY CALCULATIONS AND ERROR ANALYSIS

DESCRIPTION

The Fortran program which is given below enables the rapid calculation of Wenner resistivities and associated errors. The data processing proceeds through the following steps:

1. Observed resistances are read in as described under 'INPUT' below.
2. Any observed errors will be distributed between R_A, R_B and R_C so that the theoretical relationship $R_A = R_B + R_C$ is then satisfied.
3. E_o, E_a AND E_1 are computed.
4. R.M.S. errors are computed.
5. Wenner resistivities are computed.
6. Resistances, errors and Wenner resistivities are printed.

INPUT

Input Formats:

Card or Line 1	Number of electrode spacings, N, unformatted. (If field readings have been pre-multiplied by 2 , enter this number as a <u>negative</u> quantity).
Card or Line 2	Identification name for sounding, up to 10 letters or numbers.
Card or Line 3A	Field readings RA(1), RC(1), RD1(1), RD2(1), RB(1), unformatted but separated by commas. These are the data taken at A(1) = 0.5 meter. If any field reading has been omitted or is unavailable for some reason, enter any negative number, for example -1.0, at its entry position.
Card or Line 3B	Same, for data taken at A(2) = 1.0 meter.
Card or Line 3C	Continue, for remaining field readings.
Card or Line 3D etc.	

The entire imput sequence may be repeated with additional sets of sounding data.

To terminate the sequence, enter "0" on a final card or line.

SAMPLE INPUT DATA

```
8
STATION 14
65.5,60.9,42.6,51.5,4.42
38.6,36.3,25.7,29.7,2.36
23.9,22.7,15.3,17.5,1.36
16.8,15.6,11.,12.1,1.25
13.3,12.5,8.5,9.6,0.773
9.31,8.78,6.35,6.95,0.53
5.03,4.68,3.75,3.97,0.325
1.87,1.7,1.63,1.65,.142
0
```

SAMPLE OUTPUT DATA

```
OFFSET WENNER SOUNDING     STATION 14
NUMBER OF MEASUREMENTS =   8

FIELD READINGS SUPPLIED AS INPUTS.
 (A NEGATIVE VALUE DENOTES AN OMITTED READING.)
```

SPACING	PA	PC	PD1	PD2	PB
.5	65.500	60.900	42.600	51.500	4.420
1.0	38.600	36.300	25.700	29.700	2.360
2.0	23.900	22.700	15.300	17.500	1.360
4.0	16.800	15.600	11.000	12.100	1.250
8.0	13.300	12.500	8.500	9.600	.773
16.0	9.310	8.780	6.350	6.950	.530
32.0	5.030	4.680	3.750	3.970	.325
64.0	1.870	1.700	1.630	1.650	.142

SAMPLE OUTPUT DATA (CON'T)

SPACING	ADJUSTED RESISTANCE DATA RA	RB	RC	WENNER1	WENNER2	------WENNER------- OFFSET	RESISTIVITY
.5	65.410	4.426	60.984	42.600	51.500	47.050	147.81
1.0	38.630	2.358	36.272	25.700	29.700	27.700	174.04
1.5							188.33
2.0	23.980	1.355	22.624	15.300	17.500	16.400	206.09
3.0							244.52
4.0	16.825	1.248	15.577	11.000	12.100	11.550	290.28
6.0							384.25
8.0	13.286	.774	12.513	8.500	9.600	9.050	454.90
12.0							556.11
16.0	9.310	.530	8.780	6.350	6.950	6.650	668.53
24.0							755.67
32.0	5.017	.326	4.692	3.750	3.970	3.860	776.10
48.0							767.80
64.0	1.856	.143	1.713	1.630	1.650	1.640	659.48
96.0							428.31
128.0							117.14

SPACING	----------ERRORS---------- OBSERVED	OFFSET	LATERAL
.5	.275	-18.916	
1.0	-.155	-14.440	-.000
1.5			
2.0	-.667	-13.415	-4.878
3.0			
4.0	-.297	- 9.524	-9.091
6.0			
8.0	.203	-12.155	10.497
12.0			
16.0	0	- 9.023	-3.759
24.0			
32.0	.498	- 5.699	-10.363
48.0			
64.0	1.509	- 1.220	.000
96.0			

R.M.S. OBSERVATIONAL ERROR = .63

R.M.S. OFFSET WENNER DIFFERENCE = 11.73

R.M.S. LATERAL DIFFERENCE = 6.50

```
      PROGRAM BARKER (INPUT, OUTPUT, TAPE5, TAPE6=OUTPUT)
      DIMENSION PA(20),PC(20),PD1(20),PD2(20),PB(20),RA(20),RC(20),
     1 RD1(20),RD2(20),RB(20),A(20),RWA(20),E(20),H(20),EL(20)
C
C  ORIGINAL PROGRAM BY R.D. BARKER, UNIVERSITY OF BIRMINGHAM.
C  PROGRAM MODIFIED BY H.M. MOONEY, UNIVERSITY OF MINNESOTA.
C
C  SPECIFY THE NUMBER OF ELECTRODE SPACINGS AT WHICH MEASUREMENTS
C    WERE TAKEN.  FOR MAXIMUM SPACING OF 64 METERS, N=8; FOR
C    MAXIMUM SPACING OF 128 METERS, N=9.  TO TERMINATE RUN,ENTER "0".
C  (IF FIELD READINGS HAVE BEEN PRE-MULTIPLIED BY 2*PI, ENTER N
C  AS A NEGATIVE VALUE).
C
 10   READ (5,*),N
      IF(N.EQ.0)STOP
C
      NN=N
      N=ABS(N)
C  ENTER AN IDENTIFICATION NAME FOR THE SOUNDING.
C
      READ (5,20),TITLE
 20   FORMAT(A10)
      WRITE(6,210),TITLE,N
C  ENTER THE FIELD READINGS, SEPARATED BY COMMAS, ONE LINE FOR
C   EACH ELECTRODE SPACING VALUE IN THE SEQUENCE RA,RC,RD1,RD2,RB.
C  IF A READING IS NOT AVAILABLE, ENTER ANY NEGATIVE NUMBER SUCH
C   AS -1.0 IN ITS PLACE.
C
      DO 30 I=1,N
      READ (5,*)PA(I),PC(I),PD1(I),PD2(I),PB(I)
 30   CONTINUE
C
      WRITE (6,220)
      AA = 0.25
      DO 40 I=1,N
      AA = AA*2.
      WRITE (6,240), AA, PA(I), PC(I), PD1(I), PD2(I), PB(I)
 40   CONTINUE
C
C  IF FIELD READINGS HAVE BEEN PRE-MULTIPLIED BY 2*PI, DIVIDE IT OUT.
C
      PI = 3.14159257
      IF (NN.GT.0) GO TO 50
      TEMP = 1./2./PI
      DO 50 I=1,N
      PA(I)  = PA(I)  * TEMP
      PC(I)  = PC(I)  * TEMP
      PD1(I) = PD1(I) * TEMP
      PD2(I) = PD2(I) * TEMP
      PB(I)  = PB(I)  * TEMP
 50   CONTINUE
```

```
C
C   CHECK FOR OMITTED PA OR PC READINGS.
C
      DO 60 I=1,N
      IF(PA(I).GT.0. .AND.  PC(I).GT.0.) GO TO 60
      N = I-1
      GO TO 70
 60   CONTINUE
 70   CONTINUE
C
C   CHECK FOR OMITTED PD1 OR PD2 READINGS.
C
      DO 80 I=1,N
      IF(PD1(I).LT.0.) PD1(I) = PD2(I)
      IF(PD2(I).LT.0.) PD2(I) = PD1(I)
 80   CONTINUE
C
C   CHECK FOR OMITTED PB READINGS.
C
      DO 90I=1,N
      IF(PB(I).LT.0.) PB(I) = PA(I) - PC(I)
 90   CONTINUE
C
C   COMPUTE SEQUENCE OF ELECTRODE SPACINGS.
C
      A(1)=0.5
      A(2)=1.0
      A(3)=1.5
      DO 100 I=2,10
      A(I*2)=A(I*2-2)*2.
      A(I*2+1)=A(I*2-1)*2.
 100  CONTINUE
C
C   COMPUTE AND REDISTRIBUTE THE ERROR VALUES.
C
      EEE=0.
      HHH=0.
      NN=N-1
      DO 110 I=1,N
      E(I)=PA(I)-PB(I)-PC(I)
      EE=ABS(PA(I))+ABS(PB(I))+ABS(PC(I))
      RA(I)=PA(I)-E(I)*PA(I)/EE
      RB(I)=PB(I)+E(I)*PB(I)/EE
      RC(I)=PC(I)+E(I)*PC(I)/EE
      RD1(I)=(PD1(I)+PD2(I))/2.

      H(I)=(PD1(I)-PD2(I))*100./RD1(I)
      RD2(I)=RC(I)-RD1(I)
      E(I)=E(I)*100./RA(I)
      EEE=EEE+E(I)*E(I)
      HHH=HHH+H(I)*H(I)
 110  CONTINUE
      FN=N
      EEE=SQRT(EEE/FN)
      HHH=SQRT(HHH/FN)
```

```
C
C  COMPUTE WENNER APPARENT RESISTIVITY VALUES.
C
      RWA(1)=RD1(1)
      DO 120 I=2,NN
      RWA(I*2-2)=RD1(I)
      RWA(I*2-1)=RD1(I)/2.+RB(I)-RB(I-1)+RD1(I+1)/2.
 120  CONTINUE
      RWA(N*2-2)=RD1(N)
      RWA(N*2-1)=RD1(N)/2.+RB(N)-RB(N-1)+RD2(N)
      RWA(N*2)=RD2(N)*2.
      ELL=0.
      DO 130 I=1,NN
      EL(I)=(RD1(I+1) - 2.*(PC(I)-RD1(I)))*100./RD1(I+1)
      ELL=ELL+EL(I)*EL(I)
 130  CONTINUE
      ELL=SQRT(ELL/FN)
      EL(N)=0.
      M=N*2
      DO 140 I=1,M
      RWA(I)=2.*PI*A(I)*RWA(I)
 140  CONTINUE
C
C  PRINT OUT RESULTS.
C
      WRITE(6,230)
      WRITE(6,240) A(1),RA(1),RB(1),RC(1),PD1(1),PD2(1),
     1 RD1(1),RWA(1)
      DO 150 I=2,N
      WRITE(6,240),A(I*2-2),RA(I),RB(I),RC(I),PD1(I),PD2(I),
     1 RD1(I),RWA(I*2-2)
      WRITE(6,250),A(I*2-1),RWA(I*2-1)
 150  CONTINUE
      WRITE(6,250),A(M),RWA(M)
      WRITE(6,260)
      WRITE(6,240),A(1),E(1),H(1)
      DO 160 I=2,N
      WRITE(6,240),A(I*2-2),E(I),H(I),EL(I-1)
      WRITE(6,250),A(I*2-1)
 160  CONTINUE
      WRITE(6,270),EEE
      WRITE(6,280),HHH
      WRITE(6,290),ELL
C
      GO TO 10
```

```
C
 210  FORMAT(//,22HOFFSET WENNER SOUNDING ,7X,A10,//,
     1 24HNUMBER OF MEASUREMENTS =,I3,/)
 220  FORMAT(//,2X,34HFIELD READINGS SUPPLIED AS INPUTS.,/,
     1 5X,46H(A NEGATIVE VALUE DENOTES AN OMITTED READING.),//,
     12X,7HSPACING,3X,2HPA,7X,2HPC,7X,3HPD1,6X,3HPD2,6X,2HPB,/)
 230  FORMAT(//1X,7HSPACING,2X,24HADJUSTED RESISTANCE DATA,
     1 21X,20H - - - WENNER - - - - ,
     1/12X,2HRA,7X,2HRB,7X,2HRC,4X,7HWENNER1,2X,
     17HWENNER2,3X,6HOFFSET,2X,11HRESISTIVITY,/)
 240  FORMAT(1X,F6.1,6F9.3,F9.2)
 250  FORMAT(1X,F6.1,54X,F9.2)
 260  FORMAT(///,2X,7HSPACING,9X,6HERRORS,/,9X,8HOBSERVED,
     12X,6HOFFSET,2X,7HLATERAL,/)
 270  FORMAT(///,5X,28HR.M.S. OBSERVATIONAL ERROR = ,F6.2)
 280  FORMAT(//,5X,33HR.M.S. OFFSET WENNER DIFFERENCE =,F6.2)
 290  FORMAT(//,5X,27HR.M.S. LATERAL DIFFERENCE =,F6.2)
      END
```

BISON INSTRUMENTS, INC.

SIGNAL ENHANCEMENT EARTH RESISTIVITY SYSTEM

MODEL 2390

BISON
INSTRUMENTS
INCORPORATED

INSTRUCTION MANUAL

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BISON INSTRUMENTS, INCORPORATED
5708 West 36th Street
Minneapolis, Minnesota 55416 U.S.A.
612/926-1846

Telex 29-0208 BISON SLPK — Cable "GEOPRO"

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I. GENERAL DESCRIPTION

The Bison Model 2390 Earth Resistivity System introduces a new concept to earth resistivity instrumentation. Building upon the principle of signal enhancement which Bison pioneered in its Engineering Seismographs, the 2390 achieves substantial improvements over conventional earth resistivity meters. Signal enhancement yields increased sensitivity and depth range combined with decreased power, size, and weight. This is accomplished by the summation of many small signals over a period of time. The time duration can be selected by the operator to suit the operating conditions and sensitivity requirements.

Resistivity signal enhancement utilizes a system based upon conversion of the earth potential to a voltage-dependent frequency, followed by a precision counting and averaging operation.

The 2390 System operates with any of the standard four-electrode or three-electrode-plus-one-at-infinity arrangements. These include Schlumberger, Wenner, and the various dipole and bipole configurations.

The 2390 System consists of a Transmitter and a Receiver in separate consoles. They operate coherently using carefully synchronized waveforms. The synchronization must initially be carried out with a cable connection between the two units but, once synchronized, the units can be disconnected and operated at separate locations. This may prove especially useful with the dipole configurations, where the Transmitter can be placed at one dipole and the Receiver at the other. In addition, several Receivers may be used with a single Transmitter to obtain field data more rapidly.

The 2390 Receiver can be used separately in an SP mode for mineral exploration using the self-potential method.

II. SPECIFICATIONS

BISON MODEL 2390-T TRANSMITTER:

Voltage Output:	0 to 500V (1000V peak-to-peak), continuously and automatically adjusted to achieve selected current.
Current Output:	Panel selectable at: 10mA, 20mA, 50mA and 100mA.
Power Output:	Up to 50 watts, dependent on current selection.
Power Supply:	Internal, rechargeable, sealed lead acid, 12V, 5 amp hour battery. External power supply connector provided.
Operating Frequencies:	0.1, 0.2, 0.33, 0.5, 1, 2, 3.33, 5 Hz
Operating Periods:	Period equals total time per reading, whereby one reading equals ten samples averaged: 100, 50, 30, 20, 10, 5, 3, 2 seconds, dependent on selectable frequencies listed respectively.

BISON MODEL 2390-R RECEIVER:

Operating Frequencies:	Same as 2390-T Transmitter, plus DC measurements in SP mode.
Operating Periods:	Same as 2390-T Transmitter.
Power Supply:	Two internal, rechargeable, 6V NiCad, 1.5 amp hour batteries. System will operate from external 12VDC power supply.
Output:	Unprocessed potential signal to optional recorder.
Modes:	Resistivity and Self Potential.
Total Range:	Four ranges in 3 1/2 digits: 1999, 199.9, 19.99, 1.999 millivolts.
Resolution:	One half of least significant digit.
Precision:	1% range setting; 5% full scale (10 microvolts) in most sensitive range.
Accuracy:	2% of measured value.

III. INTRODUCTION TO ELECTRICAL RESISTIVITY AND SELF-POTENTIAL MEASUREMENTS

1. GENERAL

In this section, we provide a brief survey of subsurface exploration using electrical resistivity measurements. We include reference to the self-potential method used in exploration for base metal deposits, since the 2390 Receiver can also be used for that purpose.

This brief section supplements the detailed description of the resistivity method given in a separate Bison publication:

Handbook of Engineering Geophysics
Volume 2: Electrical Resistivity
Harold M. Mooney, 1980, 82 pages.

That text provides information on principles and applications of electrical resistivity and on interpretation of the field readings. A copy of the volume accompanies each Model 2390 system. Additional copies may be purchased from Bison Instruments.

2. METHOD

The electrical resistivity method provides means for subsurface exploration by electrical measurements taken at the surface of the earth. Figure 1 shows a typical resistivity array in cross section. Four electrodes are pressed into the ground to a depth of several centimeters, at locations a few tens or hundreds of meters apart. Electrical current is caused to flow into the earth through two of these electrodes. The resulting voltage drop (potential difference) produced by this current in the earth is measured across a second pair of electrodes. Since some earth materials are better conductors of electricity than others, the voltage drop will be affected differently by different subsurface conditions. The interpretation of electrical resistivity readings consists in deducing the subsurface conditions from the measurements.

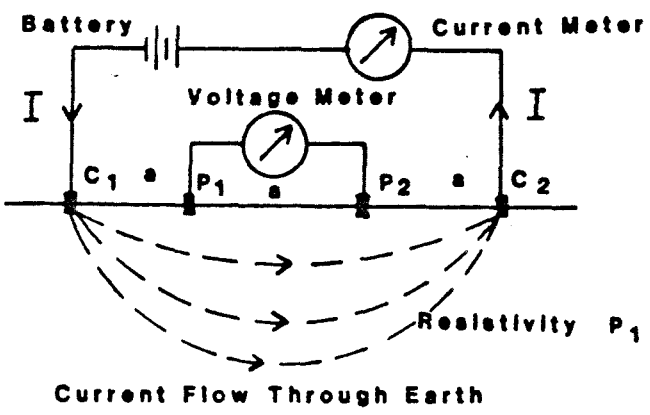


FIGURE 1

3. PRINCIPLE OF RESISTIVITY EFFECTS

The basis for the success of the electrical resistivity method rests on the following properties. Earth materials are good conductors of electricity in proportion to their content of (a) water or moisture, and (b) dissolved salts or free ions. Thus, massive rock formations such as granite or limestone are poor conductors (show high electrical resistivity) because they contain very little moisture. Clean gravels and clean sands are also poor conductors (high resistivity materials) because, even when saturated with water, the water tends to be relatively clean and free from dissolved ions. If the gravels or sands are dry, then their resistivity will be higher still. By contrast, moist clays and clay soils contain both water and dissolved ions hence they are good electrical conductors (low resistivity materials). Other earth materials will have their own characteristic resistivity values. The basis lies in the detection of this resistivity contrast between two or more materials.

4. RESISTIVITY APPLICATIONS

The electrical resistivity method finds use in a wide variety of subsurface investigations.

The most important applications have proved to be for problems involving groundwater. These include the location and delineations of water supplies, water quality evaluation, pollution studies, and salt water incursion.

Civil engineering applications include determination of depth to bedrock, location of sand or gravel deposits, and engineering classification of materials (for example, weathered vs. unweathered rock).

In mineral exploration, resistivity has been used to locate ore bodies, faults, veins, sink holes, and other deposits of commercial value.

A rapidly developing application is to geothermal studies, to take advantage of the low electrical resistivity associated with hot rocks and hot connate waters.

Additional fields of application include glaciology, permafrost study, archaeology, and cave location. Applications to petroleum exploration have been limited, although the techniques of well-logging based on electrical resistivity and self-potential measurements are widely used. The Bison Model 2390 can be used for both of these types of measurement, although Bison does not supply the downhole electrodes and cables.

5. DEPTH RANGE

The depth of investigation by the electrical resistivity method can in general, be controlled by the user. Shallow investigations are carried out by placing the electrodes relatively close together, whereas deeper investigations require increased spacing between the electrodes. No simple or fixed relationship exists between electrode spacing and depth of investigation - in fact, the term depth of investigation is difficult to define - but the following statement may serve as a starting point. Detection of a subsur face target at depth D will normally require that measurements be extended to include electrode spacings (between the two most distant electrodes of the array) at least 4 to 6 times D.

In practice, therefore, the maximum attainable depth of investigation (however defined) depends upon the maximum attainable separation of electrodes for which reliable measurements can be made. Since the voltage signal level goes down rapidly as electrode spacing is increased, we conclude that greater depths require more sensitive instruments. The Bison Model 2390 uses the principle of signal enhancement to achieve high sensitivity.

Greater depths of investigation also entail greater difficulty in data interpretation, even if the measurements are highly reliable. The reason lies in the much larger volume of earth through which the current is distributed, when large electrode spacings are used. The resistivity measurement represents a kind of weighted average of true earth resistivities throughout the volume of measurement. The larger this volume the greater will be the variety of earth material included within it.

6. SELF-POTENTIAL MEASUREMENTS

The self-potential technique has proved useful in exploration for base-metal deposits, especially massive sulfides. The method relies on natural earth currents set up by these ore bodies. The currents produce potentials which can be detected at the surface of the earth. The detection and measurement of these potentials constitutes the self-potential exploration technique.

The Bison 2390 Receiver provides a sensitive and convenient instrument for self-potential measurements. The potential readings appear digitally. The signal enhancement capabilities of the 2390 provide continual averaging and updating of the self-potential readings. By means of the "Frequency" and "Decade" controls on the Receiver, the 10-cycle averaging period may be set within a range extending between 0.2 and 10 seconds. The Receiver includes also the feature of automatic polarity display.

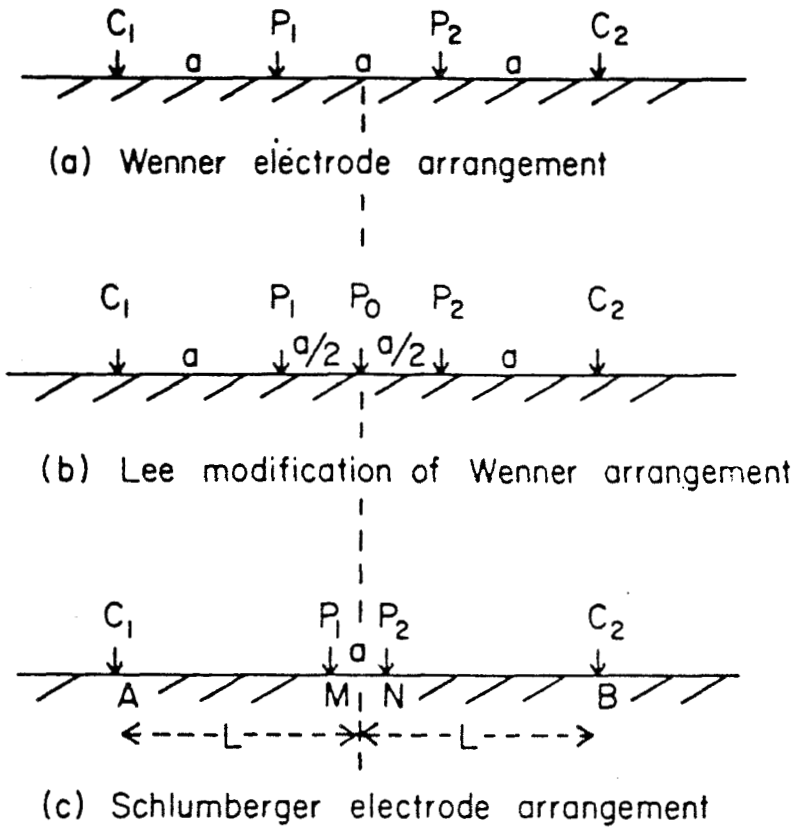
The only auxiliary equipment required is a reel of wire and two non-polarizing porous pot electrodes.

For more information on the self-potential method, the following text may be consulted:

Applied Geophysics
W. Telford, L. Geldart, R. Sheriff, and D. Keys.
Cambridge University Press, 1976, 860 pp.

IV. PRINCIPLES OF OPERATION

The Model 2390 system is desinged to work with any of the standard electrode arrangements. Representative configurations are shown in Figure 2, together with the formulas by which to compute the apparent resistivity, ρ_a.



$$\rho_a = A\left(2\pi \frac{V}{I}\right)$$

$$\rho_a = 4\pi A \frac{V}{I}$$

$$\rho_a = \pi a \frac{V}{I}\left[\left(\frac{L}{a}\right)^2 - \frac{1}{4}\right]$$

FIGURE 2:
Representative Electrode Configurations

The "apparent resistivity", ρ_a , will be the final computed quantity used for interpretation. A full discussion will be found in the Handbook referenced earlier.

The quantity ΔV equals the potential difference measured between the electrodes P1 and P2, normally expressed in millivolts. On the 2390 Receiver, ΔV corresponds to the digital readout on the panel meter.

The quantity I equals the current flowing into the earth at electrode C1 and out at electrode C2, expressed in milliamperes. On the 2390 Transmitter, I is given by the Range setting. It corresponds approximately to the digital readout on the panel meter, although this reading merely serves a monitor function, with a precision limited to several percent.

The formulas in Figure 2 can be used to provide a quick estimate of the expected potential difference in a given field situation. Apparent resistivity is defined in such a way that it equals true earth resistivity when the subsurface is completely uniform. (Normally, this condition would not be satisfied.) Thus we can take an estimated value for average earth resistivity, substitute it into the formula, and compute an estimated value for ΔV.

As an example of this calculation, suppose that the measurement will be taken with the Wenner electrode arrangement using electrode spacing A=50 meters and current setting I=20 milliamperes. If the average earth resistivity were 200 ohm meters, for example, the expected potential difference would be

$$\Delta V = \frac{(200 \text{ ohm meters})\ (.020 \text{ amperes})}{2\pi\ (50 \text{ meters})}$$
$$= 11.0 \text{ millivolts}$$

The basic function of the 2390 system is to supply current I and measure the resulting potential difference ΔV.

Certain practical difficulties arise in the course of resistivity measurements. These include:

a) Natural earth currents produce small voltages (potentials) between the potential electrodes. The instrument must distinguish these from the artificially induced potentials which we wish to measure. Sometimes these natural potentials remain constant during measurement, but more often they vary erratically.

b) Extraneous potentials may originate at the contact between the electrode and the earth. The electrodes themselves may develop undesirable potentials where they contact the earth.

c) If the current waveform consists of any shape other than a steady-state direct current, electromagnetic coupling from the current cables may induce potentials in the potential cables.

d) Induced polarization effects in the earth may round off sharp transitions in the input current waveform.

The 2390 system provides means to overcome or minimize these difficulties. The first step is to use a current waveform consisting of alternately positive and negative current directions as shown in Figure 3. The potential measurement is taken in the positive direction during positive current flow, and in the negative direction during negative current flow. This process averages out and eliminates any steady state potentials due to natural earth currents, electrode contacts, and other effects.

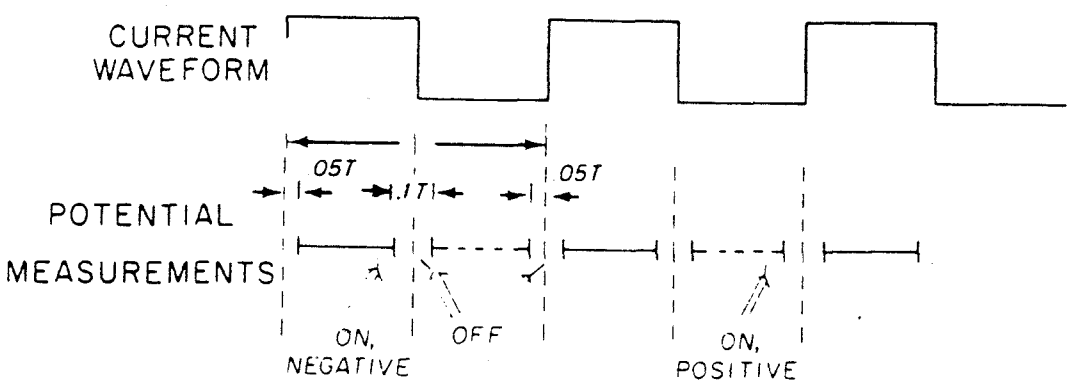


FIGURE 3

The second step in overcoming the problem of spurious potentials is to avoid making potential measurements near the time of current reversals. Figure 3 illustrates this process also. The potential measuring circuit does not begin its measurement until 5% of the current waveform has elapsed, and this measurement ends 5% in advance of the current waveform termination. This minimizes errors produced by electromagnetic and induced polarization since both effects occur principally near the current waveform transitions.

The most distinctive feature of the 2390 system lies in its introduction of signal enhancement to earth resistivity measurements. To understand the benefits from signal enhancement, we need to understand the problem against which it is directed. Figure 4 illustrates the problem. It shows a simulated voltage waveform that might be measured between the two potential electrodes. Most of the waveform consists of erratic voltage variations arising from natural earth currents or other extraneous sources. Superposed on this are the small potential steps produced by the current source. We wish to measure the steps and eliminate the erratic variations.

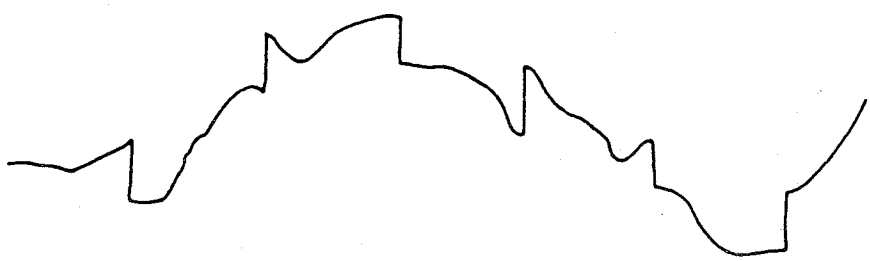


FIGURE 4:
Signal Plus Noise On The Potential Waveform

The 2390 accomplishes this separation in the following way. During the positive portion of the curent waveform from the transmitter, the receiver takes a running average of the voltage at the potential electrodes. It achieves this by converting the instantaneous voltage to a frequency by means of a precise digital voltage-to-frequency converter. A digital counter then counts pulses at a rate established by the instantaneous frequency. Thus the counter provides a measure of the average voltage over the duration of the measurement interval. This average includes contributions from every slight variation of the voltage waveform. The final output at this step consists of a digital reading of total counts, proportional to the average voltage.

At the conclusion of the positive portion of the current waveform, the counter connection is reversed so that it counts downward during the negative portion of the current waveform. At the conclusion of one full cycle, the count will be (a) zero, in the presence of a pure noise voltage, or (b) a value proportional to the signal, in the presence of a pure signal voltage.

In practice, neither of these ideal situations will exist. We can approach the ideal, however, if we carry out the averaging over many cycles rather than only over one. The 2390 accomplishes signal enhancement by counting up/counting down over ten full cycles of the current waveform before displaying the final output potential.

The counting, display, and recycling are carried out automatically. So long as the receiver is in operating mode, it will measure voltage for 10 cycles, then for 10 more cycles, and continue indefinitely. The voltage output for each sequence will be continually displayed to the operator during the following sequence, so that he or she may write it down if desired.

The 2390 Transmitter is supplied with a panel-controlled choice of waveform frequencies. Thus the voltage reading will be updated every 10 cycles of the operating frequency (i.e. for 1 Hertz or 1 second period, the voltage reading updates every 10 seconds.)

This provides a powerful technique for discriminating against the erratic random voltages which so seriously limit deep resistivity investigations. It also provides the operator with a continual check of the consistency of the readings as the noise voltages vary.

Normal measurements are carried out in the 1 hertz (1 second period) mode. The low frequency/long period options find use in the presence of severe noise conditions, especially at the large electrode spacings required for very deep investigations. Here the potential available for measurement is very small, so that signal enhancement permits it to build up to a level readable above the noise. The high frequency/short period options find use in quiet conditions, or at small electrode spacings.

A final point for explanation is the problem of synchronization. Figure 2 shows that the potential measuring circuit in the receiver must be turned on and off in a precise time relationship to the transmitter waveform. The 2390 system provides a means for achieving this synchronization.

The system makes use of an electrical connection (the "synchronizing cable") between the transmitter and the receiver. The transmitter waveform is obtained from a precision 1 megahertz oscillator by counting down either 6 or 7 decades. Similar counting circuits are present in the receiver. A "sync" control on the transmitter will, when depressed, lock the two waveforms together in synchronization. They will then remain locked together so long as the power remains on in both units and the frequency switches remain the same on both units. If either of these conditions is violated, an "out of sync" panel indicator will light on the receiver, and sync must be reestablished.

It is also possible to operate the transmitter and receiver completely separate from one another. Thus, they can be placed hundreds of meters apart if desired. This synchronization is achieved by connecting transmitter to receiver by the synchronizing cable, and then momentarily depressing the "sync" button. Following this step, the sync cable can be removed and the units operated independently for up to 24 hours, although it is a wise precaution to resynchronize after 8-10 hours.

V. DESCRIPTION OF EQUIPMENT

1. BASIC COMPONENTS AND ACCESSORIES

The Bison 2390 Earth Resistivity System consists of the following standard components.

1 2390T 50-watt Resistivity Transmitter

1 2390R Resistivity Receiver

2 Battery Chargers

1 Input Connector and cable for external power supply

1 Synchronizing Cable (2 meters standard, greater lengths optional)

5 Input Panel Plugs

1 Instruction Manual

1 Handbook of Engineering Geophysics, Volume 2: Electrical Resistivity.

In addition, the following components may be required to make the system operational in the field. To accomodate users who are already equipped with these items, they are made available separately as optional accessories:

4 Reels with Cable
Standard lengths are 450 meters for current cables and 150 meters for potential cables. This permits, for example, a maximum A-value of 300 meters with Wenner configuration. Other lengths can be supplied on special order.

4 Electrodes

1 Center Electrode and Cable for Lee Electrode Configuration

2 Fiberglass Tapes (avoid metal), 100 meters or 300 feet

1 Test Load Box

1 Bison Model 1400A Stripchart Recorder

A complete system (<u>less</u> measuring tapes and Model 1400A) is shown in Figure 5.

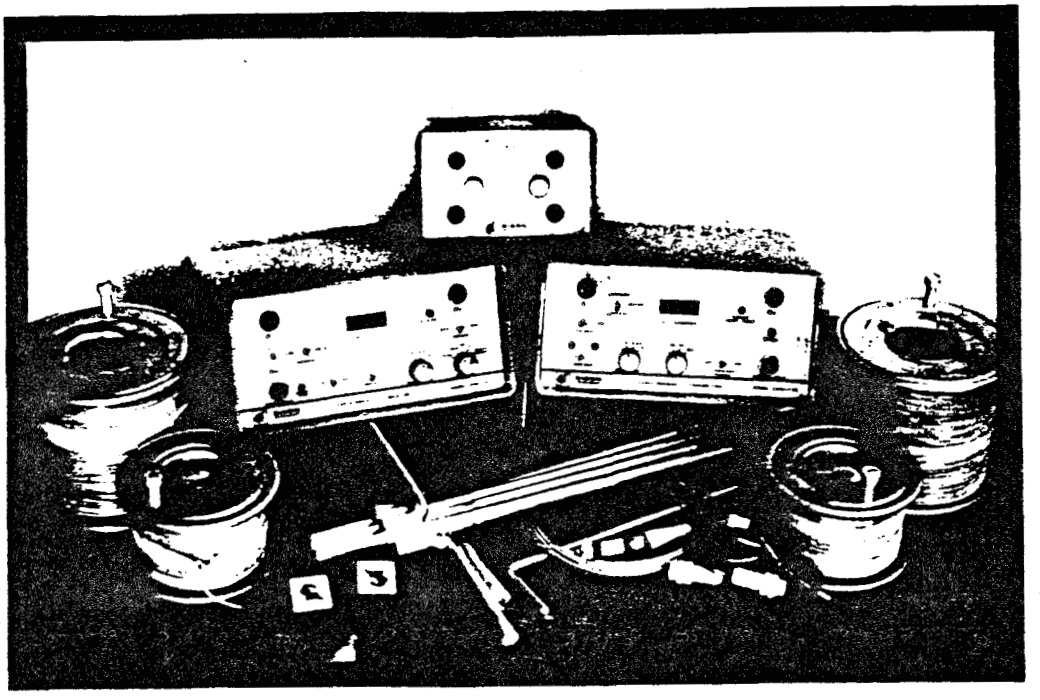


FIGURE 5:
Model 2390 ER System and Accessories

2. PANEL CONTROLS, TRANSMITTER

The transmitter panel is shown in Figure 6 with the individual controls identified by number. Their functions will now be explained.

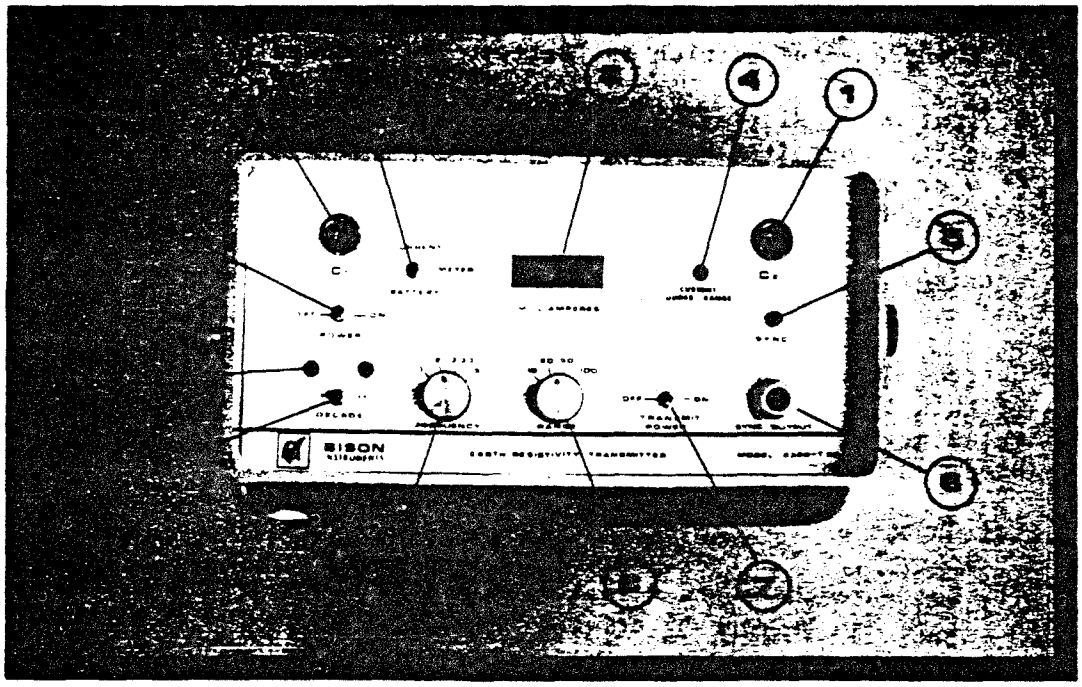


FIGURE 6:
Panel Controls, Transmitter

1) Output terminals for connection to the current electrodes C1 and C2.

2) Selector switch for use with the digital meter display, item 3. In the "Up" position, the meter reads an approximate value for the current flowing into the earth through electrodes C1 and C2.

   In the "Down" position, the meter reads battery voltage on the self-contained power supply. Further information will be found in the preceding section on "Battery Maintenance".

3) Digital meter display.
   As noted under item 2, this meter will read either the current flow or the battery voltage. When used as a curent meter, it serves only a monitor function to assure that current is actually flowing and that the value is close to the desired setting. The meter reading may be in error by several percent and may fluctuate slightly.

4) Current Under Range light.
   If this light goes on, the current has failed to reach the value selected using the Range switch. One of the following steps should be taken:

   (a) Choose a lower current value with the Range switch.

   (b) Decrease the contact resistance at the current electrodes. This can be done by driving them deeper into the earth, by pouring fresh or salt water around them, or by using two or more electrodes in parallel.

5) Sync switch.
   This switch is used to synchronize the waveforms between the Transmitter and the Receiver. Its operation will be explained below.

6) Sync Output connector.
   The synchronizing cable plugs into this connector, with the other end connected to the Receiver. Its operation will be explained below.

7) Transmit Power switch.
No current will actually pass through electrodes C1 and C2 until this switch has been turned to the "On" position. In the "Off" position, various checks and settings can be made prior to the measurement. The switch should be left in the "Off" position whenever possible to assure safety and conserve battery power.

8) Range switch.
This switch establishes the precise current value desired. The normal setting is 20 milliamperes. Higher settings may be preferred at large electrode spacing or under conditions of low earth resistivity to increase the voltage value available for measurement. A setting of 10 milliamperes may be required if the electrode resistance is unusually high due to dry ground conditions. The Range setting gives a precise value for the actual current flow, whereas the current reading on the meter display (3) gives only an approximate value for monitoring purposes.

9) Frequency selector switch.

10) Decade switch.

These two controls together establish the repetition frequency or period for the current waveform as shown in Figure 2. The actual frequency equals the "Frequency" dial setting multiplied by the "Decade" dial setting. For example, if Frequency = 2 and Decade = .1x, the current waveform has a frequency of 0.2 hertz. Since period equals 1/frequency, the corresponding period would be 5 seconds. This represents the time duration of a complete cycle (positive plus negative) shown in Figure 2.

11) Frequency indicator lights.
These lights monitor the function described under items (9) and (1) above. During positive current flow, the left light comes on, and during negative current flow the right light comes on. This permits the operator to confirm visually that the waveform generator is operating correctly.

12) Power switch.
This switch provides standby power to the system. Normally standby power is left on during the entire field operation, since power drain is relatively small. The operator should keep in mind that synchronization between Transmitter and Receiver will be lost if the Power switch is turned off. The Power switch has a special safety detent to avoid accidentally turning it off. To actuate the Power switch, pull the knob out slightly before moving.

13) Charger/External Power connector.
A connector on the right side of the case provides connections to either (a) the battery charger, or (b) an external 12-volt power supply. The latter may be useful where very long transmit times are to be used.

3. PANEL CONTROLS, RECEIVER

The receiver is shown in Figure 7 with the individual controls identified by number. Their functions will now be explained.

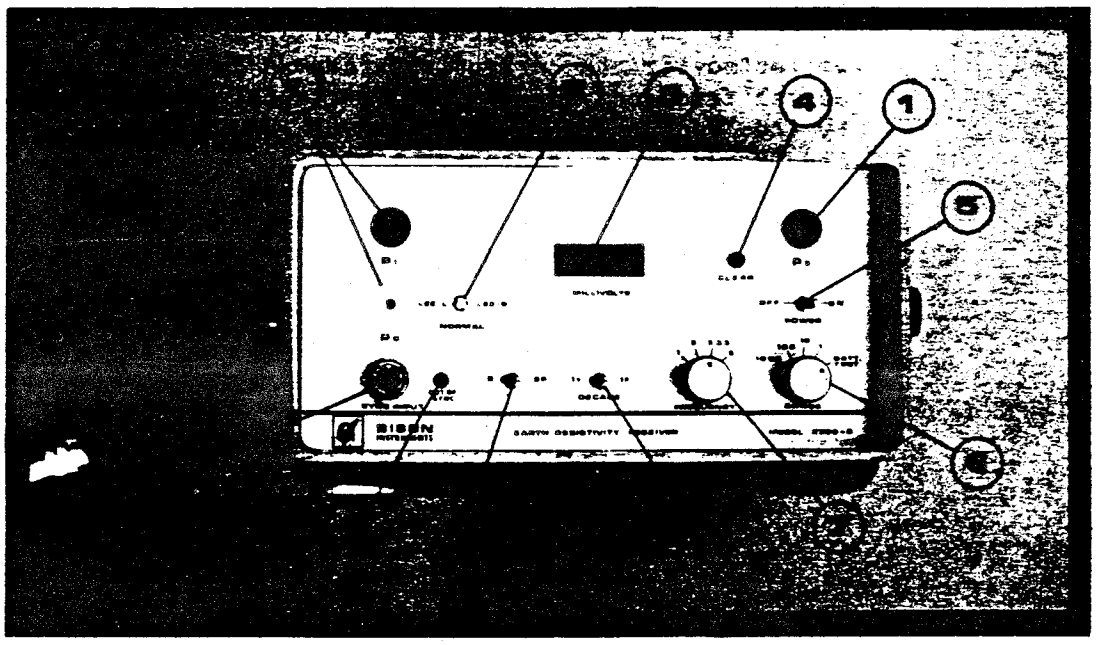


FIGURE 7:
Panel Controls, Receiver

1) Input terminals for connection from the potential electrodes P1 and P2.
   Terminals P1 and P2 are normally used. Terminal P0 provides means to use the Lee Electrode Configuration. For a description of this configuration, see Chapter 30 in Handbook of Engineering Geophysics, Volume II.

2) Selector switch for input terminals P1-P0, P1-P2 and P0-P2.
   Normal operation uses the center or "Normal" position. The other two positions provide connections for the Lee-Left or the Lee-Right connections.
   Note that this switch has a protective detent, such that the knob must be pulled outward before it can be moved.

3) Millivolt meter display.
   The voltage reading is displayed on this meter. This equals the potential difference, in millivolts, between the two potential electrodes. Negative values will be indicated by a minus sign.
   This display serves another function also. The decimal point flashes on and off at the frequency of the Receiver waveform. When properly synchronized, this also equals the frequency of the Transmitter waveform. The flashing decimal point gives visual confirmation of the frequency.

4) Clear switch.
   This switch initiates a new sequence of 10 cycles in the measuring process. Use of the switch is optional, since the Receiver continually updates the millivolt reading after every 10 cycles. If the switch is not used, however, the first update reading should be ignored since it may have started somewhere in the middle of a 10-cycle sequence.

5) Power switch.
   Power is normally left on full time during the field measurements. If the power is turned off, synchronization must be re-established.
   Note that this switch has a protective detent, such that the knob must be pulled outward before it can be moved.

6) Range switch.
This controls the position of the decimal point on the millivolt display, hence it controls the millivolt range. In the 1000 position,the decimal point is placed to the right of all digits. The reading range extends from 1 to 1999 millivolts. The 100 position displays 0.1 to 199.9 mv. moving the decimal point one place to the left. The 10 position displays 0.01 to 19.99 mv. The 1 position displays 0.001 to 1.999 mv (1 to 1999 microvolts).
The Range switch should normally be placed in the lowest possible position to provide the maximum number of significant digits. If the setting is too low, however, the millivolt display screen will go blank except for the blinking decimal point. The Range switch must then be turned to a higher value.

7) Frequency selector switch.

8) Decade switch.

These two controls together control the frequency of the Receiver waveform. Their operation is explained above for the same two controls on the Transmitter.
The Transmitter and the Receiver frequencies must be set to exactly the same values during operations. If one is changed, the other must be changed. In addition, they must be synchronized at all times as explained elsewhere. If the frequency is changed, the units must be re-synchronized.

9) R-SP switch.
This switch provides the choice between making electrical resistivity measurements and self-potential measurements. Normal operation will be in the resistivity mode.
In the self-potential mode, the Receiver will be used by itself to measure the potential difference between the two potential electrodes. These potentials arise from electrochemical phenomena in the earth, especially those associated with sulfide ore bodies. In this mode, the Receiver does not reverse the polarity of measurement midway in the the cycle, but rather measures an average value of potential over 10 cycles. Thus the signal enhancement capability of the 2390 system is used for self-potential measurements also.

10) Out of Sync light.

11) Sync Input connector.
The synchronizing cable from the Transmitter connects to the Receiver at this socket. The Out of Sync light will remain on until the two instruments have been synchronized, at which time it will go off. If synchronization should be lost, the light will go on again.

The Out of Sync light functions only when the Transmitter and Receiver are connected by the synchronizing cable. When this cable has been removed, the condition of the light has no significance.
If the Out of Sync light is blinking on and off, this means that the Frequency settings differ between the Transmitter and Receiver. These settings must always be identical during operation. The Out of Sync light will not always indicate different transmitter and receiver frequencies, so the operator should not rely on it for this purpose.

12) Charger/External Power connector.
A connector on the right side of the case provides connections to either (a) the battery charger, or (b) an external 12-volt power supply.

13) Chart connector.
A connector on the right side of the case provides an output which can be connected to the Bison Model 1400A Chart Recorder. This permits making a continual display of potential versus time for the potential electrodes.

VI. OPERATING INSTRUCTIONS

1. BASIC MEASUREMENTS

The following sequence of steps will guide the user through a set of measurements. We suggest that the beginning user may wish to carry out the measurements in the office, using a dummy load to simulate the earth. A convenient device for this purpose is the Model 2390 Test Box, an optional accessory. If this is not available, the following circuit can be used, or else the 2390 can be connected directly to electrodes under field conditions.

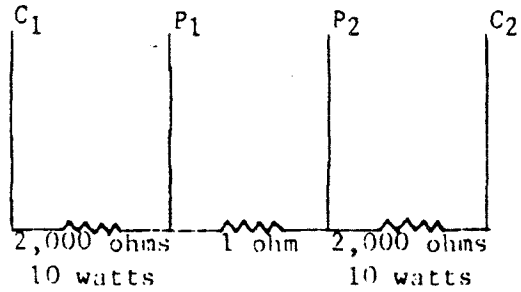


FIGURE 8:
A simple Dummy Load

Any resistance values can be used in the ranges 2,000 to 4,000 ohms and 0.1 to 1 ohm.

The user must keep in mind that the Receiver "millivolt" reading will be updated every 10 cycles. This means that the existing reading may remain unchanged for several seconds (or even several tens of seconds, at very low frequencies) after the current has been turned on. It means also that the first updated reading may be meaningless (unless preceded by use of the "Clear" button) because the signal enhancement process may have been initiated in the middle of a 10-cycle sequence.

We reccomend the following panel settings as a starting point for either field operations or office tests. They can be modified as the need arises.

On the Transmitter, set:

"Meter"	to	"Current"
"Decade"	to	"1x"
"Frequency"	to	"1"
"Range"	to	"20"

On the Receiver, set:

"Lee-L, etc"	to	"Normal" (center position)
"R-SP"	to	"R"
"Decade"	to	"1x"
"Frequency"	to	"1"
"Range"	to	"100"

Step 1: Set the panel controls as recommended above.

Step 2: Make connections to input and output sockets P1, P2, C1, and C2 such that C1 and P1 are on the same side of the array. These must go to either the electrodes or to the test load. If the Model 2390 Test Box is used, set left knob to "4K" and the right knob to "1 ohm".

Step 3: Connect the synchronizing cable between Transmitter and Receiver.

Step 4: Turn on the Transmitter and Receiver. Numbers will appear on the display meters. (Reminder: On the Power switches, the knob must be pulled out slightly before it can be moved). The Out of Sync light should come on and remain on. If it fails to do so, turn the Receiver off for a few moments.

Step 5: Check the battery voltages. Turn knobs to "Battery" and "Batt Test" positions. (Reminder: The Receiver reading may not appear for several seconds because the Receiver must pass through 10 cycles before the reading will be updated).
The battery voltages will differ substantially because the two units use different battery types. Typically, the Transmitter reading will be about 12 volts and the Receiver reading about 13 volts. Further information will be found in the Maintenance section.

Return the battery test knobs to the current settings.

To review, the panel settings which we have chosen have the following significance. We selected a current value of 20.0 milliamperes through the load at a frequency of 1.0 hertz. The Test Box setting of 1 ohm simulates an earth resistance reading of

$$\Delta V/I = 1 \text{ ohm}$$

where ΔV will equal the "millivolt" reading on the Receiver.

The Test Box setting of 4K = 4,000 ohms (or 2,000 + 2,000 ohms in Figure 8) has no direct bearing on the readings, so long as the resistance value is small enough to produce the full 20.0 milliamperes of current. The Transmitter produces a maximum output of 550 volts zero-to-peak. With a 4,000 ohm test load, the Transmitter could theoretically produce 550 volts/4000 ohms = 138 milliamperes of current, but this will be automatically reduced by the Transmitter to the selected value of 20.0 milliamperes and a lower current "Range" setting would be required.

We note that the Transmitter and Receiver have been carefully set to the same frequency of 1 hertz. At this stage, the numbers on the display meters will be meaningless. We observe that the decimal point on the Receiver display meter goes on and off with a frequency of 1 hertz.

Step 6: Synchronize Trasmitter and Receiver by depressing the Sync switch on the Transmitter for several seconds, until the Out of Sync light on the Receiver will go out.
This process may take one or two seconds, since the system must go through a full 10 cycles. For very low frequencies, many seconds could elapse before the light goes out.

Step 7: Turn on the Transmitter Power switch. On the Transmitter, the red indicator lights near the "Decade" switch should alternate at a frequency of 1 hertz. This displays the operating frequency for the current waveform.

The Transmitter meter will display a number close to 20 milliamperes. This number will change frequently between two values separated by 0.3 milliamperes. Typically, the readings will be 20.0 and 20.3. As noted elsewhere, the meter serves only a monitor function to show that current is flowing at approximately the desired value. The true current value is established precisely by the Range switch setting. Typical current meter readings will be 9.7 and 9.9 on the 10 milliampere setting, 20.0 and 20.3 on 20, 50.4 and 50.7 on 50, and 100.7 and 101.0 on 100.

On the Receiver, a meaningless number will appear for several seconds on the display, until the first full sequence of 10 cycles has been completed. After this, the correct value of potential in millivolts will be displayed. This will be updated every 10 cycles (that is, every 10 seconds, for 1 hertz). The numbers may change slightly in the third decimal, but they should be slightly greater than 20.0 mv for a Test Box setting of 1 ohm (1 ohm times 20 ma equals 20 mv). The Receiver reading may be negative. This depends simply upon the polarity with which the connections were made to P1 and P2. The reading will still be correct.

Step 8: Experiment with some of the control settings.

(a) Press Clear button on the Receiver. The display reading will go to zero and remain so for 10 cycles, after which the correct reading will appear.
The Clear button may be used at any time. This will avoid waiting through one meaningless reading after the Trasmitter current has been turned on.

(b) Turn the Range switch on the Receiver to a value which is too low.
Set the Range switch at 1. The display meter now lacks enough significant figures to give a correct reading. At the conclusion of the next 10-cycle sequence, the display will disappear except for the decimal point. This shows the operator that the reading is over-range and that the Range switch must be set to a higher number. Restore the Range switch setting to 100.

(c) Throw the system out of synchronization and observe that erroneous "millivolt" readings appear on the Receiver. This step can be accomplished by turning the Receiver off for a few moments, or by changing the "Frequency" or "Decade" setting momentarily.

(d) Change the Transmitter current setting.
Change the Trasmitter Range switch to 10. The "milliamperes" meter should give readings which alternate approximately between 9.7 and 9.9.
The Receiver meter reading will of course also be reduced by a factor of 2. Restore the Transmitter Range setting to 20.

(e) Demonstrate the effect of excessive contact resistance at the current electrodes.
Turn the Test Box setting to 40K = 40,000 ohms. The warning light "Current under Range" will come on. The display meter on the Transmitter will read about 14 milliamperes, despite the Range switch setting of 20. This shows the operator that the Transmitter output voltage is too small to drive 20 milliamperes through this large load. The solution is to use a lower current setting, namely 10 milliamperes on the Range switch. Restore the Test Box setting to 4K.

2. SUGGESTIONS FOR FIELD OPERATIONS

(a) Before starting the readings, confirm that the frequency settings are identical on Transmitter and Receiver.

(b) The normal Transmitter current setting of 20 milliamperes may be increased to 50 or 100 milliamperes when the Receiver "millivolt" reading becomes small (less than 20, say).
This will increase the millivolt reading proportionately and improve the signal to noise ratio.
Conversely, a current setting of 10 milliamperes may be sufficient when the Receiver reading reaches a few hundred millivolts.

(c) The normal frequency setting of 1 hertz may be increased to 2 or even 5 hertz for shallow investigations. This will yield faster readings.
Conversely, for large depths of investigation (tens of meters) or in the presence of severe natural earth potential noise, lower frequency settings may be used. This will reduce the speed of reading but will provide signal averaging over longer time intervals.

(d) Turn off the Transmit Power switch whenever possible, to conserve battery power.

(e) Successive millivolt readings on the Receiver may vary up to a few percent, especially in the presence of large natural earth potential noise. These readings can be averaged.

(f) For readings below 10 millivolts, take a repeat reading with the potential input cables reversed and average the results. The 2390 system is designed to cancel out unwanted natural earth potentials, but at low signal levels the cancellation may not be quite complete. The averaging step can improve the cancellation.

(g) If the system falls out of synchronization with the synchronizing cable connected, this condition will be displayed by the Out of Sync light coming on.

(h) The synchronizing cable can be removed after synchronization has been completed. The Transmitter and Receiver can then be operated in complete isolation from each other, up to several hundred meters apart if desired. The system will retain synchronization for several hours, although more frequent resynchronization would be desirable.
If the system falls out of synchronization during isolated operation, the only clue will be unexpected or erratic readings. Thus the operator should be alert to such readings. The state of synchronization can then be checked by temporarily reconnecting the synchronizing cable.
In general, the system should be operated with the synchronizing cable in place whenever convenient.

(i) The current circuit and the current electrodes have high voltage on them during transmission. Take all safety precautions to prevent anyone contacting them when the Transmit Power switch is on.

(j) If the milliampere reading is zero, one of the current electrodes may be disconnected. If the millivolts reading is zero or erratic, one of the potential electrodes may be disconnected.

(k) If excessively high resistance is encountered at the current electrodes, the Transmitter may be unable to produce a full 20 milliamperes of current, or even a full 10 milliamperes. The first step to remove the difficulty should be to push the electrodes deeper into the earth. Usually a few centimeters or tens of centimeters will suffice, but sometimes a full meter may be needed.
Alternatively or in addition, the soil around the electrodes can be moistened with plain or salt water.

(l) If excessively high resistance is encountered at the potential electrodes, the potential readings may become erratic. The simplest way to check whether this condition exists is to temporarily connect the potential electrodes to the Transmitter and perform the same tests as above. Usually, however, the potential electrode contacts will be satisfactory whenever the current electrode contacts are satisfactory.

(m) Multiple Receiver units can be used from the same Transmitter. All must be synchronized.

(n) The optional Bison Model 2390 Test Box serves a useful function for trouble shooting. When trouble is suspected, a reading can be taken with the Test Box. Most field troubles originate external to the 2390, as for example broken cables or defective connections.

(o) The optional Bison Model 1400A Stripchart Recorder can supply a continuous record of earth potential versus time. This will show the actual potentials which are being averaged by the 2390 Receiver. It can display the magnitude of the noise from natural earth potentials. It may reveal the cause of erratic readings.

VII. BATTERY MAINTENANCE

1. 2390 RECEIVER

The 2390 receiver uses a 12 volt 1200 mA hour rechargeable nickel cadnium battery pack. The battery pack is of sealed construction, contains no free electrolyte and requires no servicing or maintenance other than recharging. The battery will have a useful life for many cycles of discharge with normal use and care.

When fully charged, the battery is sufficient for approximately 10 to 15 hours of continuous operation. This will considerably extend the operating time before recharging. The state of the battery can be determined at any time by turning the range switch (6 in Figure 7) to the Batt. Test position. The digital readout will then display the battery voltage in volts.

A fully charged battery will give a voltage reading of 13.0 volts or more. When the voltage falls as low as 12.0 volts, the operator should watch for erratic readings and recharge the battery as soon as possible. Operation of the instrument should cease if at any time the battery voltage falls to 11.5 volts or less.

Ensure that the 2390 receiver is turned off. The battery charger can then be connected to either 100-120 Vac or 220-240 Vac at 50-60 hertz. Make certain that the battery charger is set for the voltage level being supplied, i.e. 115 or 230. To recharge the battery, plug the battery charge accessory supplied with the 2390 receiver into the charger input connector on the side of the 2390 receiver case. Normal charge time is 16 hours or over night between field sessions.

2. 2390 TRANSMITTER

The 2390 transmitter uses two 12 volt 5000 mA hour rechargeable lead acid battery packs. Each battery pack consists of cells that are sealed in cases that prevent acid, acid vapor and water leakage. Since the batteries can be operated during their normal lifetime without loss of water, or even during continous overcharge, no water or electrolyte checks are ever required. The life of the batteries will be a function of the following variables: depth of discharge, temperature and charging rate. With normal use the useful life will be 500 to 2000 cycles or discharges.

The battery voltages should be kept at 11.5 volts or higher. If the voltage falls below this level, erratic operation may result. The solution is to recharge the battery or to use an external 12 volt power source.

Battery life in the field is dependent upon the time that the Transmit Power is on and, most significantly, upon the Current Range position. The higher positions use significantly more power and more quickly discharge the batteries.

The state of the batteries can be determined at any time by switching the meter selector switch to the battery position (2 in Figure 6). The digital readout will then display the battery voltage in volts.

Ensure that the 2390 transmitter is turned off. The battery charger can then be connected to either 100-120 Vac or 220-240 Vac at 50-60 hertz. Make certain that battery charger is set for the voltage level being supplied, i.e. 115 or 230. To recharge the batteries, plug the battery charge accessory supplied with the 2390 transmittter into the charger input connector on the side of the 2390 transmitter case. Normal charge time is 16 hours or over night between field sessions.

G-856X
OPERATORS MANUAL

18101-02

ADDENDUM TO THE G-856X MANUAL

The following is provided to correct or update the information in this manual. Please make note of the necessary changes as follows.

On page 37 under Display reads "data Err"

Survey Difficulty	Probable Cause	Corrective Action
Display reads "data Err"	1. Internal memory error.	1. Print out or transcribe all stored data, then depress ERASE ERASE.
	2. Power removed while instrument was in operating mode.	2. Dump stored data into recording device, then press ERASE ERASE.
	3. Power interrupt during AUTO cycle or OUTPUT.	3. Remove batteries. Press the INTERNAL RESET button on CPU board 16635-01. Install batteries. Set clock.
	4. Lithium battery malfunction.	4. Measure lithium battery voltage. If voltage is less than 3.9V, replace.
	5. Control board malfunctioning.	5. Return board (P/N 16621).

On page 62 under PREPARATION the paragraph should read

Configure the G-856 console for normal polarize, normal gate, disable 3 read averaging and 9600 baud rate by setting switches 1 through 4 to "off" and 6 through 8 to "on" on G-856X CPU board.

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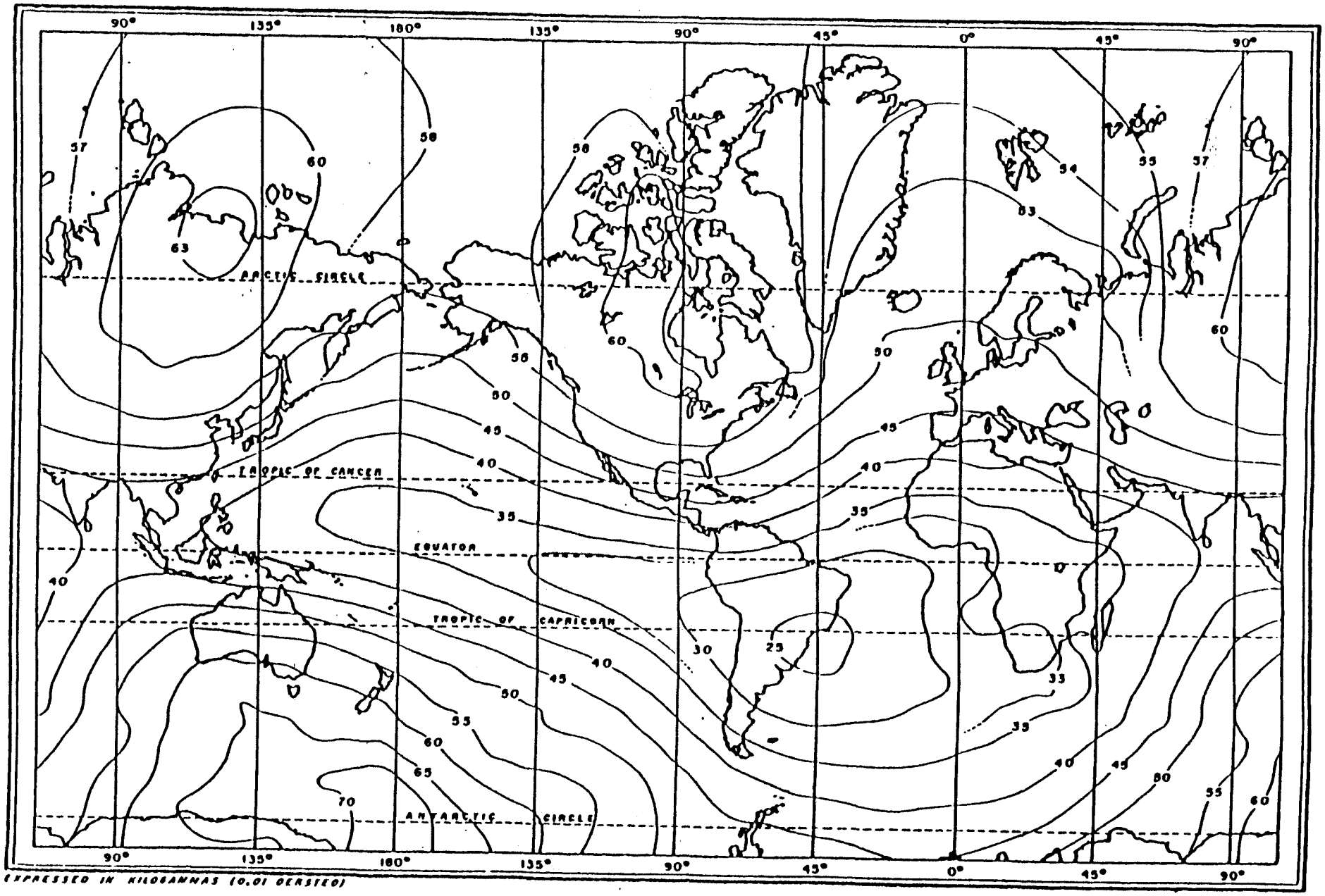


The Total Intensity of the Earth's Magnetic Field

Preface

Magnetometers

A magnetometer is an instrument for measuring the intensity of the earth's magnetic field. Most rocks contain some magnetite, the most common magnetic mineral, and therefore produce some disturbances in the magnetic field. Soils and even some man made objects such as pottery can have magnetic properties.

Through interpretation of magnetometer readings, assumptions can be made about what exists beneath the surface, whether it is a pipeline, an ancient urn, a particular mineral, or geologic structure. The interpretation of magnetic data received from a magnetometer is sometimes a difficult task, made even more complex by constant changes in the earth's overall magnetic field, the size and distance of objects from the magnetometer, the amount of magnetic material the object contains, and the susceptibility of the object to absorb magnetism from other sources. On the other hand, many applications may require only simple interpretations of anomalies.

The proton precession magnetometer has become the principal instrument for magnetic studies because it combines high accuracy and ease of use. The Applicatons Manual for Portable Magnetometers, supplied with this instrument, includes general information on the use of magnetometers. It should be studied as a companion to this volume, which deals specifically with the G-856 Memory Mag™ magnetometer.

The G-856

The G-856 is a portable, man-carried magnetometer and a "base station" magnetometer. As a hand-carried instrument, it features simple, push button operation and a built-in digital memory which stores over 1000 readings. This relieves you of the need to log data in the field, eliminates transcription errors and most important, lets you use computers to automatically record and process the data from the magnetic survey.

The G-856 Memory-Mag magnetometer will also record automatically at regular intervals, so it can be left unattended to monitor diurnal changes in the earth's magnetic field. These readings are used to correct simultaneous field measurements for high accuracy surveys. Here again, the data may be fed directly into a computer so that the field data taken with an identical G-856 may be automatically corrected. The time-of-day is recorded with each reading taken in either mode from a built-in digital clock.

All operations are controlled from a weatherproof membrane switch front panel. The sequence of operations was carefully designed to be very simple to operate and yet flexible. Erasing the memory requires an intricate, fail-safe sequence to protect the data, except for the most recent reading which can be easily deleted and replaced if desired.

A single connector is used for the sensor and data output. The output format is in the universal RS-232, understood by most small and large computers and some printers. The data may also be printed and graphed on the G-866 Recording Magnetometer, or stored for later analysis on digital tape recorders like Geometrics G-724M.

Physically, the G-856 is compact and lightweight. It is weatherproof and operates over a wide temperature range. It is powered by eight D-Cell batteries, sufficient for about 3000 readings.

Above all, the G-856 is a high-precision magnetometer, the result of many years experience in the manufacture of similar instruments. An internal programming switch allows modification of the cycle times to ensure that the G-856 works properly near the magnetic equator and in high gradients where other models may operate only marginally or fail to obtain reliable data.

> The operation of the instrument is controlled by a microprocessor and the control program may be changed at any time for product improvement or other considerations. In that event, you may find variations between this manual and the operation of your actual instrument operation. Such variations will have no adverse effect and should be recognizeable as you familiarize yourself with operation.

Contents of this Manual

This manual presents the operating instructions for the G-856. Included are step-by-step instructions on how to:

*operate the magnetometer

*use the special features in surveying

*retrieve data

*maintain the magnetometer

Clarification of Terms

The terms used to describe the actions of the operator or functions of the magnetometer may be new to some. For example, the areas or buttons, on the front panel will be called "keys". The words "sampling", "cycling", and "taking a reading" are all synonymous, and "mode" is used to refer to different parts of the magnetometer's operation, its different capablilities. The G-856 has two parts of operation--auto (automatic) mode and survey mode (regular field operation where the operator pushes buttons to take a reading).

There are two functions on most keys. When accessing the numbers on the keys, the magnetometer is said to be in numeric mode. When using a key to exercise a command (e.g. TUNE), the magnetometer is said to be in the command mode.

Chapter 1

Initial Set-up

This part of the manual contains information on operation of the G-856 and use of its accessories.

The G-856 comes packed in a strong ABS plastic suitcase, with compartments for its accessories. It contains:

*the G-856 magnetometer with a set of batteries already installed

*a sensor

*a collapsible aluminum staff

*a signal cable

*a chest harness

*a spare set of 8 D-cell batteries

*G-856 Operator's Manual

*Applications Manual for Portable Magnetometers

System Checkout

This procedure is to check the magnetometer's operation and to familiarize you with the system. Note that the magnetometer will produce incorrect readings indoors or where magnetic interference (from buildings, power lines, vehicles, etc.) is present.

1) Unfold the staff and twist each section together.

2) Mount the sensor (the white cylindrical object) on the staff by screwing the staff into the threaded sensor mount. You'll notice there are two ways the sensor can be mounted, either on its end or horizontally. Mount it vertically now. We will discuss the horizontal method (also called saddlemount) in Chapter 2. As an alternative, the sensor and magnetometer may be carried in the chest harness.

3) Using the signal cable, connect the sensor to the magnetometer.

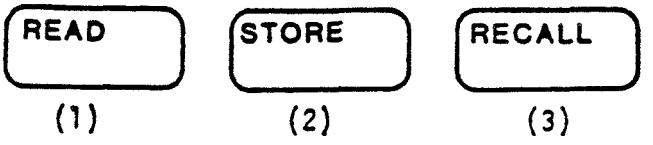
4) Depress READ. The displays will light, turn off, then light again for 5 seconds. If the displays did not light, see the maintenance and Troubleshooting section in Chapter 4.

Operation Procedure

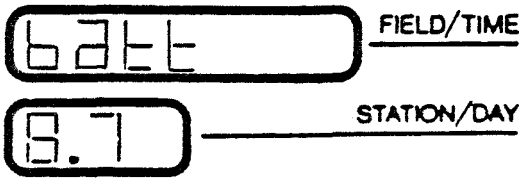
This section will show you how to take a reading, store it, and recall it from memory. After you've seen the general way in which the G-856 functions, the next section will begin the step-by-step instructions on operation.

The G-856 is really quite simple to operate. Most of the controls will not be used during the course of a normal survey and much of the sequence is automatic. The READ and STORE sequence is all you usually need.

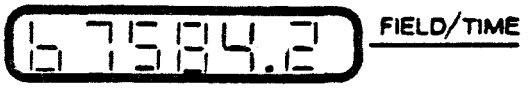
To take a reading of the magnetic field, store it, and recall it from memory, three keys will be used.



(1) a. When you depress READ, the displays will light briefly with the battery voltage, for example:



b. Then, the battery voltage will go out. After a short interval, the FIELD/TIME display will light with a 5 or 6 digit number, for example:



This is the magnetic field reading in gammas.

At the same time the magnetic field lights in the FIELD/TIME display, another number appears in the STATION/DAY display, for example:

This is the station number. Both displays will stay lit for about 5 seconds, then go out.

(2) To store the reading in memory, depress STORE while the displays are still lit. If the displays go out before you depress STORE the reading will be lost and the ERROR message will come on. After you depress STORE the display will go out.

(3) To recall the reading from memory, depress RECALL

The FIELD/TIME display will light with the field reading and the STATION/DAY display will light with the station number that was stored with it.

In summary,	by depressing READ	you've taken a reading of the magnetic field
	by depressing STORE	you've stored that reading in memory
	by depressing RECALL	you've recalled the reading from memory

The next section provides instructions on every phase of operation. Each part of operation is presented in the order in which it would normally be done in actual use.

Actual Use

This section includes operational instructions. Notice that the operational procedures are divided into nine parts, and they are listed below in the order in which they appear in the manual.

(I) Clearing a Key Sequence

(II) Setting the Clock

(III) Using the Line Number Marker

(IV) Tuning the Magnetometer

(V) Taking and Storing a Reading

(VI) Recalling from Memory

(VI-A) Recalling from Memory - last reading

(VI-B) Recalling from Memory - particular reading

(VI-C) Recalling from Memory - second half of memory line

(VII) Erasing Data

(VII-A) Erasing data - last reading

(VII-B) Erasing data - last group

(VII-C) Erasing data - entire memory

(VIII) Setting Auto Mode

(VIII-A) Displaying the last field reading taken

(VIII-B) Accessing real time

(VIII-C) Shutting off Auto Mode

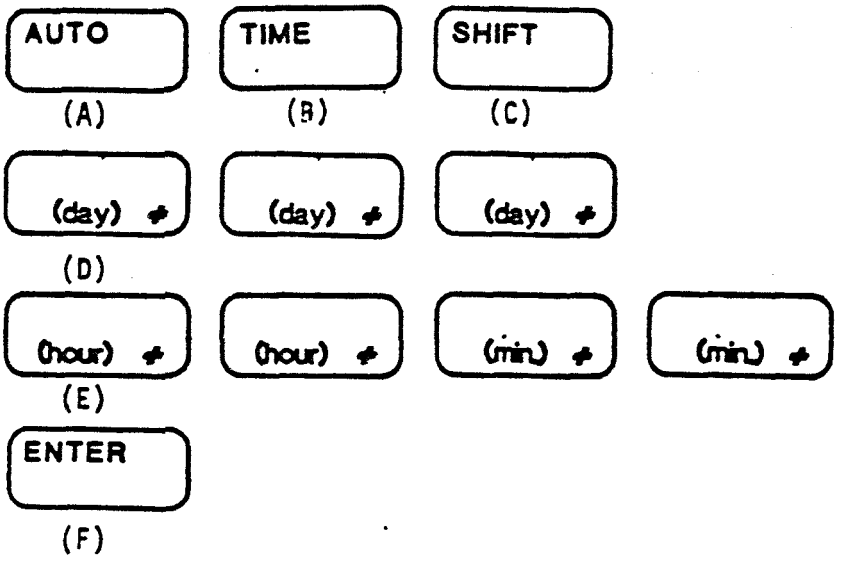
(IX) Retrieving Data

(I) Clearing a key stroke or key stroke sequence

Depress

(A) When you depress CLEAR the displays will go blank and any key stroke(s) will be "erased."

(II) Setting the Clock



There are a number of features of the internal clock, and they are discussed in several places in this manual. To briefly describe the key sequence involved in setting the clock, you will:

1. Check the clock to see if it needs setting.

2. Select a time in the near future when you will start the G-856 clock.

3. Shift into AUTO mode (the clock can only be set if AUTO is pressed before TIME).

4. Depress TIME, SHIFT, numbers for the day, the hour, and the minutes.

5. Wait for real time to match your preset time, and press ENTER to synchronize the G-856 clock.

Start by determining if the clock needs setting. Depress TIME. The time will light in the displays. Hour, minutes, and seconds will light in the FIELD/TIME display. The seconds will be running. Another number will light STATION/DAY display. Compare this indicated time to your watch, time standard, or your base station instrument and decide whether you need to set the clock. The display will go blank automatically in 5 seconds; to speed the process, depress CLEAR. If you decide that you need to set the clock, go through the following sequence.

(A) Depress [AUTO]

(B) Depress [TIME]

The displays will light with the current time setting. The STATION/DAY display will show the Julian Date. To change it, determine the time at which you will start the clock, and key in the numbers as follows.

(C) Depress [SHIFT] to access the numbers on the keys

When you do this the lower display will show:

(D) Depress [(day) ◆] [(day) ◆] [(day) ◆]

Numbers for the Julian day, for example, April 13 is day number 103. As you do this, the STATION/DAY display will fill with the new setting. If you don't wish to change the day-of-year value, just re-enter the old number.

(E) Next, depress [(hour) ◆] [(hour) ◆] [(min) ◆] [(min) ◆]

Numbers for the hours and minutes. As you do this, the FIELD/TIME display will fill with numbers.

(F) Depress [ENTER] at the instant that the display

matches your time standard. When you do this the new setting will be entered and the display will go blank.

1) You can check that the time is correct by depressing TIME. The displays will light with the newly set time. The seconds will be running.

2) Note that the old clock keeps running inside the G-856 until you press ENTER. If you make a mistake in the sequence, just press CLEAR and you will have the old time restored.

3) ENTER can also be used after the Julian Date is keyed in so you can change that number without resetting the clock. In other words, you are free to use the Julian Date as another variable like the Line Number but remember that in auto mode this number increments every 24 hours; (see section III).

Notice that depressing [SHIFT]

accesses the numbers that are on the bottom portion of the key. This is different than most other types of keyboards, (for example typewriters) where SHIFT will access what is on the top portion of the key.

(III) Setting the Line Number (Survey Mode)

In surveying, you will want to use a special designation called the line number to help you in mapping (see Chapter 2, Mobile Survey Operation, for further details). When in Survey Mode, this 3 digit number appears in the STATION/DAY display when TIME is depressed. (When in AUTO Mode, the three digit number appearing when TIME is depressed is the Julian day of the year).

> Both the current line number setting and the Julian day are recorded for each reading taken, although both are not available for viewing on the displays. (If the reading is taken in survey mode, the line number is displayed when TIME is depressed; if the reading was taken in auto mode, the Julian day is displayed when TIME is depressed). The automatic printout of the G-856, however, provides all the information: the line number, the time and Julian day, the field reading, and the station number. (See Chapter 3 for a more thorough discussion).

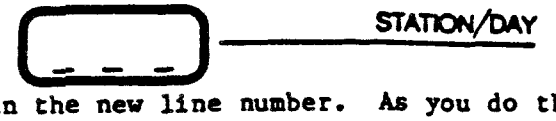
Be sure you are not in auto mode when setting the line number.

To change the line number, you will:

(A) Depress [TIME]

The FIELD/TIME display will light with the real time and the STATION/DAY display will light with the current line number.

(B) Depress SHIFT to access the numbers on the keys. When you do this the STATION/DAY display will show



Now key in the new line number. As you do this the display will fill.

(C) Depress [ENTER]

The display will blank and the new line number will be stored with the next field readings. To verify proper entry, press TIME.

(IV) Tuning the Magnetometer

The magnetometer needs to be tuned for the same reason that a radio requires tuning, to achieve the best signal strength. The tuning procedure is a matter of matching the circuits response to the intensity of the actual field value.

Usually, fairly accurate readings can be obtained by merely entering a guess at what the tuning value should be, but occasionally a survey may require very precise tuning where you will want to receive the maximum signal.

If you do not know the approximate magnetic field for your area, locate your position on the world magnetic map on page iii of this manual. The map will provide you with the approximate field for your location; one or two digit accuracy is sufficient.

The magnetometer may be tuned to 3-digit resolution (e.g. 57.4 kilogammas) but internally it selects from 256 possible steps. This allows you to tune the magnetometer very precisely which will result in less scatter and more accurate readings. Approximate tuning will be adequate for most surveys.

Remember--the following sequence only works if the magnetometer is functioning properly. You will need to be outdoors, away from power lines and large metal objects.

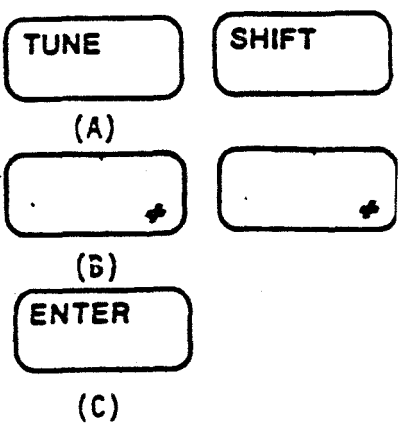
To tune:

1) Use the world magnetic map to determine the normal field for the area being surveyed.

2) Tune the magnetometer to two digit accuracy, (54 is 54,000 gammas).

3) Take a reading.

4) Retune to match the reading obtained.
You will depress:



READ

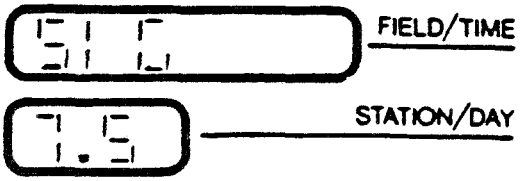
(D)

TUNE

(E)

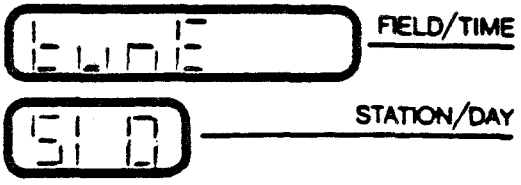
(A) Depress TUNE TUNE

(1) When TUNE is depressed, a number will appear in the display.



This is the signal strength, a number ranging from 0.0 to 9.9 which describes the strength of the signal received on the previous measurement.

(2) After the signal strength goes out, the current tuning value will appear in the displays.



This number should be read as 51,000 gammas. The tuning range is between 20,000 and 90,000 gammas.

Next, decide if the present tuning value is valid. If it needs to be changed you will need to enter in numbers for whatever the new tuning value should be.

Depress SHIFT to access the numbers or the keys.

(B) Depress numbers for the new tuning value, for example:

(56,000 gammas). Zeros will be entered for any space on the display not given a number.

(C) Depress

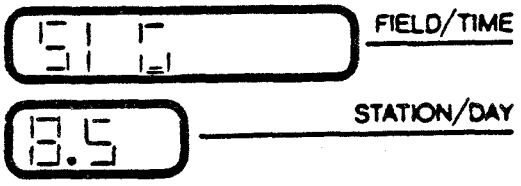
When ENTER is depressed the new tuning value will be activated. The displays will go blank.

(D) You will want to check the tuning by taking a reading.

Depress

(E) You will want to check the signal strength achieved at the new tuning value. Depress

The displays will again light with a signal intensity number, for example,



(F) If this is satisfactory signal strength, you will begin your survey. If you need to increase the signal strength, you will want to be more precise in the tuning value entered. You might want to take a reading and enter in the first three digits of that reading for the tuning value. Some trial and error is usually required to receive the maximum signal strength possible. In general, maximum signal strength is received when the tuning value matches that of the field.

(V) Taking and Storing a Reading

This part of operation was explained in the section called OPERATION PROCEDURE. Briefly, the keys depressed to take and store a reading are

The next operational procedure, Recalling from Memory, expands on the use of the RECALL key to access the memory.

(VI) Recalling from Memory

A good way to understand the memory is to think of the data as being in a "stack" of lines, each line being made up of 2 parts. One part is the FIELD READING and STATION NUMBER, the other part is the TIME and LINE NUMBER or DAY. The line number will appear if the reading was taken in survey mode. You will see the Julian Day if the reading had been taken in AUTO mode.

The memory is accessed by depressing RECALL. When you do this the first half of the last ("top") line in the memory stack will light in the display. See Figure 1.

Figure 1

Memory Stack

If you depress RECALL, the last line stored in memory lights in the display.

	(field)	(station)	(time)	(line no.)
This reading lights in-----> display	67856.8	009	12.32.55	10
	68645.5	008	12.32.30	10
	68857.4	007	12.32.00	10
	68682.9	006	12.32.54	10
	68432.8	005	12.32.20	10
	68845.7	004	12.31.59	10
	68723.8	003	12.31.37	10
	68245.6	002	12.31.02	10
	68290.0	001	12.30.45	10

If you depress RECALL again, the memory decrements again, and the next reading will be displayed. See Figure 2.

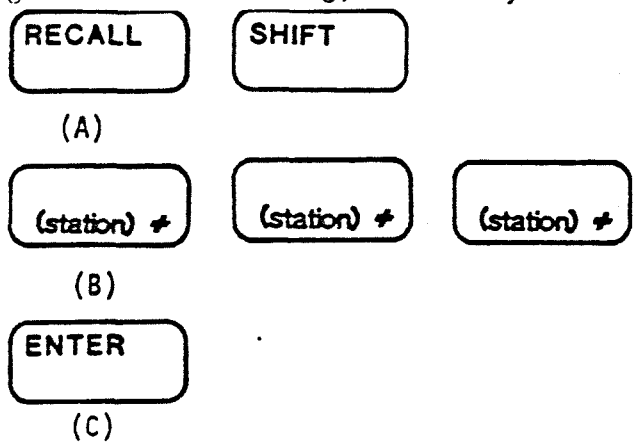
Figure 2

Decrementing the Memory Stack

This reading lights in display-------->	(field)	(station no.)	(time)	(line no.)
	67856.8	009	12.32.55	10
	68645.5	008	12.32.30	10
	68857.4	007	12.32.00	10
	68682.9	006	12.32.54	10
	68432.8	005	12.32.20	10
	68845.7	004	12.31.59	10
	68723.8	003	12.31.37	10
	68245.6	002	12.31.02	10
	68290.0	001	12.30.45	10

Depressing RECALL will continue to decrement the memory and each reading down the line will be displayed. Depressing ENTER will increment the memory.

In a large stack of data, it is not necessary to keep depressing RECALL or ENTER until the desired reading is found. In cases where you wish to look at the 5th reading or the 65th reading, the memory will respond if you depress:



(A) Depress RECALL SHIFT

to access the memory and the numbers on the keys.

(B) Depress the numbers of the station number you wish to look at, for example 3, 5, 6. As you depress these numbers, the display will fill.

(C) Depress ENTER

The STATION/DAY display will read 356 and the FIELD/TIME display will light with the field reading taken at that station.

Accessing the other half of the memory line (the time and line number) requires depressing the TIME key while the first half of the memory line is being displayed. For instance, let's say you recall station number 555 from memory. (Depress RECALL, SHIFT, 5, 5, 5, ENTER). The field reading along with the number 555 will light in the displays. See Figure 3.

Figure 3

Display of First Half of Memory Line

The first half of this reading lights in display

(field)	(station no.)	(time)	(line no.)
68856.8	558	13.32.55	10
68845.5	557	13.32.30	10
68857.4	556	13.32.00	10
68882.9	555	13.32.54	10
68832.8	554	13.32.20	10
68845.7	553	13.31.59	10
68823.8	552	13.31.37	10
68845.6	551	13.31.02	10
68890.0	550	13.30.45	10

While the reading and station number are displayed, depress TIME, and the second half of the line, which consists of the time the reading was taken and the line number marker (or Julian Day, if the reading was taken in AUTO mode) will be displayed. See Figure 4.

Figure 4

Display of Second Half of Memory Line

(field)	(station no.)	(time)	(line no.)
67856.8	009	13.32.55	10
68645.5	008	13.32.30	10
68857.4	007	13.32.00	10
68682.9	006	13.32.54	10
68432.8	005	13.32.20	10
68845.7	004	13.31.59	10
68723.8	003	13.31.37	10
68245.6	002	13.31.02	10
68290.0	001	13.30.45	10

Depressing TIME displays this half of the line.

Remember that when viewing the second half of the memory line, the time that's displayed is an historial record--the time at which the reading was taken. This is different than real time which is displayed with the seconds running.

While you are in the second half of the memory line, you can decrement or increment also, just by depressing RECALL or ENTER. To get the first half of the memory line back, depress FIELD.

With the concept of the memory stack in mind, the following directions on using the RECALL key will be clear.

(VI-A) Recalling from Memory--last reading

Depress [RECALL]

(A)

(A) The last magnetic field reading in memory will be displayed in the FIELD/TIME display, and its station number will appear in the STATION/DAY display.

(VI-B) Recalling from Memory--particular reading in mid-stack

Depress [RECALL] [SHIFT]

(A)

[(station) ≠] [(station) ≠] [(station) ≠]

(B)

[ENTER]

(C)

(A) Depress [RECALL] [SHIFT]

To access the memory and the numbers on the keys.

(B) Depress numbers for the station number you wish to view, for example, 1, 2, 3.

(C) Depress [ENTER]

The STATION/DAY display will light with 123 and the FIELD/TIME display will light with the magnetic field reading taken at that station. (If you need to recall a four digit station number, simply enter in 4 digits. The STATION/DAY display will flash with the first digit, blank, then flash with the next three least significant digits.)

NOTE: You cannot reach a memory location without data in it. If you don't have 123 readings stored, the stack will go to the highest valid number. You can also find the highest number by pushing READ.

(VI-C) Recalling from Memory--second half of memory line

Part of recalling data from memory has been performed by depressing RECALL, the station number and ENTER. However, that key sequence only gets you the first half of the memory line. To see the time at which that reading was taken, and also the other 3 digit number stored with it, depress [TIME] (A)

(A) [TIME] must be depressed while the field reading is still being displayed. The FIELD/TIME display will then light with the hour, minutes, and seconds at which the reading was taken and the STATION/DAY display will light with the line number marker (or Julian Day if the reading had been taken in auto mode. See Setting the Clock and Setting the Line Number (Survey Mode).

Any time you depress TIME when no field reading is being displayed, the real time will be displayed with the seconds running. This is how you can be sure of keeping historical time and real time separate. Real time seconds run. Historical time seconds do not.

Once you get the second half of the memory line, that half of the data will be displayed. You can increment and decrement in the second half just as you would in the first half, by depressing ENTER and RECALL respectively.

(B) When you want to return to the first half of the memory line: Depress [FIELD]

The FIELD/TIME display will revert back with the field reading, and the STATION/DAY display will show the

station number. The instrument will also return to the first half or the memory line if you take a reading.

(VII) Erasing Data

The G-856 will allow you to erase the last reading, a last group of readings, for example from 356 on, or the entire memory.

(VII-A) Erasing Data - last reading

(A) Depress READ

The READ key will move the memory stack to the position of the last reading taken.

(B) Depress RECALL

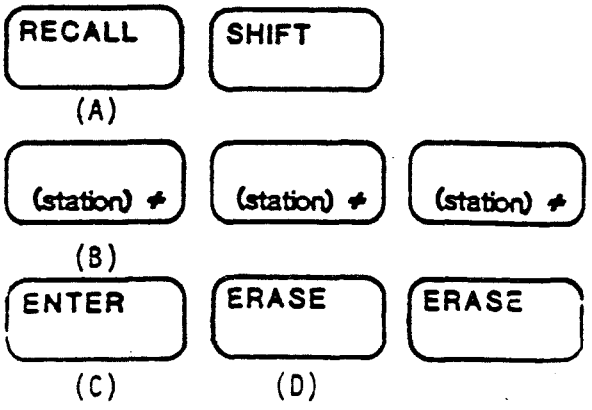
The last reading taken will appear in the displays. While the displays are still lit with that reading:

(C) Depress ERASE twice.

The displays will go blank and the last reading will be erased from memory. ERASE must be depressed twice in order for the reading to be erased. This is a data protection feature. If ERASE is accidentally pressed, depress CLEAR, or any other key, to abort the erase operation.

(VII-B) Erasing Data - last group

To erase the last group of readings, first determine at what station number you wish to begin the erasure. All data will be erased from that station number to the last reading stored in memory.



(A) Depress [RECALL] to access the memory and depress [SHIFT] to access the numbers on the keys.

(B) Depress numbers for the station number at which you wish to begin the erasure, for example 7,4,8.

(C) Depress [ENTER]. The displays will light with the station number 748 and the field reading taken at that station. While the displays are still lit with that reading,

(D) Depress [ERASE] [ERASE]. The displays will go blank and all data from 748 to the last reading will be erased from memory. ERASE must be depressed twice for the data to be erased.

(VII-C) Erasing Data - entire memory

To completely clear the memory of information, you need to enter in the first station number (0) and depress [ERASE] twice.

Depress [RECALL] [SHIFT]

(A)

[0]

(B)

[ENTER]

(C)

[ERASE] [ERASE]

(D)

(A) Depress [RECALL] to access the memory and depress SHIFT to access the numbers on the keys.

(B) Depress 0, which is the first station number in memory.

(C) Depress [ENTER] The displays will light with 0 and the field reading taken at that station. While the displays are still lit,

(D) Depress [ERASE] [ERASE] The displays will go blank and the entire memeory will be cleared of information.

(VIII) Setting Auto Mode

Auto Mode allows the magnetometer to take readings automatically at a specified interval. When the magnetometer is "cycling" automatically, it is usually stationary and is then called a base station. It's purpose is to record readings of the earth's diurnal field that can then be compared with the survey magnetometer's readings. In this way, a more accurate picture of the magnetic subsurface can be obtained.

The G-856 is able to store about 2500 readings in the auto mode compared to the 1000 readings it stores in survey mode. The reason is that the time interval at which readings are stored is fixed, and so the specific time that each reading is taken can be automatically calculated when retrieving data. Since these items don't need to take up memory space, the memory for magnetic field data becomes larger in auto mode, (but notice that no information is lost). In auto mode, the Memory-Mag magnetometer can record as much as one reading every minute for over 40 hours.

In auto mode, when viewing the second half of the memory line, the three digit number displayed in the STATION/DAY display increments at 24:00 midnight. This number should be set to represent the Julian (numerical) Day of the year. (Refer to Figure 5).

You'll recall that this differs from how the magnetometer functions under regular survey conditions. In survey mode, the three digit number doesn't increment automatically because it is most often used as a line number marker.

Figure 5

Display Differences in Auto and Survey Mode

Memory Stack

FIELD	STA.#	TIME	DAY
567890	347	12.19.20	112
567900	348	12.20.20	112

AUTO MODE

Memory Stack

FIELD	STA.#	TIME	LINE #
567980	176	12.19.20	100
567980	177	12.20.00	200

SURVEY MODE

The following instructions assume that the clock has already been set (see Setting the Clock). Setting AUTO mode requires selecting the sample interval at which the magnetometer will take samples. The procedure is as follows:

Depress [AUTO] [SHIFT]

(A)

[(seconds) ←] [(seconds) ←] [(seconds) ←]

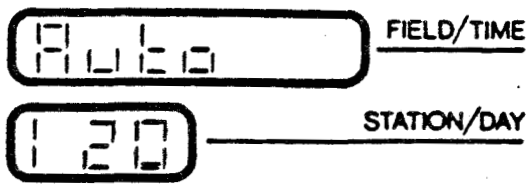
(B)

[ENTER]

(C)

(A) Depress [AUTO]

The displays will light with a number.



(B) This is the current sample interval in seconds. If you like that setting, you can just depress ENTER [step (c)], and the magnetometer will begin taking readings every 120 seconds. If you need to change that sample interval, depress SHIFT to access the numbers or the keys. The displays will show spaces.

Next, depress numbers for the new sample interval, for example, 60 seconds. The display will fill with those numbers. Before 5 seconds lapse,

(C) Depress [ENTER]. If ENTER is not depressed within 5 seconds the setting will clear. When you depress ENTER, the instrument will start taking and storing readings automatically.

There is a setting on the internal Option Switch that allows the displays to be turned off in Auto Mode to save battery power. See Using the Programming Switch in Chapter 4. If this switch is used, the displays will light with each sample for 5 minutes, then shut down. You can enable the displays again for 5 minutes by depressing any key.

(VIII-A) To read the memory during AUTO mode, you depress RECALL and FIELD or TIME as desired. The Julian day will be displayed with TIME.

(VIII-B) To access the real time.

Depress [TIME]

The FIELD/TIME display will light with the real time and the STATION/DAY display will light with the line number. If you press AUTO first, then TIME, the Julian day will come on. Look for the seconds to tick to verify correct time.

(VIII-C) To shut off Auto Mode

Depress [AUTO] [CLEAR]

The displays will blank and Auto Mode will shut off.

When the cycle time is short, the above operations (VIII-A, B, C) will be slightly delayed because the instrument and displays will be busy taking readings. For instance, to shut off auto mode you will have to hold AUTO down for one complete cycle, then hold CLEAR down for one complete cycle.

As explained in the section Recalling from Memory, you may recall a 4 digit station number simply by depressing 4 digits. The STATION/DAY display will flash briefly with the most signficant digit, followed by the three least significant digits. The FIELD/TIME display will flash with the magnetic field reading taken at that station.

NOTE: There are 4 key sequences that will produce an ERROR message in auto mode. They are:

1. Depressing the OUTPUT key.
2. Depressing the READ key.
3. Depressing the STORE key.
4. Attempting to change the sample interval while the magnetometer is automatically cycling. You must shut down auto mode to change the sample interval.

(IX) Retrieving Data

Data can be retrieved both manually (See Chapter 3) and automatically.

To begin automatic retrieval of data, connect the G-856 to an auxiliary piece of equipment (computer, printer, magnetic tape recorder, or another magnetometer) using the optional RS-232 interconnect cable:

Depress [OUTPUT] [ENTER]

The information stored in memory, beginning with the first station number, will be automatically transmitted. The station number will flash so you can monitor progress. To interrrupt (stop) the process, press CLEAR. The data will remain in the memory until you erase it.

You may begin automatic retrieval at any station number. The key sequence to begin transmitting data from station number 123 would be:

A) Depress OUTPUT

B) Depress SHIFT

C) Depress the desired numbers, for example 1, 2, 3.

D) Depress ENTER

The G-856 will begin transmitting data at the designated station number.

Summary

This chapter has presented the steps needed to operate the G-856. As a further aid, a short reference section summarizing this information is presented in the appendix. Chapter 2 discusses the features and performance of the G-856 in special survey situations. The chapter begins with instructions on connecting the sensor; proceeds with information sensor orientation, positioning, and repeatability; continues with a section on the magnetic environment, and ends by discussing some possible techniques that might be used in data collection.

Chapter 2

Field Operation

This chapter will discuss the features and performance of the Memory-Mag magnetometer in regard to actual survey use. Included here is information on sensor attachment and a discussion of sensor orientation and positioning in relation to the repeatability of the instrument's readings. Discussed also are testing for magnetic noise and some particular features concerning the use of the magnetometer as both a base station and also a survey unit.

Sensor Attachment

Inside the sensor case are coils of wire submerged in a hydrocarbon fluid, in this case decane.* The following section presents proper mounting procedures for the sensor.

1. Check for sensor fluid volume by shaking and listening for a "sloshing" sound. The fluid should sound like its about 1 cm. from the top of the sensor. If you need to add fluid:

   A. Remove the blue cap plug on the sensor.

   B. Fill with Decane to within 1 cm. from the top.

   C. Replace plug.

2. Attach the signal cable to the sensor. The short one is for backpack use, the longer cable for use with the staff.

3. Attach the sensor to the staff and assemble the sections, or place the sensor in the backpack and attach it to the carrying harness.

Sensor Orientation

The sensor is marked with an arrow and the letter "N". During operation this arrow should be roughly pointed either north or south. Aligning the sensor this way will place the coil axis perpendicular to the earth's field and produce an optimum signal.

As surveys approach low magnetic latitudes where the field dip is less than 40° and the field value generallly below 40,000 gammas, (such as near the magnetic equator where the field is close to horizontal) the sensor should be mounted horizontally (saddlemount) on the staff. In this manner the sensor coils will be properly oriented for maximum signal.

*Decane is available from chemical supply houses, oil refineries, petroleum products distributors, or Geometrics. Decane is flammable, but unlike gasoline is not explosive, so it may be carried on airplanes.

Sensor Position/Repeatibility

Sensor position, in this case meaning the exact and consistent placing of the sensor, is very important to the repeatability of the system. Repeatability means getting the same count for several readings taken consecutively when the sensor is not moved. This relationship between sensor position and repeatability becomes more and more critical as portable magnetometers increase in sensitivity. The following instances are of particular concern: areas of high gradients, areas where the diurnal field is changing rapidly, and areas where magnetic dust is present. It's because of these instances that a 0.1 gamma magnetometer may not repeat as consistently as a 1 gamma unit. To illustrate, consider the following comparisons:

HIGH GRADIENTS: In an area of 1 sq. meter where the magnetic field varies by several tenths of a gamma every 15 centimeters, a 1 gamma magnetometer will not be affected by moving the sensor slightly, or even moving it as much as 30 or 40 cm.

However, given those same conditions, the repeatability of a 0.1 gamma magnetometer will be affected, and possibly quite noticeably by moving the sensor as little as a few centimeters.

RAPID DIURNAL CHANGES: Consider also that even if the sensor is held perfectly still, a 0.1 gamma magnetometer will pick up subtle changes in the diurnal field that a 1 gamma magnetometer would never detect. The is of particular concern during high sunspot activity.

MAGNETIC DUST: Added to this is the possibility that the sensor itself may be magnetically contaminated due to an inclusion or surface adherence. This may affect data greatly if the sensor is rotated or the orientation continually changed.

As a note to the above, there may be other complications to repeatability. One is electrical noise in the system that may produce variations on the order of 0.1 gamma. Another possibility is the random count of protons by the system. Again, a comparision between a 1.0 gamma magnetometer and a 0.1 gamma magnetometer is needed to make the point.

To explain further, the G-856 operates by counting the frequency of spinning protons in the sensor (for more information see Applications Manual for Portable Magnetometers). The length of, or the amount of time involved in this count affects repeatability in a very subtle way. For instance, in a 1 gamma magnetometer, given a normal 3 second cycle time, a certain number of protons will be available for the count. As an example, 53795.2. The 1 gamma magnetometer will round that count to 53795. The next count is 53795.3. Again the magnetometer rounds to 53795. In a 0.1 gamma magnetometer, however, that count will be more accurate; the magnetometer reports the counts as 53795.2 and 53795.3 respectively. Of course, this accuracy lessens the repeatability.

Truncating Digits on the Display

In areas of very high gradients, often times the environment does not permit the magnetometer to capture an accurate count. This happens because the sensor signal collapses, or dies, before the count time has ended, creating an inaccurate picture of the field. The operator will recognize the symptoms of high gradients by noting truncated digits on the display. When the signal has collapsed too soon, the magnetometer will drop the least significant digit and leave an incomplete reading on the display.

Depending on the resolution you need, this is most likely not a problem. If the cause is high gradients, there is no need for 0.1 gamma resolution. A similar effect may be observed in very low fields. You can usually improve the signal strength by lengthening the polarization time and/or shortening the count time. See Using the Programming Switch in Chapter 4.

Magnetic Environment

In surveying, it's important that magnetic field readings be as true as possible and not be affected by articles of clothing and personal accessories. Jewelry, keys, watches, belt buckles, pocket knives, zippers, etc. can affect the total magnetic field reading. Objects suspected to be magnetic may be checked in the following manner:

1. Mount the sensor on the staff, place the suspected article far away from the sensor, and take several readings. Each reading should repeat to ±1 gamma. (For details see Sensor Position/Repeatability on the previous page.)

2. Place the suspected article fairly close to the sensor, and again note the readings.

3. Remove the article and again take several readings to check for a diurnal shift in the earth's field. If a shift is present, repeat the test.

4. If no diurnal shift is present, you can assume that the article is magnetic if the first group and the second group of readings varied by more than 1 gamma.

If the article is highly magnetic, or if the sensor is inside or near a building or vehicle, the proton precession signal will be lost, giving completely erratic readings.

The magnetometer can not reliably be operated in areas that are known sources of radio frequency energy, where power line noise (transformers) is present, in buildings, or near highly magnetic objects. The sensor should always be placed on the staff above the ground, or in the "backpack". The sensor will NOT operate properly when placed directly on the ground.

Magnetic Surveys

SURVEY OPERATION

During survey operation and after the instrument is tuned to the local field intensity (refer to Chapter 1), the operator need only depress the READ key to observe the reading, and if the reading is acceptable, the STORE key. If the reading is in question, for example a sudden shift of several hundred gammas, another reading should be taken.

The sensor is normally mounted on the staff or may be mounted in the backpack for surveys requiring lower mapping accuracy, rapid operation, or in rugged terrain. Because of the magnetic properties of most D-cell batteries, however, only the cardboard or plastic jacketed batteries should be used in the console for this application (refer to Chapter 4, Batteries).

USE OF THE LINE NUMBER IN SURVEYING

The memory feature of the G-856 offers some unique methods for logging a survey. The Memory-Mag magnetometer obviously eliminates the need to write down each magnetic field reading, but it also can eliminate other kinds of notes usually taken during a survey. The use of the line number marker (the three digit number set by depressing TIME, SHIFT, the numbers, and ENTER) is efficient in two ways:

1) It can be changed every time a new survey line is begun, thereby eliminating the need to count stations in a line, and

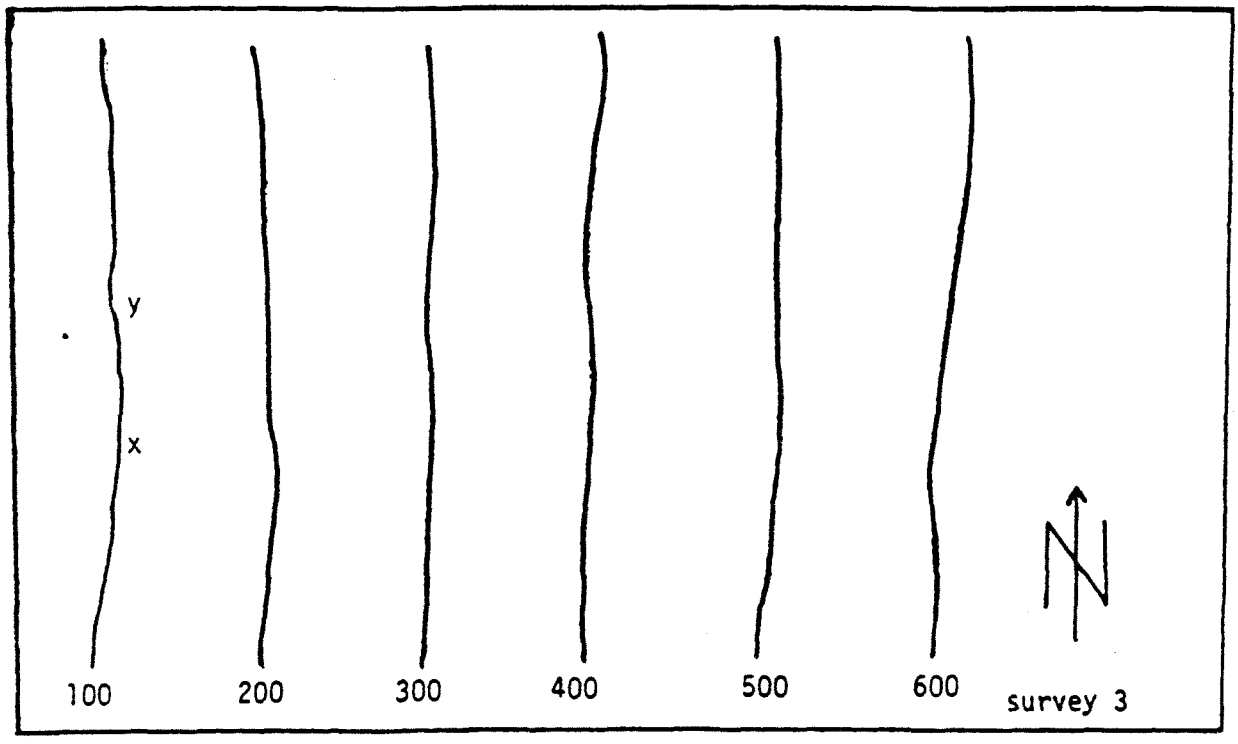
2) When anomalies show up, and the points on a line previously surveyed need to be filled in, the line number marker can be used as a coded notation.

As an example, presented here is a hypothetical study of a section of ground suspected to have a linear magnetic anomoly such as a fault, a dike or a buried stream channel. As in all such surveys, you would start with a map of the area (see Figure 6). You would mark survey lines on the map either in a grid or along some natural topographic features. Actually, locating your survey point geographically is one of the most difficult aspects of magnetic surveys, but a detailed analysis is not necessary for this illustration. The six lines have been labeled as shown from 100 to 600.

In the field, you would locate yourself at the Southwest corner at the bottom of line 100. If you are using a base station, you would check the clock on the G-856. The Julian Day will label your data as occuring on this date, but assume that you are conducting six similar surveys and that this is the third one today. You could mark your field logs with the time of day you started, but instead label this job number 3 by setting the Julian Date to 3. Depress AUTO, TIME, SHIFT, 3, and ENTER. There are of course, three digits available, so other information could be recorded.

Figure 6

Use of the Line Number in Surveying



Tune the magnetometer and take a few readings (but don't store any) and establish that the horizontal gradient is small and your best interval between readings is 25 meters. Now you are ready to start the survey. You will label the data by setting the Line Number to 125 (line 100, interval 25 meters). Press TIME, SHIFT, 1, 2, 5, ENTER. That information will be recorded with each reading stored in the memory and you will use it later. The coding scheme should also be recorded in your field notes, along with the date and exact time the survey was started. Since you have already done two other surveys, log the battery voltage and the first station number to be used (press READ to see the numbers) and signal strength (press TUNE).

Now that you are ready, conducting the survey is easy. Stand at the beginning of line 100, press READ, wait for the answer, visually check it, and press STORE. Walk up the line 25 meters and take another reading. Continue on in this same manner.

Now suppose that you reached point X on the map and noticed that the last two readings were unusually different than the previous ones. Of course you can review your data at any time by pressing RECALL a few times, and confirm that the last two readings are different than several of the preceeding ones.

You conclude that you may be in the area you're looking for, and that you really want to take readings much closer together, starting back two stations. You are standing still all this time, so you are physically at the last point. You will erase that record while you stand there by pressing READ (to make sure you're at the top of the data), RECALL (do not store the last reading), ERASE, ERASE. Now, you walk back to the previous station. Press RECALL, ERASE, ERASE. Continue until you have relocated yourself at the last station where you have good data.

Now change to five meter intervals to get a more precise profile of the anomaly. Press TIME, SHIFT, 1, 0, 5, ENTER, which sets your Line Number to 105, coding the line and the interval. You would now continue your survey by walking up the line five meters, storing the data, and continuing thus until you notice that at point Y the field again becomes constant.

Now reset the line number to 125. Depress TIME, SHIFT, 1, 2, 5, ENTER, and walk up the line 25 meters. Take and store a reading and continue to the end of the line. At the end of line 100, you should record the ending station number and any other remarks relevant to the survey--but its just insurance. Everything regarding the data is in the memory.

Now move to the north end of line 200 and, as an example, suppose that you decide to tighten up the survey a little by changing to 20 meter intervals. Record 220 as the line number. Depress TIME, SHIFT, 2, 2, 0, ENTER. Start surveying south. Again, if anomolies show up, edit, change the intervals, and label the record as before. Continue for the rest of the lines and note in your field book that you walked north on the odd numbered lines and south on the even numbered lines. Record your ending time, signal strength, and battery voltage.

Other procedures can be contrived to use the Julian Day and Line Number for record labeling purposes. This example is only one of many posible combinations. Once a procedure is adopted, an attempt should be made at consistency. If the previous procedure is above the skill level of your operators, try the following alternatives.

Set the clock and Julian Date at the base camp. Go to the start of line 100 and tune the magnetometer to the field reading. Push READ, STORE, and RECALL. Write the station number displayed during RECALL on the map. Continue the sequence, surveying along line 100 and writing the station number on the map at each location. The operator might as well also write the field number on the map, which at first glance would seem to defeat the purpose of the memory, but this does provide a check against transcription errors.

A more likely procedure is to write the station number on the map at locations of specific interest including the start and finish of each traverse, physical landmarks, any point where the interval changes, and areas with interesting anomalies. The unrecorded station numbers can be filled in later by manual or computerized interpolation.

Now suppose that your survey is complete and you are ready to list the data on your printer. At the base camp you would plug in your optional RS-232 adaptor cable to a printer, and list the information from just this survey. The log book would tell you that the first station is 372, so you want to start your list from a little before that one. Press: OUTPUT, SHIFT, 3, 7, 0, ENTER. The display starts flashing OUT and the station numbers and the printer start listing a column of data like this:

825	2	131527	370	512498
825	2	131545	371	512511
125	3	140511	372	498733
125	3	140622	374	498710
125	3	140651	375	498725
125	3	140705	376	498735
105	3	141211	377	498744
105	3	141225	378	498772
105	3	141245	379	49879
105	3	141303	380	49882
105	3	141325	381	498833
105	3	141241	382	498841
105	3	141359	383	498845
125	3	141429	384	498853
125	3	141455	385	498874
125	3	141507	386	498882
220	3	141902	387	498557
220	3	141922	388	498551
220	3	141945	389	498542

At this point, you press CLEAR which stops the printer. The first column is the line number and interval spacing. The second column is the Julian Date, which you used instead to label the survey area. The third column is time of day (24 hour clock), the fourth column is the station number, and the last is the magnetic field to six digits.

You would then attempt to construct your survey from the data. Looking at column 2, notice that the first two readings are from a different survey so you can ignore them. The time difference between the readings at stations 371 and 372 is further verification. The third line, column one, tells you that the reading is from line 100 with a 25 meter interval between stations as per our adopted convention in survey area 3, and you started at 2:05 in the afternoon. The readings proceed up (north) on line 100 until station number 377. Notice here that the interval expressed in column one changed to 5 meters (377 is 5 meters from 376) and notice the extra time consumed between readings while you backtracked and erased. The readings at stations 379 and 380 have only five digits, which tells you that the signal was weak, probably because of a high local magnetic gradient from a buried magnetic object. At reading 384, you resumed a 25 meter interval for the balance of line 100. Reading 387 is of course the first reading headed south on line 200 at 20 meter intervals. The time between reading 386 and 387 is about right for a line change.

The above example is intended to show that by using a standard operating convention and some common sense you can reconstruct the field activities with a minimum of note taking. It is prudent to examine the data while your memory is still fresh os that you can account for long time gaps and strange information.

Summary

This chapter has discussed field operation in general, and has included information on sensor attachment and orientation, sensor positioning with respect to repeatability, magnetic noise, and survey techniques.

The following chapter, Data Retrieval, presents some of the configurations possible for automatic retrieval of data.

Chapter 3

Data Retrieval

This chapter explains manual transcription of data. It also explains the process of using other instruments to retrieve data collected by the G-856 Memory-Mag magnetometer, presenting the possibilities that can be achieved. In some cases special programming and some computer knowledge is helpful in performing automatic retrieval of data. Nevertheless, even a novice or hobbiest programmer will be able to print the magnetic field reading, time each reading was taken, the line number, and the station number just by depressing a single key.

Before beginning retrieval of data, be sure to check that the batteries are holding a sufficient charge, well above 7.5 volts. Failure to do this could result in incorrect or incomplete data. A simple test of the battery voltage is to press READ when the sensor is not attached. A voltage of 9.0 volts or greater should be noted before beginning retrieval.

Manual Transcription

To manually retrieve data, find the first reading in the survey (often 000) from your field notes or by iteration (see Recalling from Memory). After the first reading is found and data written down, depress ENTER to increment the magnetometer as many times as needed to see and record all the data.

If you are retrieving data from a base station, you will be looking for a specific time rather than a station number. Start with a guess and iterate until you find the precise time.

Assume that you have done a field survey which took four hours and during that time had a base station operating from one hour before to 20 minutes afterward, taking readings at 10 second intervals. You have made a list of the field data including the time of each reading, and the first reading was recorded at 13:04:27. When the base station READ button is pushed, the STATION/DAY display flashes 1, followed by 919, so you know that your first reading is about one hour after the start of your five hour and twenty minute record containing 1919 readings.

Pick reading 300 as a first guess and press: RECALL, SHIFT, 3, 0, 0, ENTER, TIME. The display will light with the Julian Date and a time, for example 12:50:02. This first guess was too early, so try 400 next: RECALL, SHIFT, 4, 0, 0, ENTER. Notice that you do not need to press TIME again once you are in the Time display mode. This time the display reads 13:07:42, a little too late. When you repeat the guess with 390, you get 13:05:02, a fairly close number. Now push RECALL over and over, getting a sequence of numbers: 13.04.52, 13.04.42, 13.04.32, 13.04.22. The last number is close enough. If your last guess had been just a little early, you could have advanced by pushing ENTER to increment the stack pointer.

Once you have the desired time in the window, push FIELD, which returns the magnetic field reading to the display. That becomes your baseline.

Use with a Printer

Data transcription becomes automatic when the G-856 is connected to a printer with an RS-232 interface. When OUTPUT is depressed, the printer will begin printing columns of data:

312	211	121527	33	512473
312	211	121603	34	512495
312	211	121645	35	512353

This should be recognized as the line number marker, the Julian day, the time, station number, and magnetic field reading.

If the data you print out has been recorded in auto mode, the lines will be marked with an asterisk:

*190	213	121500	0	512473
*190	213	121600	1	512480
*190	213	121700	2	512480

Printers are available through home computer and electronics stores. Some printers have an RS-232 interface, but not all RS-232 interfaces are alike. The real test, of course, is to connect the G-856 to a printer to see if the two are compatible.

Use with the G-866 Recording Magnetometer

With a special cable available as an option, the G-856 can be connected to the G-866 recording magnetometer. By depressing OUTPUT, the G-866 will accept data and print it out digitally along side an analog chart.

Use with the G-724M Digital Tape Recorder

With a special cable available as an option, the G-856 can be connected to the G-724M digital tape recorder (as well as some other digital tape recorders and data acquisition systems). The tape recorder can be used either in real time (operating during normal data acquisition) or can be used as a data receptacle at the end of a survey. The advantage is of course that much larger amounts of data can be stored on tape, and the tapes can be constantly replaced so that data from an extensive field project is collected for later analysis at the computer center.

Use with a computer

The G-856 can be connected to a computer with an RS-232 interface. The G-856 will stop transmission of data either when it receives the ASCII code DC3 (the Control and S keys on a typical key board to get 13 hexadecimal), or if CTS (clear to send) is false. The magnetometer will resume transmission of data with the ASCII code DC1 (which are the Control and Q keys on a key board, 11 hexadecimal), or if CTS is true.

There are many ways a computer can be used to manipulate data. A few are listed below:

- Perform base station time corrections.
- Remove regional gradient in order to look at the local.
- Remove local gradient in order to look at the regional.
- Perform complex digital filtering.
- Plot profiles.

Use with Other Devices

The magnetometer provides a real time character BCD (Binary Coded Decimal) output interface, and will "talk" to anything that will accept data in this format. Possibilities include various kinds of terminals for printing or recording on magnetic tape, and also modems that can connect the magnetometer to a telephone or radio line so operation can be controlled from a distant location.

Summary

This chapter has included a description of manual and automatic data retrieval procedures, and the possibilites of computer aided analysis.

The following chapter presents information on instrument storage, batteries, switch options, the RS-232 interface, accessories, and specifications.

Chapter 4

Supplemental Information

Instrument Storage

After use: Disconnect the sensor cable from the magnetometer.

Store all the components in the shipping container to prevent magnetic contamination.

If the magnetometer system will be stored for a long time, remove the batteries to prevent electrolytic leakage or corrosion of the contacts. DO NOT REMOVE THE LITHIUM BATTERY which is soldered into the circuit board.

The recommended temperature for maximum battery storage is 40°F (4°C). If you wish to store batteries for a long time, do so in your refrigerator. In addition, wrapping the cells in a plastic bag will prevent moisture formation while in the cold. These batteries should be allowed to warm up in the bag before being used.

Batteries

There are two kinds of batteries in the G-856 Memory-Mag™ magnetometer. Basic operation is powered by 8 D-cell batteries, and the clock and memory are powered by a lithium battery installed on the digital circuit board when the main batteries are disconnected or removed.

D-Cell Battery Types

When the magnetometer is used with the sensor mounted on the staff, standard D-cell batteries will work satisfactorily. Figure 7 compares the expected number of readings possible for different battery types.

When the sensor is used in the "backpack" only cardboard or plastic jacket batteries should be used. If steel jacketed batteries (carbon zinc or alkaline) are used in the console during "backpack" operation, a directional dependent shift of several gammas will occur and will bias the measurement.

Figure 7

Number of Readings per Battery Type

Battery Type	Brand Name	Readings at 25°C	Readings at 0°C	Jacket type
Alkaline	Burgess, Eveready Ray-o-Vac	6,000	4,000	Steel
Standard Carbon-Zinc (flashlight)	Burgess, Eveready Ray-o-Vac	1,500	700	Card-board
Premium Carbon-Zinc	Eveready #1250*	3,000	1,700	Card-board

Figure 7 is based upon one reading every 30 seconds, using the 3 second cycle time setting (see Switch Options following). Faster sampling rates will yield fewer readings, especially at lower temperatures. Photoflash and "Energizers" are not designed for this type of application, but may be used until proper batteries are available. It should be noted that battery capacity decreases rapidly below 0°C to only a few hundred readings at -20°C. These battery types will recover, however, when warmed above 0°C. (See D-Cell Battery Low Temperature Operation.)

D-Cell Battery Voltage Indicator

After READ is depressed and before a reading of the magnetic field comes up on the FIELD/TIME display, a number indicating battery voltage appears. The indicator will display BATT and some number up to 19.9. This number is the actual battery voltage. Because the measurement of this voltage occurs during the polarize cycle of the magnetometer, the battery voltage indicator reports the amount of charge left in the batteries when they are under load.

It's possible that you may want to use an auxiliary power source with the G-856, which is why the indicator will read up to 19.9. When using just the internal D-cell batteries, however, the maximum voltage will read around 12 volts. When the indicator reads 7.5 volts, the magnetometer will stop polarizing, and the batteries should be replaced.

If you continue to use batteries that have discharged below 7.5 volts, the magnetometer may not respond to keyboard commands. Also, complete and accurate data cannot be ensured if you begin retrieving data when the batteries aren't holding a sufficient charge. See Chapter 3, Data Retrieval for details.

*Available from Geometrics

D-Cell Battery Low Temperature Operation

At temperatures below 0°, battery life decreases rapidly. At -20°C, for example, operation may be limited to only 100 readings per set of batteries. At these lower temperatures, an optional Battery Belt (P/N 16069) should be used, or the console may be held close to the operator's person, under warm clothing.

D-Cell Battery Replacement

1. Unsnap and remove instrument cover.

2. Replace batteries matching the polarity markings on the battery holders.

3. Replace instrument cover. Be sure the instrument is seated all the way down in the case before trying to snap on the clips. Don't use the clips to force the unit into the case. Forcing them could cause breakage.

Lithium or Keep Alive Battery

In addition to the 8 D-cell batteries used to power the magnetometer in normal operation, there is an AA-size lithium battery, called the "keep alive" battery, used to power the clock and keep data in memory should the D-cell batteries fail or be removed. The keep alive should be changed about every 10 years. It's soldered into and underneath the top circuit board and should be replaced in the same manner. Be sure all data is removed from memory and recorded before the lithium battery is unsoldered from the circuit board.

Lithium or Keep Alive Battery Replacement

1. Unclip the cover and slide it off the circuit boards.

2. Remove the four screws holding the circuit boards together. As you separate the boards, unplug the cables noting their positioning as you do so. Lay the top circuit board down so the battery can easily be worked on.

3. Unsolder the battery wires and wipe any debris from the battery area.

4. Check the polarity, then thread the lead wires on the new battery through the holes in the board.

   WARNING: Shorting the lithium battery could result in over heating and possible explosion. Be sure battery lead wires don't meet.

5. Turn the board over and solder the lead wires to the pads. Trim off any extra wire. Connection is made with wires running through the center of the board.

6. Replace the circuit boards, cables, screws, and cover.

The clock will have to be reset after the battery is in place.

Maintenance and Troubleshooting

POSSIBLE SURVEY DIFFICULTIES

The following is a list of possible survey difficulties, probable causes, and recommended corrective actions.

Survey Difficulty	Probable Cause	Corrective Action
Low Signal Amplitude (Display indicates less than 6 volts)	1. Magnetometer out of tune.	1. Retune magnetometer.
	2. Very high gradients.	2. Move out of the area, or try switching to short count.
	3. Broken sensor cable.	3. Replace or fix cable.
	4. Loss of sensor fluid.	4. Fill sensor with decane to about 1/2 cm. from the top.
	5. Sensor coil axis parallel to field.	5. Align sensor North-South or in the saddle-mount position.
Field display shows truncated digits (poor signal to noise ratio.)	1. 50-60 Hz interference.	1. Move away from interference.
	2. Microphonics.	2. Avoid vibration and mechanical shock to sensor while surveying.
	3. Broken sensor cable.	3. Replace or fix cable.
	4. High gradients.	4. See Erratic Readout.
	5. Generally weak signal.	5. Lengthen polarize time.
Erratic Readout	1. Magnetic storm or micropulsations.	1. Try later, especially at night.
	2. High geomagnetic gradient.	2. Hold sensor perfectly still. Try shortened count.

	3. Magnetic objects on operator.	3. Remove iron objects from pockets, belt, etc.
	4. Magnetic dirt on sensor.	4. Scrub or scrape magnetic particles off sensor.
	5. Review causes under "field display shows truncated digits."	
	6. Low battery voltage.	6. Replace batteries.
Displays don't light.	1. Poor battery contact.	1. Check for loose batteries.
	2. Low battery voltage.	2. Remove batteries, then repress reset switch(SW2).
	3. Internal memory error.	3. Replace batteries.
No reading on STATION/DAY display.	1. Interboard cable not connected.	1. Check cable for proper connection.
Low Battery Voltage Indication.	1. Low voltage.	1. Replace batteries.
Display reads "ERROR."	1. STORE depressed when no reading lit on the display.	1. Take new reading, depress STORE before displays go out.
	2. FIELD depressed when depressing TIME did not precede it.	2. FIELD reading already displayed. The FIELD key is used to return to the first half of memory line. See Chapter 1, "Recalling from Memory."
	3. Incorrect or invalid key or key sequence depressed.	3. Consult Chapter 1. Depress key sequence again.
Display reads "data Err"	1. Internal memory error.	1. Print out or transcribe all stored data, then depress ERASE ERASE.
	2. Power removed while instrument was in operating mode.	2. Dump stored data into recording device, then press ERASE ERASE.
	3. Lithium battery malfunction.	3. Measure lithium battery voltage. If voltage is less than 3.9V, replace.
	4. Control board malfunctioning	4. Return board (P/N 16621).

Display reads FULL.	1. Memory capacity is full of data	1. Transcribe and erase some data to create memory space.
Console will not tune.	1. Poor signal-to-noise ratio. See display reads truncated digits.	
	2. Low battery voltage.	2. Replace batteries.
Partial numeric Display	1. Control board malfunctioning.	1. Return board (P/N 16621).

The RS-232 Interface

WHAT IS RS-232C?

In 1963, the Electronic Industry Association (EIA) established a standard to specify levels and protocol for interfacing data-terminal and data-communications equipment that use serial binary interchange. The latest revision to this standard has been in effect since 1969 and is referred to as RS-232C. While RS-232C specifies a very complex group of datalines and signal levels, most devices equipped with interfaces called "RS-232" in fact offer a subset of the standard as their interface method. The G-856 is one such device.

The RS-232C standard specifies that a 25-pin connector shall be used for the interface, and assigns functions to 22 of the 25 pins, but does not specify what kind of connector you should use. The connector most commonly used is a 25-pin "D connector". This is available from many sources under the generic part number DB-25P (male) or DB-25S (female). The male connector is generally used on data terminal equipment (desktop computers, terminals, etc.) while the female connector is used on data communications equipment (modems, computer multiplexers, etc.) These uses have by no means been standardized. The RS-232 cable for the G-856 is provided with a female connector.

CONNECTOR PIN ASSIGNMENT

Only 5 of 22 standard RS-232C data transmission lines are used in the G-856. The Geometrics standard RS-232C interface cable, Part Number 16492-01, is wired in the Data Communications Equipment or "DCE" configuration. It may only be connected to equipment wired in the Data Terminal configuration. Such equipment includes the HP-85 microcomputer with the HP-82939A-001 interface cable, and most printers and terminals. The difference between the two configurations is that pin 3 of the G-856 interface cable (DCE) carries data transmitted from the magnetometer, while pin 3 is used for receiving data on equipment wired in the DCE configuration. Pin 2 is used for transmitting data in DCE and for receiving data in DTE. Pins 4 and 5 are also inverted for DTE as opposed to DCE. These are used for "Clear To Send" (CTS) and Request To Send" (RTS) lines, which allow a transmitting device to send bursts of data to a receiving device that must process these data as they are received. If the

CTS line of the G-856 is grounded, data transmission will be stopped. If it is left open or connected to a logic high, data transmission will be controlled by operation of the G-856 front panel, and at the baud rate selected by the internal programming switch.

The terms DTE and DCE were designated for the original application of the RS-232C interface standard; DCE (i.e. a modem used in communications) is designed to interface with DTE (i.e. a teletype) and vice-versa. One piece of DTE equipment cannot directly interface with another piece of DTE equipment; it can only interface with equipment wired as DCE equipment.

The following figure lists the functions assigned to each pin of the RS-232 cable from the G-856. This is the standard DCE configuration.

Figure 8

RS-232 Cable Pin Assignments (DCE)

RS-232C Connector "DCE"	G-856 Front Panel	G-856 Cable Color	Function Description
1	D	shield	Ground - AC power ground and chassis ground.
2	U	white	Receive Data - (to the G-856)
3	T	black	Transmit Data - (from the G-856)
4	G	red	Clear To Send - When low, inhibits G-856 output. Leave open if not used.
7	D	shield	Signal Ground - Zero reference for interface.

The RS-232C interface cable is now supplied with a connector having moveable pins, and an insertion/extraction tool. If you need to reconfigure the connector to the DTE configuration in order to interface with a modem or mainframe computer, the white wire should be rerouted to Pin 3, the black wire to Pin 2, and the red wire to Pin 5. The pins are moved by threading the wire (crimped to the pins) through the slot in the top of the red end of the tool and inserting the tip of the tool into the socket for the pin being moved. When the tool is fully seated in the socket, pull the wire and the connector pin will come out.

To insert the new pin, use the white end of the tool. The same process is repeated in reverse; the wire is seated in the tool, with the shoulder of the pin at the tip of the tool. Insert the tool and pin in the new position and withdraw the tool; the pin will remain seated in the body of the connector. The new configuration is as follows:

Figure 9

RS-232 Cable Pin Assignments (DTE)

RS-232C Connector "DTE"	G-856 Front Panel	Cable Color	Function Description
1	D	shield	Ground - AC power and chassis ground
2	T	black	Transmit Data -(from the G-856)
3	U	white	Receive Data - (to the G-856)
5	G	red	Clear To Send - When low, inhibits G-856 output.
7	D	shield	Signal Ground - Zero reference for interface.

The pin numbers can be found in the molded plastic of the connector body.

VOLTAGE LEVELS

The RS-232C standard specifies voltage levels for the various data and protocol lines of the interface as ± 12 V nominal, with voltages from 5 V to 25 V being acceptable. A logical "1" (mark, off or false state) is indicated when the voltage at the interface point is more negative than -3 V; a logical "0" (space, on or true state) is indicated when the voltage is more positive than +3 V. Many "RS-232" devices, including the G-856, use 0 and +5 volts for these two logic levels ("TTL level") instead of ± 12 V. Most devices designed to work with ± 12 V will operate correctly with "TTL levels" but there are exceptions. Many large mainframe computers and some minicomputers require the full positive and negative swing of voltage, especially when transmitting data over long cables. If your external equipment requires full ± 12 V RS-232 levels, you will need to construct or purchase a TTL-to-bipolar interface driver. A schematic of such an interface driver appears in Appendix B.

Figure 10

Wiring Diagram - Front Panel Connector

Pin	Function	Remarks
A	Sensor	
B	Sensor	
C	Sensor Shield	
D	Ground	Power and Control Ground
E	No Connection	
F	Data Accepted	Input from External Device
G	Clear to Send	
H	Battery Positive	Connected to Internal Battery
J	Data 0	
K	Data 1	Character Serial BCD Out
L	Data 2	
M	Data 3	
N	$\overline{\text{Data Valid}}$	
P	End of Data	
R	Instrument Power	External Power In. Otherwise Jumper to H
S	$\overline{\text{Synchronization}}$	External Read/Store Command
T	Transmit Data	Part of RS-232
U	Receive Data	

WARNING. Clear all operating functions before removing external power or internal batteries. Failure to clear functions may produce a DATA ERROR. Before clearing the error it is imperative that stored data be dumped into a recording device to prevent complete loss of data stored in memory.

OUTPUT FORMAT

The G-856 data format on RS-232 and BCD outputs is as follows:

1. Each transmitted character is in ASCII code and consists of:

   a. 1 start bit (always logic "1")
   b. 7 data bits (ASCII encoded)
   c. 1 parity bit (always logic "0")
   d. 2 stop bits (always logic "0")

2. Each line of data transmitted by the G-856 is as described on Page 31 and consists of 29 ASCII characters:

		# of Characters
a.	Space or asterisk (*)	1
b.	Line number	3
c.	Space	1
d.	Julian day	3
e.	Space	1
f.	Time	6
g.	Space	1
h.	Station number	4
i.	Space	1
j.	Field	6
k.	Carriage return, line feed	2

3. After all data has been transferred by the G-856, a final character (ASCII EOT) is transmitted.

4. Transmission of data is initiated as described in the G-856 manual, page 31.

   a. Press "Output"; Display: Out
   b. Optional: Press "Shift, NNN"; to begin output from station number NNN
   c. Press "Enter"; display should begin flashing with number in lower window incrementing as each station's

   Be sure that baud rtes of magnetometer and device being transmitted to match and that G-856 Txd line is connected to computer Rxd line.

EXTERNAL POWER

The G-856 may be run from external power if desired. Usually you will want to do this because the internal batteries are not sufficient for some specific applications: when surveying in extremely cold weather, or when using the three-reading average (or long polarize) on a base station. The instrument may also be run on 18 volts instead of 12 to improve the signal-to-noise ratio.

In any case, connect the external battery positive to pin R, and the negative terminal to pin D (ground). Note that pin R is also jumpered to pin H (the terminal battery), and the external power will be paralleled with the internal battery. This means that you should remove the jumper or the internal D-size batteries to prevent current from flowing into or out of the internal batteries. An exception can be made if both sets of batteries are the same type and level of charge, so an external battery pack could be made from eight D-cells. The G-856 may also be operated from a DC power supply, but this usually introduces interference that noticeably reduces signal quality.

EXTERNAL CONTROL OF OPERATION

If pin S, Synchronization, is connected to pin D, ground, the instrument will take a reading and store it automatically. This feature was provided so that an external device could control operation of the magnetometer, and so that readings could be synchronized as desired. You can connect two G-856 magnetometers together so that the readings will be made simultaneously. In a small-area survey (most commonly in archaeological applications) a long cord can be run to the base station for more precise diurnal corrections. You may also wire two G-856 magnetometers together to make a portable gradiometer.

Possibly the most interesting application is in simplifying field operation. If you locate a push-button switch (non-magnetic) and tape it to your staff about shoulder height and wire it to $\overline{\text{SYNC}}$, you can use the hand holding the staff to operate the magnetometer. You sacrifice the discretion of examining each datum before storing it, but you gain a lot in convenience. Note also that you can use the Auto operation as an alternative. Once you establish a good interval between readings, just walk and stop while the instrument takes its data, then walk to the next point.

Note: $\overline{\text{SYNC}}$ is an output as well as an input. If a G-856 starts a cycle, either because read was pressed or because of Auto operation, $\overline{\text{SYNC}}$ is pulled low and held low until the end of the polarize time, then it is released. If $\overline{\text{SYNC}}$ is pulled low externally, the cycle is started. External $\overline{\text{SYNC}}$ may be momentary or held low. If momentary, Pol will shut off at the normal time. If held low, Pol time will be extended until $\overline{\text{SYNC}}$ is released. In this manner, two G-856s, wired in parallel, will be synchronized. Either unit may provide the start command.

USING THE BCD SIGNALS

The data is provided on several lines on the connector in character serial BCD as it is read and also during Ouput in addition to RS-232. This information is used by data acquisition systems such as some digital tape recorders.

BCD means binary coded decimal. There are four lines (wires), each being "on" (plus five volts) or "off" (zero volts) in a code shown in:

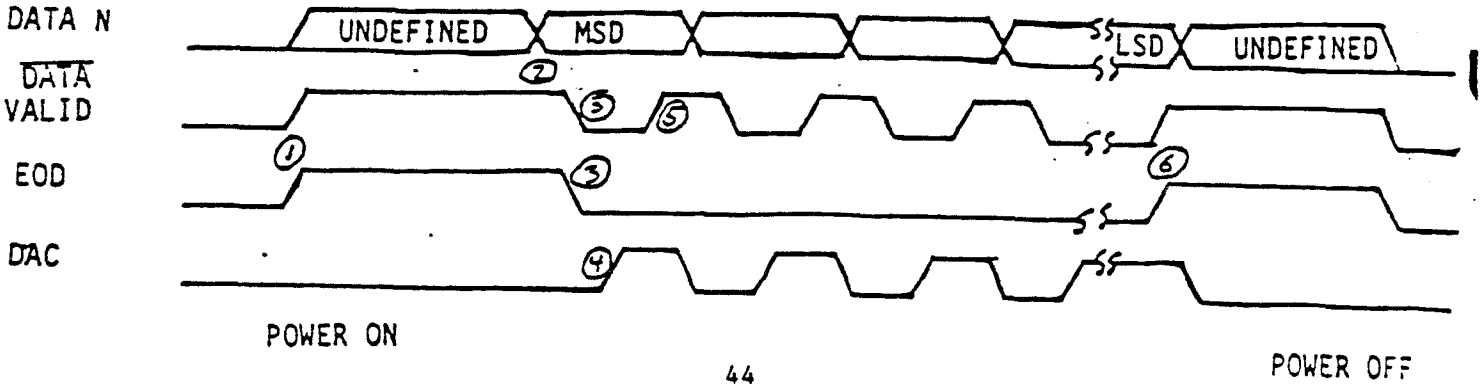
Data Line	3	2	1	0	Decimal Value
	off	off	off	off	0
	off	off	off	on	1
	off	off	on	off	2
	off	off	on	on	3
	off	on	off	on	4
	off	on	off	off	5
	off	on	on	off	6
	off	on	on	on	7
	on	off	off	off	8
	on	off	off	on	9

Notice that the lines have arithmetic weights of 8, 4, 2, and 1 which are added depending on their on or off state to generate the decimal equivalent.

Character serial means that each digit is sent out in sequence on the four lines (or in "serial"). To synchronize the sequence, some additional wires are needed to keep track of which digit is coming out at any particular time. This sequence of events is normally described in a graph called a "timing diagram" shown in Figure 14. Do not be disturbed if you find this information of limited value. It is provided only as reference material for users who wish to interface their instrument to data acquisition systems of their own design. If you would like to record on digital magnetic tape, EG&G Geometrics can provide suitable instruments and interfaces that are more user oriented.

Figure 11

Timing Diagram



For those of you who wish to interface your G-856, the timing sequence is as follows, (note that DAC is an input to the G-856 from an external device):

1. When the instrument powers up, DATA is undefined, $\overline{DAV}$ and EOD are pulled high. DAC should be held low by the external device.

2. After the polarize and count period, the most significant digit of the field is set on the DATA lines.

3. After the DATA lines settle, DAV and $\overline{EOD}$ are pulled low by the G-856.

4. The external device accepts the data, then releases DAC to float high.

5. $\overline{DAV}$ is pulled up, then the second digit is set onto the DATA lines. After that settles, $\overline{DAV}$ goes low again, and the cycle repeats until all six digits have been transmitted.

6. After the last digit has been accepted, EOD goes high, signifying the end of the data.

If the external device can accept the data fast, and there are no critical timing problems, then DAC can be driven by an inverter connected to $\overline{DAV}$, and the system will self clock at its maximum rate. If the transition at 4 does not occur within 1/2 second of $\overline{DAV}$, the G-856 will assume there is no external device and not output the BCD data.

The above sequence describes how the data is output during a normal read cycle. If instead you wish to read from memory that is possible but differs from the above sequence. The BCD data comes out at the same time as the RS-232 output but in reverse modified order:

Field	six digits	MSD first
Time	six digits	MSD first
Day	three digits	MSD first
Line #	three digits	MSD first

Notice that there are no spaces or station number. Station number is derived by counting the number of data sets. EOD goes high after each set of data.

Using the Programming Switch

LOCATION AND PURPOSE

The G-856 has a small programming switch on the microprocessor circuit board. This switch is actually a set of eight individual switches in a small plastic assembly about 1 cm by 2-1/2 cm in size. Its purpose is to allow you to adjust the operation of the instrument to make it more reliable, accurate, or suited to your specific application.

To locate the switch, remove the instrument from its case just as you do to replace batteries. Look near the left rear corner on the bottom circuit board. You will find a rectangular switch with eight small levers. Because of its size, you will need a small, pointed object like a pencil to change the switch settings. Notice that the eight levers will have their "on" position identified by the word ON or by a small dot (different types are available and interchangeable). You will also find the number 1 through 8 next to each small lever, identifying the individual switches.

SWITCHES 1 THROUGH 4 (POLARIZE AND COUNT TIME)

The first four switches adjust the polarize time and affect the sensitivity, speed, and power consumption of the instrument. As you know, there are two operations in a proton precession magnetometer. In the first, a current is fed to a coil of wire immersed in the hydrocarbon fluid, causing the protons in the fluid to align (polarize cycle). Then, the current is removed and proton precessions are counted for a short period (count cycle). These operations take time, and there are tradeoffs to be made in the selection of the length of time involved in each.

In the case of the polarize cycle, the current should be left on long enough to produce a good signal, but not so long that battery power is wasted and not so long that the reading cycle becomes inconveniently long. The precession signal, on the other hand, decays rapidly, and the best readings are obtained by counting for most of the strong (early) part of the cycle. Selection of the best time is again a tradeoff, since the duration depends on the polarization power, and also on the field strength and the magnetic gradient (high gradients cause the signal to collapse more rapidly).

SETTING OPTIONS

Switch 1, when on, will extend the polarize time from under two seconds to almost three seconds. Using this switch will give you a stronger precession signal, but lengthen the total cycle time and therefore shorten battery life.

Switch 2, when on, will shorten the polarize cycle to less than one second regardless of switch 1's position. This will speed up the cycle time and increase battery life, but the result is a weaker precession signal which in turn can result in lower accuracy.

Switch 3, when on, will shorten the precession signal count time. This, of course, will speed up the cycle slightly, but more importantly this setting will help you get good, valid data under conditions where the precession signal might decay very rapidly, in areas of high gradients and low field values. When the switch is on, however, the resolution of the magnetic field becomes .2 rather than .1 gammas.

Switch 4, when on, will cause the instrument to automatically take three readings, and compute the average. This obviously is designed to give you the highest possible sensitivity, at some significant sacrifice of cycle time and power consumption.

APPLICATIONS

Near the magnetic equator, the field is very weak and many proton magnetometers do not operate well, especially those optimized for higher latitudes. Often, the signal may be small and decays before the end of the count period. The solution is to extend the polarization time (switch 1) and shorten the count time (switch 3) so that counting is finished before the signal goes away. You may find that switch 3 is sufficient for good data, or you may need both switches. Remember that you may also want to rotate the sensor into the saddlemount position using the optional mounting bracket.

In high gradients, the problem is similar to the situation at the magnetic equator in that the signal collapses before the end of the count. You will know you are in an area of high gradients when the display truncates, or drops the least significant digit. The solution is the same as that for the equator, switch 1 and switch 3 are used.

Using switch 2 and switch 3 gives a much faster cycle time, longer battery life, and less sensitivity. You would use this combination when accuracy is not important, but speed and battery life are.

Remember that you can also improve the signal by operating the G-856 at a higher voltage. External power connections as well as all other inputs are accessed through the front panel connector. The instrument will operate on 18 volts, with a corresponding increase in polarization power. You can also operate with longer cables in this manner. Please note that the G-856 should give satisfactory performance with its normal 12-volt supply and the above option is only for special situations.

For highest sensitivity, switch 1 (long polarize) will help. In addition, switch 4 (3 reading average) used with or without switch 1 will again increase signal to noise ratio. Because of the lengthening of the total cycle time needed to perform 3 count averaging, this setting is probably most applicable to base station recording.

Because of the increased power needed to perform 3 reading average (when switch 4 is on), you should consider using alkaline batteries, or external power if switch 1 (long polarize) is also used. The standard batteries supplied with the G-856 will not last through the time it takes to fill the memory when 3 count averaging is being applied.

In summary, proper selection of the polarize and count options will require some judgement on the part of the user, but having this flexibility can produce better data under difficult condition.

Switch 5 (Auto Mode)

APPLICATIONS

Switch 5 is applicable to the AUTO mode. In some uses of automatic recording, it will be desirable to have the readings displayed as they are taken and stored. Typical would be portable surveys where the operator may

wish to automatically record (to save button pushing and to increase the number of readings storable), yet would want to monitor the operation. But, in other cases, base station recording for example, there would be no value in lighting the display, since the display uses about half the power consumption.

SETTING OPTIONS

If switch 5 is turned on, the display will blank if the keyboard is not exercised for five minutes. When you first set up the instrument, the display will light for five minutes to allow initial monitoring of the operation, but after you leave and those minutes have elapsed, the display will shut down to save power.

If switch 5 is off, the display will continue to light each cycle indefinitely.

SWITCHES 6 AND 7 (BAUD RATE)

Switches 6 and 7 are used to set the baud rate. The RS-232 interface will output data at selected speeds, called the baud rate. Different types of devices can send and receive at different rates or combinations of rates. A mechanical teletype with an RS-232 interface will receive at 110 baud. A standard telephone line with a modem will communicate at 300 baud. Printers with RS-232 interfaces may handle 300 or 600 baud (and others). Computers, of course, can handle very high speeds of data transmission. The data handling device that you connect to the G-856 will either have a specified baud rate or a selection of baud rates. You will want to use the fastest combination available between the two instruments, but they must be set to the same baud rate to transfer data.

The data transfer rate in characters per second is approximately one/tenth the baud rate. A reading contains about 30 characters (FIELD, TIME, STATION NUMBER, DAY, LINE NUMBER, spaces, punctuation marks, carriage returns, line feed, and some null characters to allow time for the mechanism to return to the start of a new line). That means that a single reading will require as much as three seconds to print on a slow telex machine, or as little as 1/5 of a second to feed into a computer.

SWITCH 8

See Table C-1

Figure 12 and Table C-1 show the switch option settings.

Figure 12
Switch Setting Options

SWITCH		S1	S2	
1	POLARIZE TIME	OFF	OFF	NORMAL
		ON	OFF	LONG
2		ON	ON	SHORT
		ON	ON	SHORT
3	READ TIME	OFF		NORMAL - 920 ms
		ON		SHORT - 460 ms
4	3 READING AVERAGE	OFF		NORMAL
		ON		AVERAGE
5	AUTO CYCLE DISPLAY	OFF		NORMAL
		ON		DISPLAY SHUTS DOWN
6, 7, 8	BAUD RATE SELECT (See Table C-1.)			

SPECIFICATIONS

Displays	Six digit display of magnetic field to resolution of 0.1 gamma or time to nearest second. Additional three digit display of station, day of year, and line number.
Resolution	Typically 0.1 gamma in average conditions. May degrade to lower resolution in weak fields, noisy conditions or high gradients.
Absolute Accuracy	One gamma, limited by remnant magnetism in sensor and cystal oscillator accuracy.
Clock	Julian clock with stability of 5 seconds per month at room temperature and 5 seconds per day over the temperature range of -20 to +50 degrees Celsius.
Tuning	Push button tuning from keyboard with current value displayed on request. Tuning range 20 to 90 kilogammas.
Gradient Tolerance	Tolerates gradients to 5000 gammas/meter. When high gradients truncate count interval, maintains partial reading to an accuracy consistent with data.
Cycle Time	Complete field measurement in three seconds in normal operation. Internal switch selection for faster cycle (1.5 seconds) at reduced resolution or longer cycles for increased resolution.
Manual Read	Takes reading on command. Will store data in memory on command.
Memory	Stores more than 1,000 readings in survey mode, keeping track of time, station number, line number, day and magnetic field reading. In base station operation, computes for retrieval but does not store time of recording designated by sample interval, allowing storage of over 2,500 readings.

Output	Plays data out in standard RS-232 format at selectable baud rates. Also outputs data in real time byte parallel, character serial BCD for use with digital recorders.
Inputs	Will accept an external sample command.
Special Functions	An internal switch allows: 1) adjustment of polarization time and count time to improve performance in marginal areas or to improve resolution or speed operation, 2) three count averaging, 3) choice of lighted displays in auto mode.
Physical	Instrument console: 7 x 10-1/2 x 3-1/2 inches (18 x 27 x 9 cm) 6 lbs (2.7 kg) Sensor: 3-1/2 x 5 inches (9 x 13 cm) 4 lb (1.8 kg) Staff: 1 inch x 8 feet (3 cm x 2.5 m) 2 lbs (1kg)
Environmental	Meets specifications from 1 to 40 degress Celsius. Operates satisfactorily from -20 to 50 degrees Celsius. Weatherproof.
Power	Operates from 8 D-cell flashlight batteries (or 12 volts external power). May be operated at 18 volts external power to improve resolution. Power failure or replacement of batteries will not cause loss of data stored in memory.

ACCESSORIES

Standard:	Sensor Staff Backpack Two sets of batteries Carrying case Operation Manual Applications Manual for Portable Magnetometers
Optional:	RS-232 interface cable Cold weather battery belt Digital tape recorder with interface cables

APPENDIX A

Operation Short Reference Guide

1) Clearing a key sequence [CLEAR]

2) Taking and Storing a Reading [READ] [STORE]

3) Recalling from Memory — last reading taken

[RECALL] (continue pressing RECALL to decrement
press ENTER increment

4) Recalling from Memory — specific station number

[RECALL] [SHIFT] [(station) ⇔] [(station) ⇔] [(station) ⇔] [ENTER]

5) Tuning the magnetometer

[READ] [TUNE] [SHIFT] [⇔] [⇔] [ENTER]

6) Erasing data -- last reading

[READ] [RECALL] [ERASE] [ERASE]

-- last group of readings

[RECALL] [SHIFT] [(station) ⇔] [(station) ⇔] [(station) ⇔] [ENTER] [ERASE] [ERASE]

— entire memory

[RECALL] [SHIFT] [0] [ENTER] [ERASE] [ERASE]

7) Time and Line Number read

[TIME] (press while reading is
being displayed--see RECALL)

8) Line Number set

TIME | SHIFT | (line) ↵ | (line) ↵ | (line) ↵ | ENTER

9) Julian Day set

AUTO | TIME | SHIFT | (day) ↵ | (day) ↵ | (day) ↵ | ENTER

10) Julian Day and Time Set

AUTO | TIME | SHIFT | (day) ↵ | (day) ↵ | (day) ↵

(hour) ↵ | (hour) ↵ | (min) ↵ | (min) ↵ | ENTER

11) Output In

OUTPUT | ENTER

12) Output Stop

OUTPUT | CLEAR

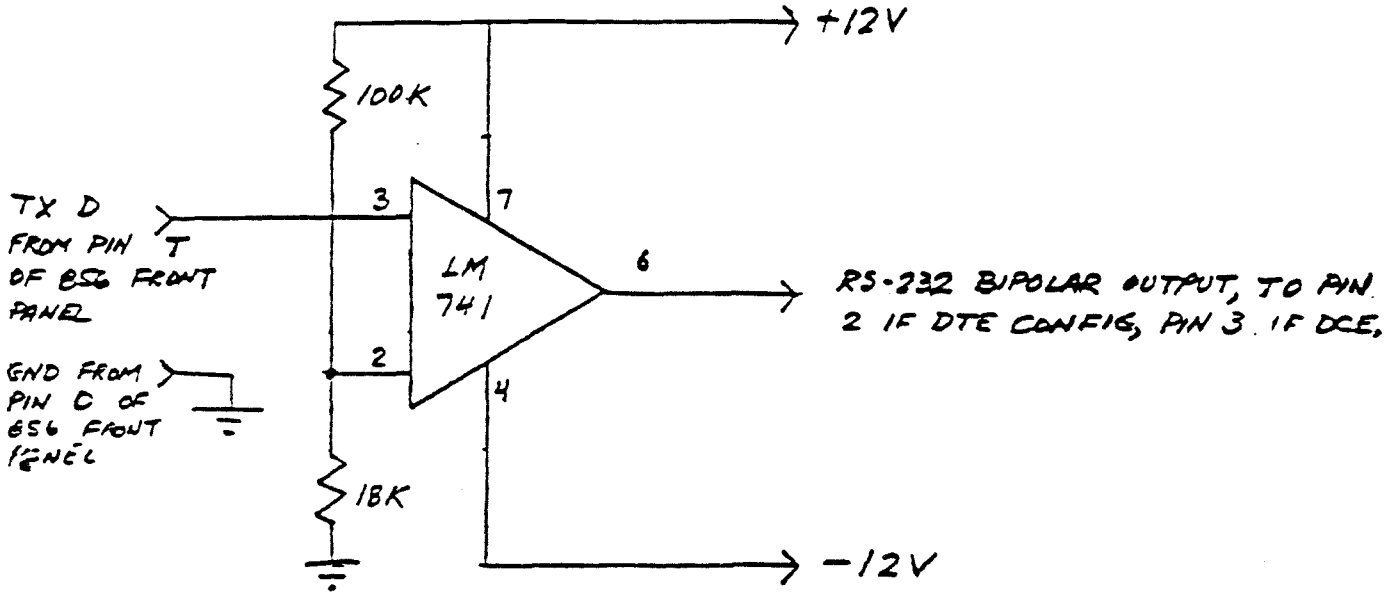
13) Setting Auto Mode

AUTO | SHIFT | (seconds) ↵ | (seconds) ↵ | ENTER

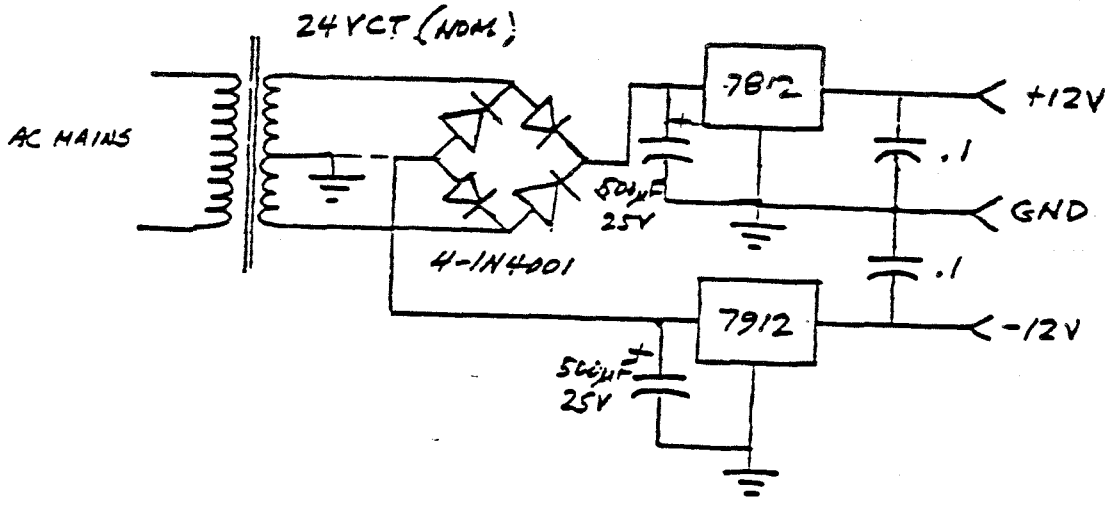
14) Auto Mode Off

AUTO | CLEAR

Appendix B



TTL-TO-RS232C INTERFACE DRIVER



±12V POWER SUPPLY

N.B. THE INTERFACE DRIVER WILL ALSO WORK WELL ON TWO 9-VOLT TRANSISTOR RADIO BATTERIES FOR ±9V.

Appendix C

OPERATING THE MODIFIED MODEL G-856 (UNITS HAVING SERIAL NUMBER 27351 AND ABOVE, AND USER-MODIFIED UNITS) AND THE MODEL G-856X

Because of several performance improvements included in the (1) Model G-856X, (2) later models of the Model G-856, and (3) instruments that have been retrofitted to upgrade their performance*, the operating procedures of these instruments differ from those of the earlier, unmodified Model G-856 magnetometers. This appendix describes these performance improvements and the new operating procedures.

Beeper/Annunciator

The beeper/annunciator sounds once each time a key is touched, three times after data from memory have completely transferred through the RS-232 output, and five times whenever high gradients or noise are read.

Julian Date Display

To distinguish a Julian date from a line number, each Julian date is displayed with a trailing decimal point in all modes (DISPLAY, RECALL, etc.).

Expanded Baud Rate Selection

Table C-1 lists the expanded baud rate selection and the programming switch settings required to configure the magnetometer for a specific rate. Note that Switch 8 is now operable.

Table C-1

BAUD RATE SELECTION

Baud Rate	Programming Switch Setting		
	Switch 6	Switch 7	Switch 8
110	OFF	OFF	OFF
150	ON	OFF	OFF
300	OFF	ON	OFF
600	ON	ON	OFF
1200	OFF	OFF	ON
2400	ON	OFF	ON
4800	OFF	ON	ON
9600	ON	ON	ON

*Two retrofit kits are available: Kit 16640-01 upgrades an earlier model G-856 to have the newer software features described in this appendix. Kit 16640-02 will essentially convert a Model G-856 to a Model G-856X, complete with expanded memory.

Operation in the Base Station (Auto Cycle) Mode

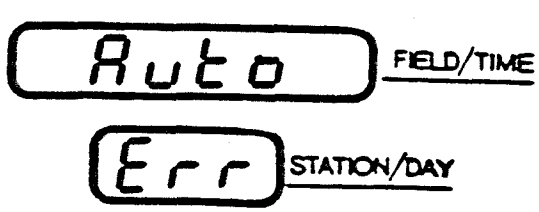
Table C-2 is a listing of the functions that can and cannot be executed in the base station (auto cycle) operating mode.

Table C-2

BASE STATION MODE (AUTO CYCLE) FUNCTIONS

Allowed Functions	
RECALL	(recalls stored readings)
TUNE	(tunes the magnetometer)
TIME	(displays time and line number)
AUTO-TIME	(displays time and Julian day)
AUTO-TUNE	(enters or exits auto-tune mode)
AUTO-TUNE-SHIFT	(adjusts cable capacitance)
Disallowed Functions*	
OUTPUT	(outputs data)
READ	(takes a reading)
STORE	(stores reading)
AUTO-ENTER	(enters auto cycle)
AUTO-TIME-SHIFT	(changes time or day)

*If an attempt is made to activate a disallowed function, the display will read out



Faster Cycling In Base Station (Auto Cycle) Mode

As shown in Table C-2, single and three-cycle-averaged times for operation in the base station mode have been reduced by approximately one second for all polarization and reading (gate) configurations. The table breaks out the selection of cycle time and the appropriate programming switch configurations.

Table C-3

CYCLE TIME SELECTION

Single Cycle (seconds)	Three-Reading Averaged (seconds) (Switch 4 ON)	Programming Switch Setting: Switch 0 (Long Pol, if ON)	Switch 1 (Short Pol)	Switch 2 (Short Gate, if ON)
4	10	OFF	OFF	OFF
5	13	ON	OFF	OFF
3	7	OFF	ON	OFF
3	7	ON	ON	OFF
3	7	OFF	OFF	ON
4	10	ON	OFF	ON
2	6	OFF	ON	ON
2	6	ON	ON	ON

Memory Operation

The Model G-856X has a memory capacity of 12,000 readings taken in the base station operating mode or 5,700 readings taken in the field reading operating mode. Models with serial numbers of 27351 or greater have a memory capacity of 2,950 base station readings and 1,450 in-the-field readings. Note that you have the additional option of specifying a G-856X memory for retrofitting your early model G-856 to maximum memory capacity. See footnote on page 53.

A reading is stored in memory when the [STORE 8] key is pressed after a reading is made. To indicate that a reading has been stored, [StorEd] FIELD/TIME is displayed.

To erase a reading recalled from memory and all readings following that reading, the [ERASE 3] key is pressed twice while the recalled reading is being displayed. The display will change to [ErASEd] FIELD/TIME

By continuously depressing the [ENTER] or [RECALL 7] key when recalling readings, the readings will be automatically reviewed at an increasing rate; for example, the read out rate will start at one reading every half second, then increase within 10 seconds to 5-6 readings every second.

Should data in memory become corrupted,

dAtA FIELD/TIME
Err STATION/DAY

will be displayed whenever a key is depressed. However, even though this message is displayed, most keystroke sequences are valid. If the stored data are not totally corrupted, the stored information may still be reviewed or output to an RS-232 device to recover the remaining uncorrupted data. Once the data have been recovered, the [ERASE 3] key can be depressed twice to reset the instrument and completely clear the memory. See note on page 58.

One way that memory may be corrupted is by removing power (either by disconnecting an external power device or by removing the internal batteries) while the G-856 is in an operating mode; e.g., auto cycle. In most cases only the last reading will be affected, so the remaining stored data should be transferred to a storage device (a printer or recorder). This transfer must be done before the ERASE-ERASE sequence is followed or all of the data in memory will be lost. Untill the error is cleared, you will not be able to reactivate the auto cycle mode.

Tuning

Tuning is accomplished automatically. When the automatic tuning function is activated, the tuning value is automatically updated after each field reading--unless a high gradient is being read. To activate the automatic tuning function press [AUTO 2] [TUNE 6] [ENTER]

This key sequence will activate the following displays:

Auto FIELD/TIME
:: :: STATION/DAY

A tunE FIELD/TIME
oFF STATION/DAY

While the automatic tuning function is enabled, the instrument cannot be manually tuned. The tuning value and signal level may be displayed but they cannot be changed. Attempts to manually tune the instrument will produce this display:

A tunE FIELD/TIME
Err STATION/DAY

Note: For best performance, manually tune the G-856 before taking the first reading of a survey area, then activate the automatic tuning function.

To deactivate the automatic tuning function press

AUTO 2 TUNE 6 CLEAR . The display will be

Auto FIELD/TIME A tunE FIELD/TIME

STATION/DAY on STATION/DAY FIELD/TIME

To determine whether the instrument is in the automatic tuning mode, press AUTO 2 TUNE 6 . The display will indicate whether the automatic tuning is on

A tunE FIELD/TIME

on STATION/DAY

or off

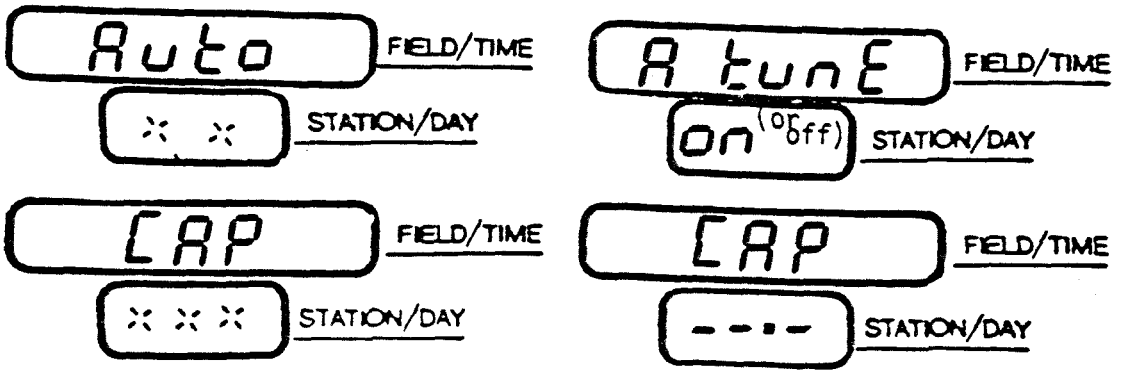
A tunE FIELD/TIME

oFF STATION/DAY

To ensure the optimum performance of the automatic tuning function, the magnetometer tuning value should be matched to the capacitance of the sensor cable. Most EG&G Geometrics cables for portable sensors have a capacitance of .03 nano-farads per foot; thus, the standard portable sensor cable supplied with the G-856 has a total capacitance of 0.2 nano-farads. To match the instrument's automatic tuning function to this standard cable, press

AUTO 2 TUNE 6 SHIFT 0

The display will read out



Key in the capacitance of the sensor cable [SHIFT 0] [SHIFT 0] [AUTO 2]

and press [ENTER]

Addendum to 'Memory Operation'

In the field mode, a reading can be taken and automatically stored each time

[READ 9] is depressed. To enter the auto store mode, depress the

following keys: [AUTO 2] [STORE 8] [ENTER]

To clear the auto store mode press: [AUTO 2] [STORE 8] [CLEAR]

In the base station mode the G-856X can be configured to take readings even if the memory is full. In this auto erase mode, the earliest sixteen stored readings will be deleted and the instrument will continue to take readings. To enter the auto erase mode, depress the folling keys:

[AUTO 2] [ERASE 3] [ENTER]

To clear the auto erase mode, depress: [AUTO 2] [ERASE 3] [CLEAR]

To determine if either the Auto Store or the Auto Erase feature is ON or OFF, press [AUTO 2] then press either [STORE 8] or [ERASE 3].

The display will indicate whether the feature is ON or OFF.

APPENDIX D

G-856 GRADIOMETER OPTION INSTRUCTIONS

1. PURPOSE

The G-856 Gradiometer Option allows a single G-856 chassis to take successive reads from two vertically separated sensors. The result is a measurement of vertical gradient independent of time variations. See Note 1.

2. CONTENTS

This option consists of a Remote Start Switch Box, two special sensor cables, a special second sensor, a staff modification kit, and a Velcro strip.

3. PREPARATION

Configure the G-856 console for normal polarize, normal gate, and disable 3 read averaging. To do this, set switches 1 through 4 on the G-856 cpu board to the "off" position.

Assemble the staff and sensors. Start by removing the standard cable from the original sensor and attaching one of the special sensor cables. Next, connect the staff modification kit parts to the top of one staff section and the bottom of another staff section so that the threaded shafts point towards each other. The second sensor, with two threaded caps, will mount between these two staff sections. Sensor separation may be controlled by choosing an appropriate pair of staff sections.

Then assemble staff sections and mount the sensors. The sensor cables may now be connected to the Remote Start Switch box, and the Remote Start Switch may be connected to the G-856 front panel connector. Attach the Velcro strip to the top of the G-856 black front panel bezel. Mount the Remote Start box to this mating Velcro strip.

4. OPERATION

To initiate a gradiometer read cycle, depress the Cycle button on the Remote Start Switch. The G-856 will then take two readings, the first from the bottom sensor, an the second from the top sensor.

Data may be automatically stored by entering the following key sequence on the G-856 front panel prior to starting the read cycle :

AUTO / STORE / ENTER

The G-856 will then store all readings until the following key sequence is entered :

AUTO / STORE / CLEAR

5. DATA STORAGE

Gradiometer readings are stored a pairs of field readings. Assuming that the G-856 memory were cleared before operation as a gradiometer, reading 000 would be the first bottom sensor reading and 001 would be the first top sensor reading. From then on each even numbered reading will be from the bottom sensor and each odd numbered reading will be from the top sensor. The RS232 output format is described on page 42 of the G-856X manual.

NOTE 1

In situations where changes in the earth's field are significant during the interval between sensor reads, some correction of the data may be necessary.

CLEAR

Clears a key stroke or key stroke sequence.

SHIFT 0

Accesses the numbers on the keys rather than the functions.

ENTER

Designates the end of a key sequence and transfers command to system. Also increments memory location displayed during recall operations (see RECALL).

OUTPUT 1

Begins automatic output of data to external device.

AUTO 2

Starts and stops automatic recording mode. Sets interval for automatic recording.

ERASE 3

Erases a reading, the last group of readings, or the whole memory. (Must depress twice).

FIELD 4

Used during memory recall to recover the field reading after TIME has been depressed.

TIME 5

Accesses the real time clock. Also displays the time at which readings were taken.

TUNE 6

Displays and/or sets the tuning. Provides display of the signal strength received from last reading.

RECALL 7

Accesses the memory. Also decrements the memory location displayed.

STORE 8

Stores reading in memory.

READ 9

Takes a measurement of the magnetic field.

FIELD/TIME

Displays the magnetic field or the time.

STATION/DAY

Displays the station number, the Julian Day, or the line number. Also displays signal strength, tuning, and battery voltage.

Connects G-856 to sensor, recorder, printer, computer, or external power.

WARRANTY AND SERVICE

Warranty

EG&G Geometrics fully warrants the Proton Precession Magnetometer to be free of defects in material and workmanship for a period of one year from the date of acceptance, but no longer than fifteen months from the date of shipment from the factory. EG&G Geometrics maintains good commercial practices in the manufacture of equipment. In the event of malfunction, EG&G Geometrics, at its own expense will repair or replace any material, equipment, work, or parts that prove defective or deficient under normal operating conditions.

Except for the express warranty stated above, EG&G Geometrics disclaims all warranties of merchantability and fitness, and any stated express warranties herein are in lieu of all obligations or liability on the part of EG&G Geometrics for damages, including but not limited to special, indirect or consequential damages arising out of, or in connection with the use or performance of the equipment.

EG&G Geometrics reserves the right to perform warranty services FOB Sunnyvale or at the customer's installation site. EG&G Geometrics is not responsible for delays or defects in the quality of results from misuse, mishandling, unauthorized modifications, installation, or other operation conditions outside its control.

Should warranty service or technical advice be required, contact EG&G Geometrics. No warranty service will be performed unless customer secures authorization from EG&G Geometrics prior to returning equipment. If this instrument or any part of it is returned to the factory for any reason, please complete this form and include it with the instrument or part being returned.

SHIP TO:

EG&G Geometrics
395 Java Drive
P.O. Box 497
Sunnyvale, CA 94089
(via San Francisco International Airport)
Phone: (408) 734-4616
Telex: 357-435

Name_____

Company_____

Address_____

City, State, Zip, Country_____

Telephone_____

IMPORTANT

Please explain why this instrument or part is being returned; include a complete description of any malfunction (use additional paper if necessary). Thank you._____

_____

_____

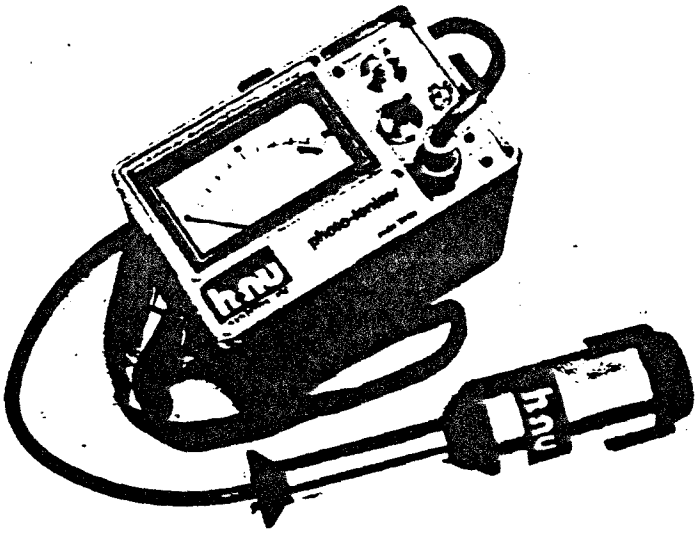
hnu systems inc.

INSTRUCTION MANUAL

FOR

MODEL PI 101

PHOTOIONIZATION ANALYZER



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hnu chemical instrumentation
systems inc.

11.7 eV Lamp

The 11.7 eV lamp is a new lamp introduced by HNU Systems. The 11.7 eV lamp is identified by the 11.7 eV marking near the lamp number on the glass envelope. The relative sensitivity of the 11.7 eV lamp in a PI101 is about 1/10 that of a 10.2 eV lamp. It is direct reading with benzene at a span setting of approximately 1.0.

If the window in the lamp becomes dirty, do not clean with water or any organic solvent miscible with water such as acetone or methanol. The window should be cleaned with a soft tissue dipped in an organic (non-water miscible) solvent or freon.

The 11.7 eV lamp will respond to methanol, ethylene, dichloride, formaldehyde and other vapors with IP's up to approximately 11.8 eV.

Note that the window of this lamp is not smooth. The striations are an integral part of its construction.

HNU SYSTEMS, INC., 30 OSSIPEE ROAD, NEWTON, MA 02164 • TWX 710-336-7682 • TEL. (617) 964-6690

11.7 eV Lamp for the HNU Photoionization Detector

DESCRIPTION

The 11.7 eV lamp is the second of the new interchangeable lamps to be introduced by HNU Systems. The 11.7 eV lamp is identified by the inscription "11.7 eV" near the lamp number on the glass envelope. Use of these interchangeable lamps allows the selective determination or exclusion of classes of compounds since the energy of each ultraviolet source is monochromatic (single wavelength). A comparison of the 11.7 and the 10.2 eV lamps in an HNU photoionization detector is given below:

TABLE I

	LAMP	
	11.7 eV	10.2 eV
Upper Range (μg)	20	20
Detection Limit (pg)	30	2
Dynamic Range	10^6	10^7
Relative Sensitivity	1	10
Sensitivity (Coulombs/gram of Benzene)	0.03	0.3
Relative Noise	1	8

The relative sensitivity of the 11.7 eV lamp is about 1/10 that of the 10.2 eV lamp as shown by the data in Table II. The 11.7 eV lamp provides a more universal response than the 10.2 lamp in a PID.

Molecules with ionization potentials up to ~12 eV are ionized. The sensitivity ratio remains about the same for the 11.7 and 10.2 eV lamps to ~10.2 eV then the sensitivity of the 10.2 falls rapidly and that of the 11.7

lamp increases resulting in ratios larger than 1. A typical chromatogram is shown in Figure 1. Note that none of these species can be done with the 10.2 eV lamp.

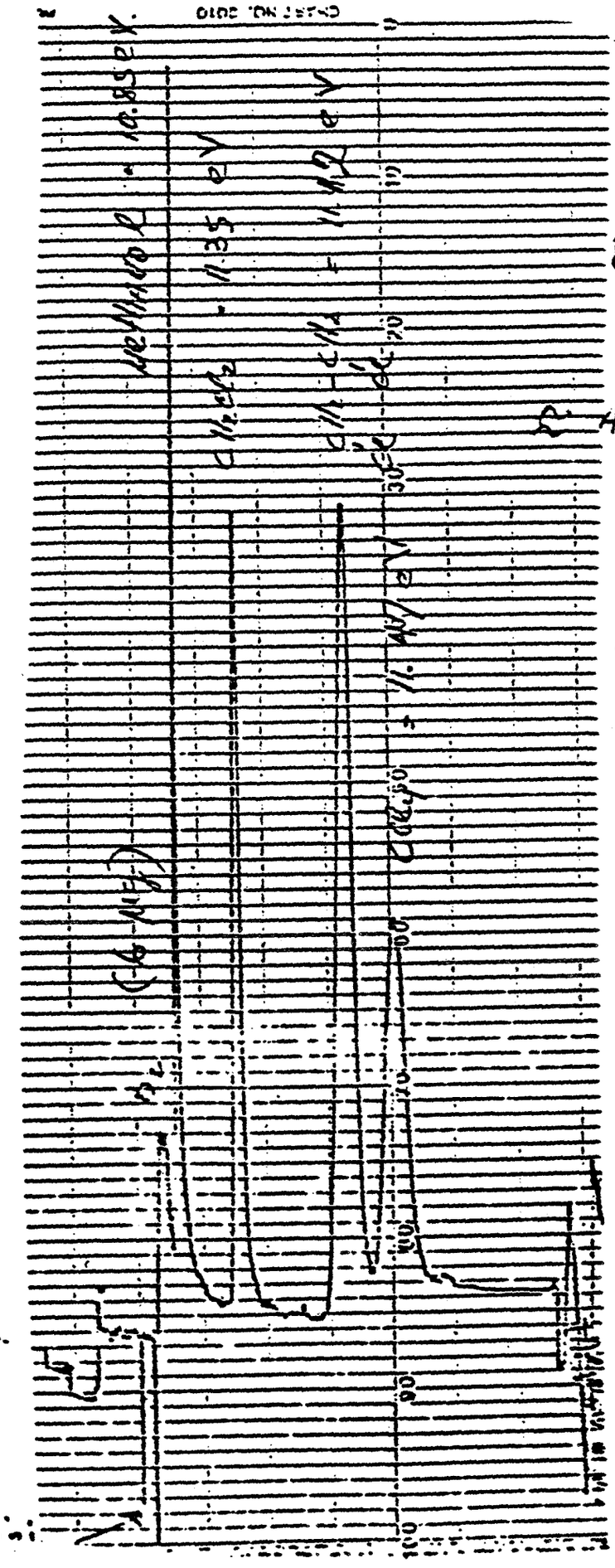
To optimize the performance of these interchangeable lamps, we recommend the HNU PI52 electrometer which has an integral continuously variable control for optimization of lamps in the HNU photoionization detector.

Do not clean this window with water or any water miscible solvent (CH_3OH, acetone). It will damage the lamp. Use a freon or chlorinated organic solvent to remove any deposits. The cleaning compound for the 10.2 eV lamp should not be used under any circumstances. An organic based abrasive cleaning compound for the 11.7 eV lamp will be available shortly from HNU Systems.

TABLE II

COMPARISON OF THE RELATIVE SENSITIVITY
OF THE 11.7 TO THE 10.2 eV ULTRAVIOLET SOURCE

Compound	Ionization Potentials (eV)	Relative Response Ratios 11.7/10.2 eV
p-Xylene	8.44	1.04
p-Chlorotoluene	8.70	1.12
Toluene	8.82	1.12
o-Chlorotoluene	8.83	1.12
Ethyl Acetate	9.19	1.12
Benzene	9.24	1.0
Methyl Mercaptan	9.24	0.72
Pyridine	9.32	1.22
Allyl Alcohol	9.67	1.12
Crotonaldehyde	9.88	1.04
Amyl Alcohol	9.80	1.16
Cyclohexane	9.88	1.04
Vinyl Chloride	9.95	1.12
Butanol	10.94	1.76
Ammonia	10.15	1.60
Acetic Acid	10.37	5.60
Ethylene	10.52	3.20
Ethylene Oxide	10.56	2.98



8X10^{-11} amps

≈ 40 ng.

PID/11.7eV
1 amp

Conditions:

5' x 1/4" OD.
porapak Q
40ml/min N
Col. temp. 10

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NOTE

This manual contains operation, service, and maintenance information for HNU Model 101 Photoionization Analyzers equipped with the 10.2 eV lamp and calibrated for direct reading in ppm vol/vol of benzene.

Specific information relative to units equipped with an 11.7 eV or 9.5 eV lamp or calibrated on species other than benzene is contained in the addendum at the back of the manual.

ERRATA

Page		
25	Figure 7	Electrical Block Diagram of Photoionization Analyzer Readout Assembly: Point 19 Fan Voltage (DC)
44	Table XVIII	Relative Sensitivities for Various Gases

Species	Photoionization Sensitivity
Ethylene	1.0

52 Power Supply PC Board

Pads	Voltage
18	+19.4V

SECTION 1

INTRODUCTION

The model PI 101 has been designed to measure the concentration of trace gases in many industrial or plant atmospheres. The analyzer employs the principle of photoionization for detection. This process is termed photoionization since the absorption of ultraviolet light (a photon) by a molecule leads to ionization via:

$$RH + h\nu \rightarrow RH^{+} + e^{-}$$

where RH = trace gas

$h\nu$ = a photon with an energy $\geq$ Ionization Potential of RH

The sensor consists of a sealed ultraviolet light source that emits photons which are energetic enough to ionize many trace species (particularly organics) but do not ionize the major components of air such as O_2, N_2, CO, CO_2, or H_2O. A chamber adjacent to the ultraviolet source contains a pair of electrodes. When a positive potential is applied to one electrode, the field created drives any ions, formed by absorption of UV light, to the collector electrode where the current (proportional to concentration) is measured.

To minimize adsorption of various sample gases, the ion chamber is made of an inert fluorocarbon material, is located at the sampling point, and a rapid flow of sample gas is maintained through the small ion chamber volume.

The analyzer will operate either from a rechargeable battery for more than 10 hours or continuously from the AC battery charger. A solid state amplifier board in the probe and a removable power supply board in the readout module enable rapid servicing of the unit in the field.

The useful range of the instrument is from a fraction of a ppm to about 2,000 ppm. For measurement at levels above 2,000 ppm, dilution of the sample stream with clean air is recommended. Some typical specifications for the model PI 101 Photoionization Analyzer are given in Table 1.

TABLE 1

SPECIFICATIONS FOR MODEL PI 101

PHOTOIONIZATION ANALYZER

performance (benzene referred)

range 0.1 to 2000 ppm
detection limit 0.1 ppm
sensitivity (max) 0-2 ppm FSD over 100 division meter scale
repeatability ± 1% of FSD
linear range 0.1 to 600 ppm
useful range 0.1 to 2000 ppm
response time < 3 sec to 90% of full scale
ambient humidity to 95% RH
operating temperature ambient to 40°C*

physical

size:	probe 6.3 DIA x 28.5L (cm)	(2-1/2 x 11-1/4")
	readout 21W x 13D x 16.5H (cm)	(8-1/4 x 5-3/16 x 6-1/2")
	stowed 21W x 13D x 24H (cm)	(8-1/4 x 5-3/16 x 9-1/2")
	cable 80 cm long (32")	

weight: probe .55 kg (20 ounces)
readout 3.2 kg (7 pounds)
total (shipping) 5.4 kg (12 pounds)

controls and functions

mode switch Off, Battery Check, Standby (zero), 0-2000, 0-200, 0-20 ppm
low battery indicator light
zero (10 turn ± 300% FSD max)
span (10 turn counting dial 1.0 to 10 times nominal sensitivity)
readout 4-1/2" (11.3 cm) meter Taut Band movement graduated 0-5-10-15-20, divisions
signal output for recorder 0-(-5V) FSD
power output for recorder 12 VDC - jack on side of instrument

power requirements of operating times

continuous use, battery > 10 hours
continuous use with HNU recorder reduces instrument battery operating time to 1/2 normal time
recharge time, max < 14 hours, 3 hours to 90% of full charge
recharge current, max .4 Amps @ 15 VDC

TABLE 1 (Continued)

construction

Designed to withstand the shock and abuse to which portable instruments are often subjected. The readout is housed in a two piece aluminum case, and finished with a solvent resistant baked acrylic textured paint.

The probe is fabricated from extruded aluminum sections and machined plastic.

serviceability

The probe and readout are of a modular design allowing rapid servicing and/or replacement of mechanical and electrical components. All module interwiring includes quick disconnects.

maintenance

The instrument contains only one moving part, and consumes no gases or reagents. The only routine maintenance procedure is cleaning the light source window every several weeks.

calibration check

Check instrument calibration at least once per week with HNU calibration standard to ensure that the high sensitivity of the instrument is maintained.

* Instrument is temperature compensated so that a 20°C change in temperature corresponds to a change in reading of < ± 2% full scale at maximum sensitivity.

SECTION 2

OPERATION

2.1 Unpacking

Unpack the instrument carefully and remove the housing, the probe and any spare parts from the shipping carton. Place the instrument on a table or bench with the label upright. Remove the top section of the instrument by opening the two fasteners on the cover (see figure 1). The inner panel of the top section can be removed by pulling up on the fasteners. The top section of the instrument contains the battery charger and a waist strap. The waist strap clips on to the strap brackets of the instrument when needed.

Before attaching the probe, check the function switch on the control panel to make sure it is in the off position. The 12 pin interface connector for the probe is located just below the span adjustment on the face of the instrument (see figure 2). Carefully match the Alignment Key in the probe connector to the 12 pin connector on the control panel, and then twist the probe connector until a distinct snap and lock is felt.

Attached to the instrument is a warranty card which should be filled out completely and returned to HNU Systems.

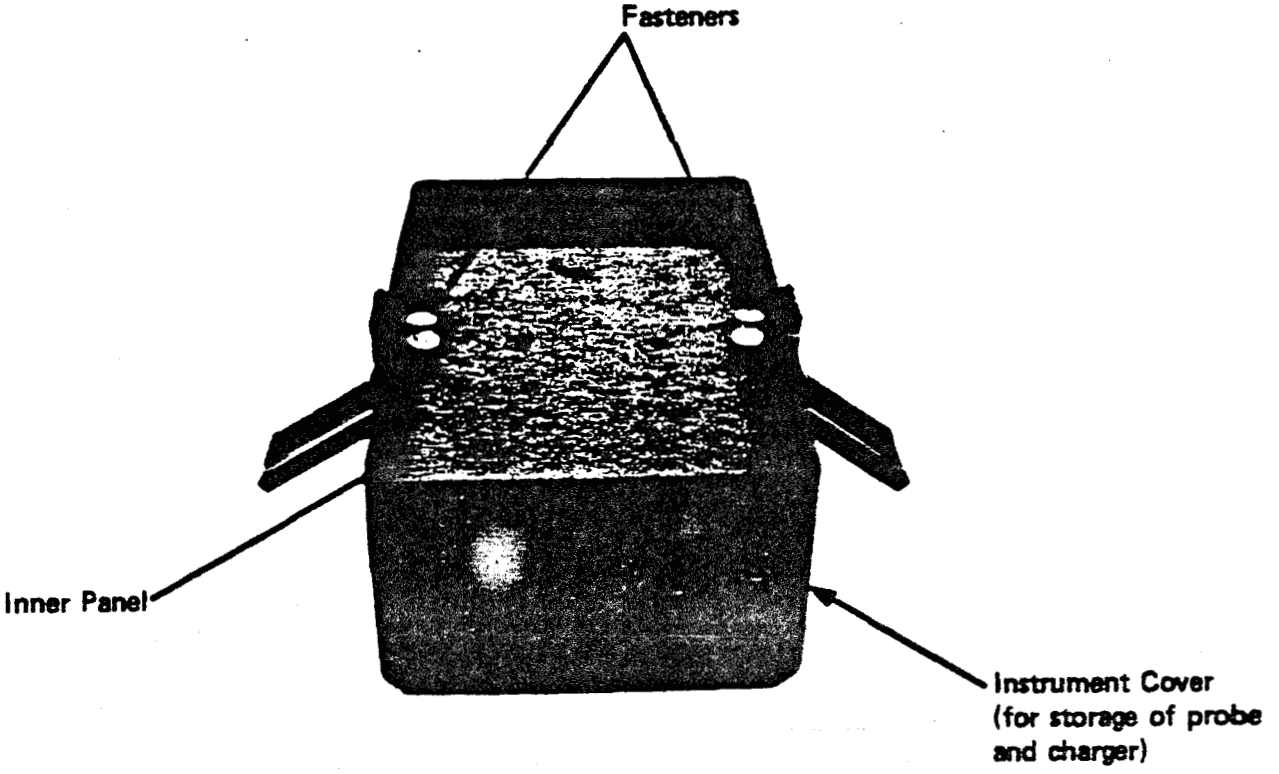
2.2 Operation

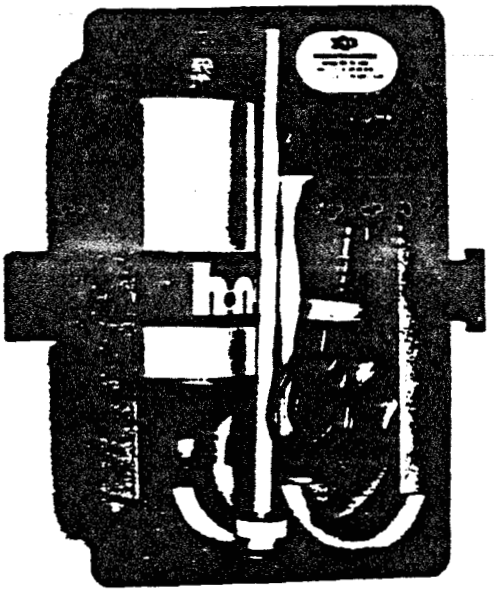
Turn the function switch to the battery check position. The needle on the meter should read within or above the green battery arc on the scaleplate. If the needle is in the lower portion of the battery arc, the instrument should be recharged prior to making any measurements. If red LED comes on, the battery should be recharged.

Next, turn the function switch to the on position. In this position the UV light source should be on. Look into the end of the probe to see the purple glow of the lamp.

A brief description of the instrument controls and functions is shown in Figure 2.

Figure 1 (Continued)





Top View

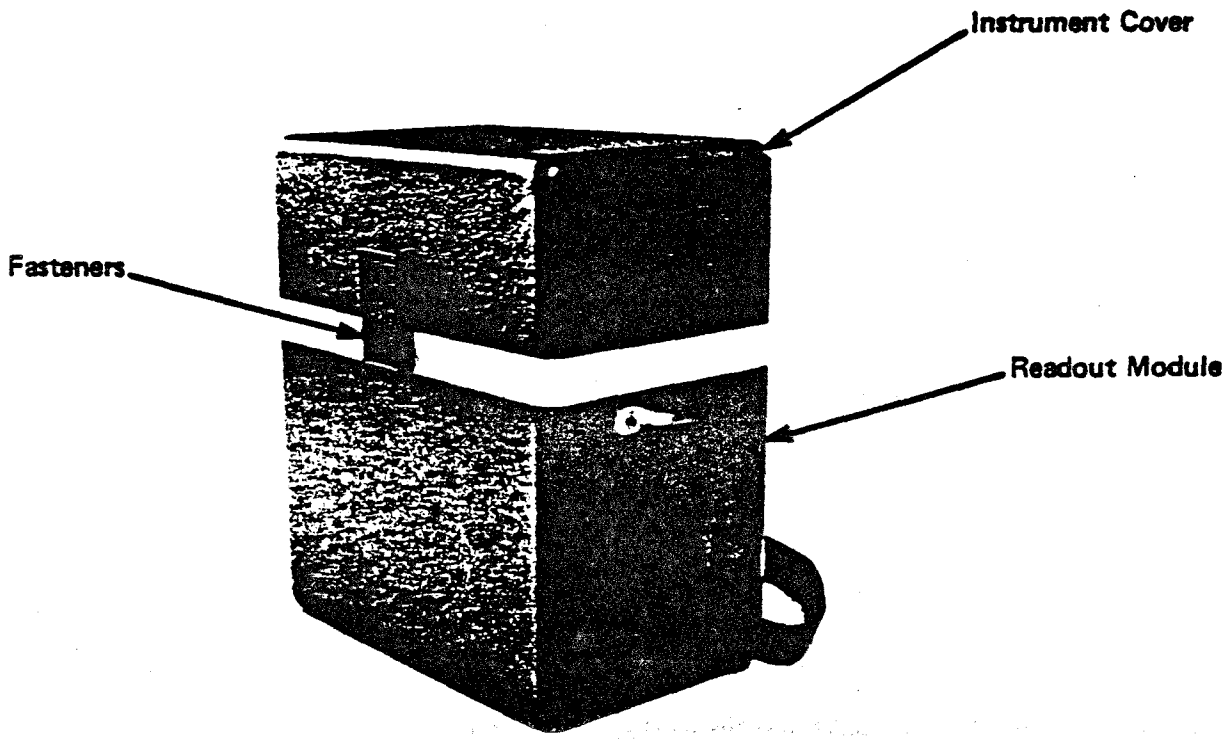


Figure 1. Unpacking the Photoionizer.

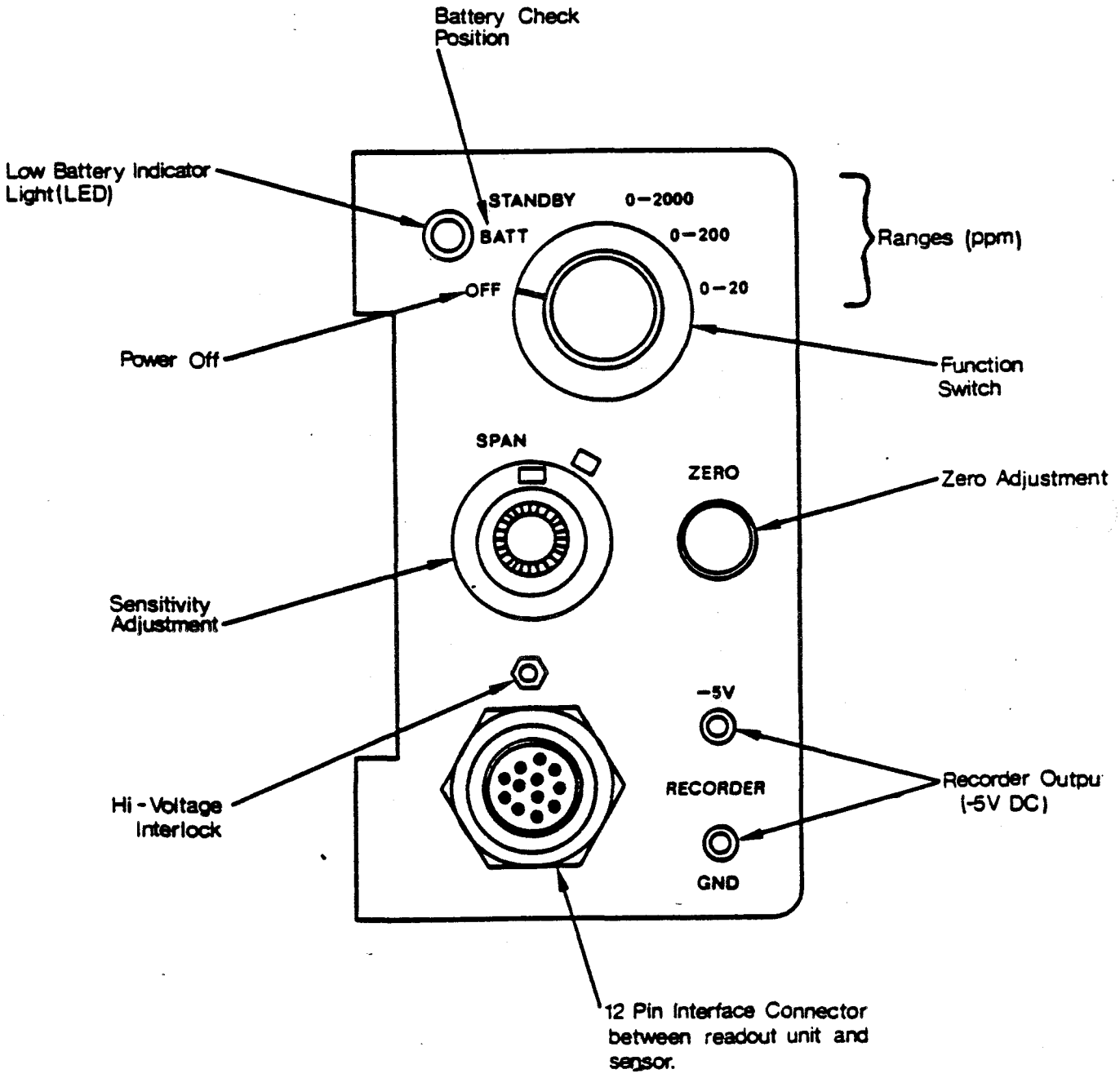
TABLE II

BRIEF DESCRIPTION OF INSTRUMENT
CONTROLS AND FUNCTIONS*

Control	Function
Six Position Switch	OFF - Shuts off all power and removes DC voltages. ON - In any other function position or measuring mode, the electronics are on. BATTERY CHECK - Indicates the condition of the battery. If needle position is in lower portion of green battery arc, the instrument should be recharged. STANDBY - UV lamp is off but electronics are on. This position will conserve power and extend the useful operating time between recharges of the battery. This position is also utilized to adjust the electronic zero. RANGES - 0-20, 0-200, 0-2000 direct reading ranges available at minimum gain for benzene. More sensitivity is available by adjusting the span potentiometer.
Zero Potentiometer	A ten turn potentiometer is employed to adjust the zero electronically when the instrument is placed in the standby position with the probe attached. This eliminates the need for a hydrocarbon free gas.
Span Potentiometer	A ten turn counting potentiometer is utilized for upscale setting of the meter on calibration gas. Counter-clockwise rotation increases the sensitivity (~10 times). This pot can increase the sensitivity to make the instrument direct reading for nearly any gas which the instrument responds to.

*For position of layout controls see Figure 2.

Figure 2 Control Panel Functions



To zero the instrument, turn the function switch to the standby position and rotate the zero potentiometer until the meter reads zero. Clockwise rotation of the zero potentiometer produces an upscale deflection while counterclockwise rotation yields a downscale deflection. Note: no zero gas is needed, since this is an electronic zero adjustment (see below). If the span adjustment setting is changed after the zero is set, the zero should be rechecked and adjusted, if necessary. Wait 15 or 20 seconds to ensure that the zero reading is stable. If necessary, readjust the zero.

The instrument is now ready for calibration or measurement by switching the function switch to the proper measurement range. The instrument is supplied calibrated to read directly in ppm (v/v) 0-20, 0-200, 0-2000 of benzene with the span position set at 9.8. For additional sensitivity, the span potentiometer is turned counterclockwise (smaller numbers) to increase the gain. By changing the span setting from 10.0 to 1.0 the sensitivity is increased approximately ten fold. Then, the 0-20, 0-200, and 0-2000 ppm scales become 0-2, 0-20, and 0-200 ppm full scale, respectively. This span control is also utilized to make the instrument scale read directly in ppm of the compound being measured. E.g., it is adjusted to match the value of a calibration gas to that same reading on the instrument scale. The span control can be utilized to calibrate nearly any compound, measured by photoionization, to be direct reading on the 0-20 ppm range. For example, gain settings of 4.5 or 8.9, respectively, will provide direct reading capability (0-20, 0-200 ppm) for vinyl chloride and trichloroethylene, respectively, For a listing of approximate gain setting values see Table IV.

A small DC operated fan is used to pull air through the photoionization sensor at a flow rate of three to seven hundred centimeters per minute (ca. 0.5 lpm). The fan provides nearly instantaneous response times (Figure 3) while consuming little power. The characteristics of a fan are such that it cannot tolerate a significant pressure drop without affecting the flow rate and therefore either the instrument reading or response time. Since photoionization is essentially a nondestructive technique, changes in flow rate do not affect the signal but if a large pressure drop is imposed at the inlet of the probe, the sample may not reach the sensor.

TABLE III

VERIFICATION OF ELECTRONIC ZERO FOR PHOTOIONIZATION ANALYZER*

Sample	Instrument Reading (ppm)	% of F.S.
Room Air	0.7	35
Room Air Passed Through 6" x 3/4" OD Charcoal Scrubber	0.1	5
Zero Air	0.25	12.5
Zero Air Passed Through 6" x 3/4" OD Charcoal Scrubber	0.04	2

*Maximum Gain = 2 ppm full scale.

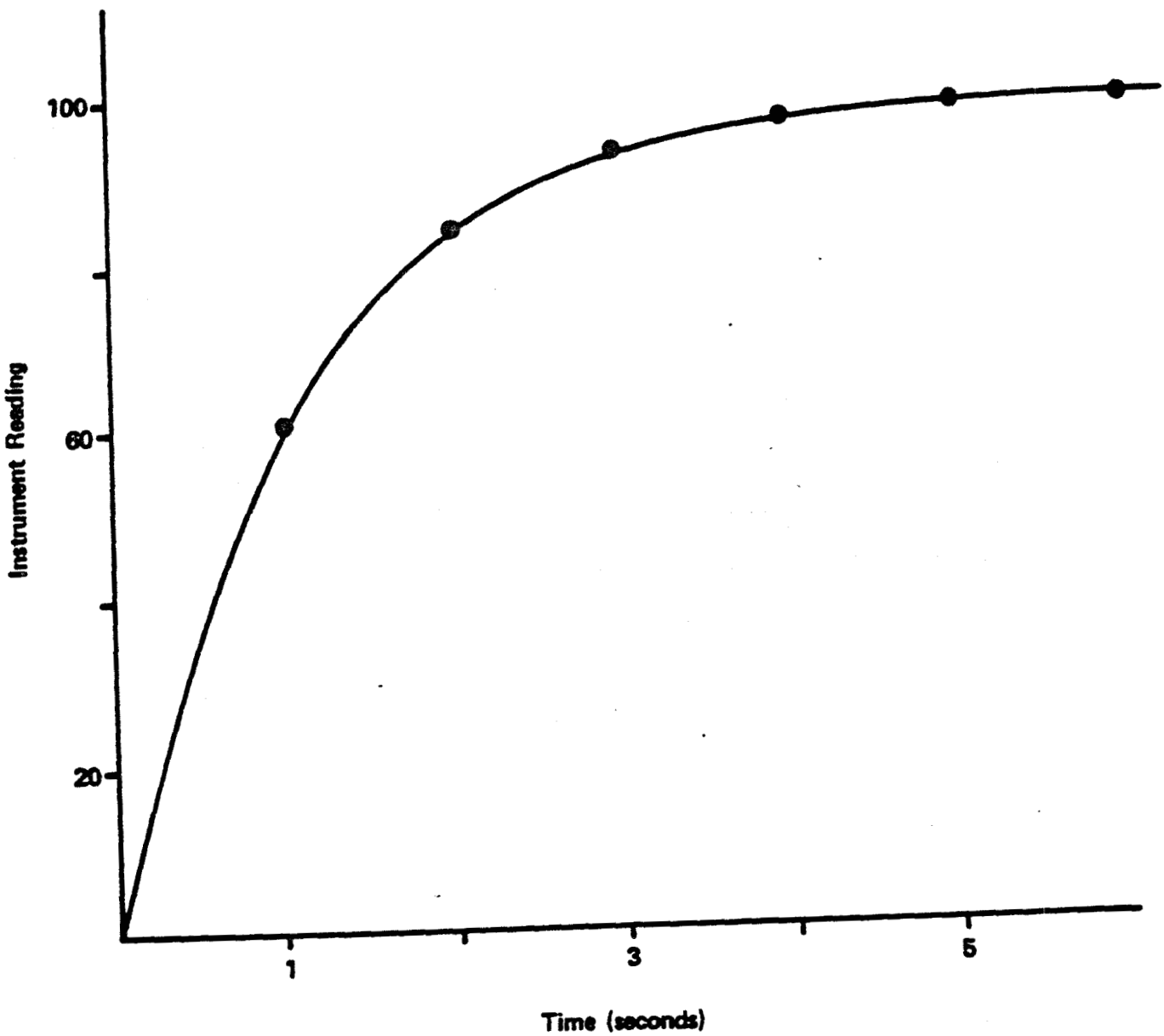
TABLE IV

RELATIVE PHOTOIONIZATION SENSITIVITIES* FOR VARIOUS GASES

Chemical Grouping	Relative Sensitivity	Examples
Aromatic	10.0	Benzene, Toluene, Styrene
Aliphatic Amine	10.0	Diethylamine
Chlorinated Unsaturated	5-9	Vinyl Chloride, Vinylidene Chloride, Trichloroethylene
Carbonyl	5-7	MEK, MIBK, Acetone, Cyclohexene
Unsaturated	3-5	Acrolein, Propylene, Cyclohexene, Allyl Alcohol
Sulfide	3-5	Hydrogen Sulfide, Methyl Mercaptan
Paraffin (C_5-C_7)	1-3	Pentane, Hexane, Heptane
Ammonia	0.3	—
Paraffin (C_1-C_4)	0	Methane, Ethane . . .

*Sensitivities in ppm (v/v).

Figure 3. Time Response for the Photoionization Analyzer.



The instrument was designed to measure trace gases over a concentration range from less than 1 ppm to 2000 ppm. Higher levels of various gases (to percentage range) can be measured but the recommended procedure is to dilute the sample with clean air to a concentration of less than 500 ppm. This is generally within the linear range of the instrument and if the measured concentration is multiplied by the dilution ratio the correct concentration in the stream can be determined. A typical calibration curve is shown in Figure 4. Note that the calibration curve for benzene (the photoionization standard) is linear (over more than three decades) up to about 600 ppm (v/v).

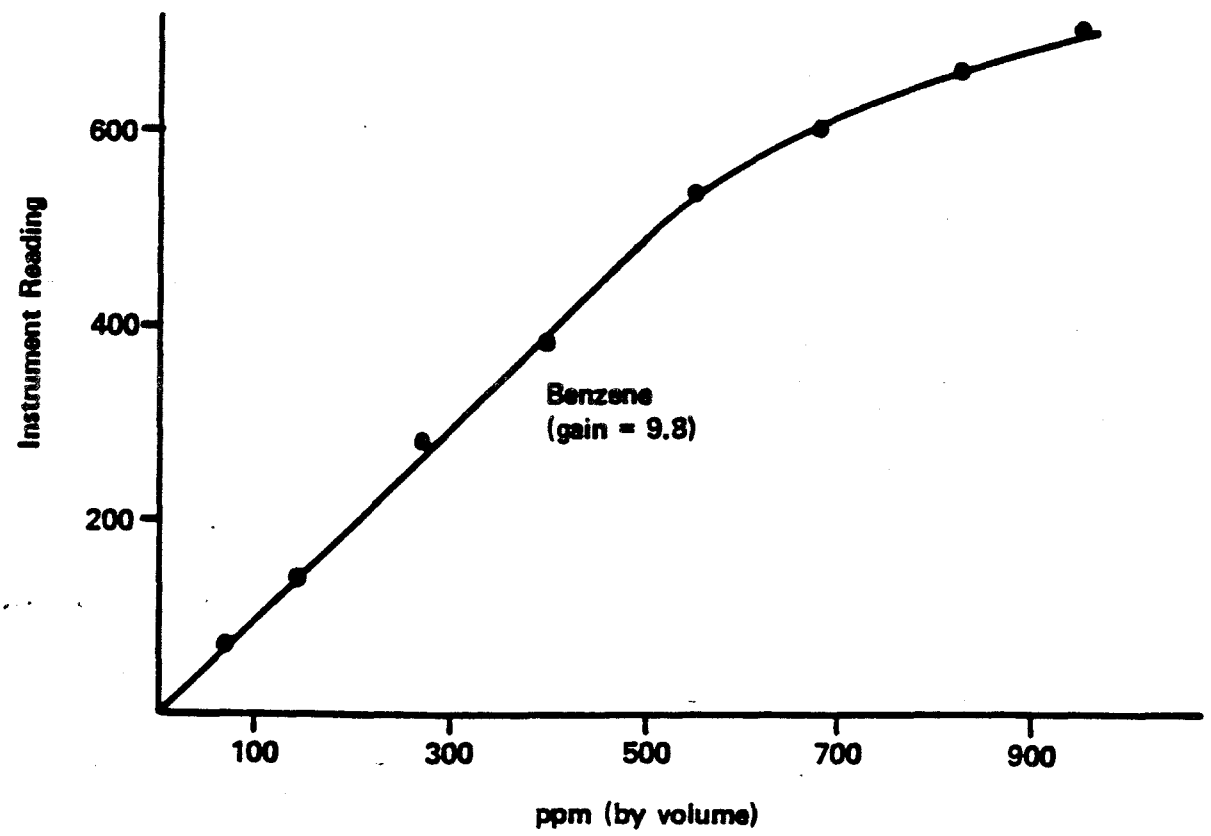
If the probe is held close to AC power lines or power transformers, an error may be observed. For measurements made in close proximity to such items, their effect on measurements can be determined by the following procedure. Zero the instrument in an electrically quiet area, in the standby position, then move the instrument to the questionable area involved. If AC pickup is going to be a problem, the meter (in the standby position) will indicate the magnitude of the error.

The instrument is equipped with an automatic solid state battery protection circuit. When the battery voltage drops below ~ 11 volts, this circuit will automatically turn off the power to the instrument. This prevents deep discharging of the battery and considerably extends the battery life. If the instrument is unintentionally left on overnight, the battery will be unharmed because of the battery protection circuit. If the instrument battery check reads low and the lamp doesn't fire, plug the charger into the instrument. The power to the analyzer should then be returned.

To charge the battery, place the mini phone plug into the jack on left side of the bezel prior to plugging charger into 120 VAC. When disconnecting charger, remove from 120 VAC before removing mini phone plug. The battery is completely recharged overnight (ca. 14 hours). To ensure that the charger is functioning, turn the function switch to the battery check position, place phone plug into jack and plug charger into AC outlet. The meter should go upscale if charger is working and is correctly inserted into the jack.

The instrument can be operated during the recharge cycle. This will lengthen the time required to completely recharge the instrument battery.

Figure 4. Typical Calibration Curve for Photoionization Analyzer.



SECTION 3

CALIBRATION

Static or dynamic gas generation systems can be utilized for calibration of the instrument. A number of such systems for generating test atmospheres for various gases have been described by G. O. Nelson in "Controlled Test Atmospheres," Ann Arbor Science Publishers, Ann Arbor, Michigan (1971).

The most convenient packages for calibration are the non-toxic analyzed gas mixtures available from HNU Systems in pressurized containers (Catalogue #101-350).

A rapid procedure for calibration involves bringing the probe and readout in close proximity to the calibration gas, cracking the valve on the tank and checking the instrument reading. This provides a useful spot check for the instrument.

The recommended and most accurate procedure for calibration of the instrument from a pressurized container is to connect one side of a "T" to the pressurized container of calibration gas, another side of the "T" to a rotameter and the third side of the "T" directly to the 8" extension to the photoionization probe (see Figure 5). Crack the valve of the pressurized container until a slight flow is indicated on the rotameter. The instrument draws in the volume of sample required for detection, and the flow in the rotameter indicates an excess of sample. Now adjust the span pot so that the instrument is reading the exact value of the calibration gas. (If the instrument span setting is changed, the instrument should be turned back to the standby position and the electronic zero should be readjusted, if necessary.)

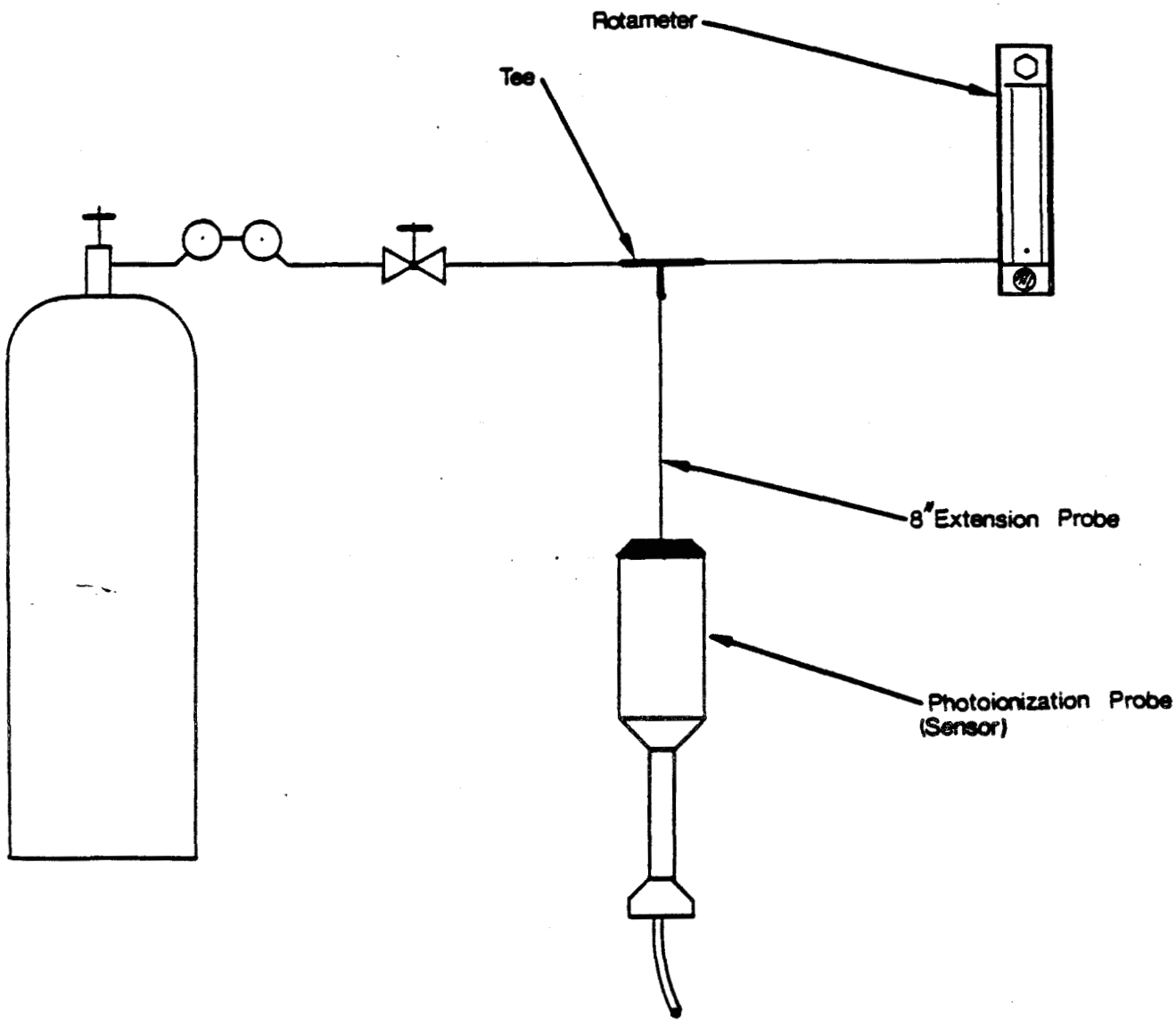


Figure 5. Recommended Calibration Procedure for Photoionization Analyzer

The calibration gas* should be prepared in the same matrix (air, nitrogen, hydrogen, etc.) in which it is to be measured, otherwise an inaccurate reading may be obtained. The increased response which is seen in oxygen free gases can be attributed to a reduction in the quenching of ions by oxygen (actually O_2^-) and is typical of any ionization detector. The quenching effect of oxygen is constant from about ten percent O_2 to very high levels.

If a gas standard prepared in nitrogen is to be used for measurements in air, fill a 0.5 or 1 liter bag with the standard then add 50 or 100 cc of pure oxygen to bring the level to 10-12%.

Any error between this value and 20% oxygen is quite small.

If the sample to be measured is in nitrogen, standards should be prepared in nitrogen. This will result in an increase in sensitivity of approximately 4.

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* Calibration with toxic gases should be performed in a hood since the 101 is a non-destructive analyzer.

SECTION 4

DETECTION PRINCIPLE AND THEORY

The detection principle of this portable instrument is photoionization. A wide variety of organic compounds and some inorganic compounds can be measured with this technique. Photoionization (with ~ 10 eV photons) applied to the analysis of trace gases in air can eliminate fragment ion formation (signals) from the major components of air yet still allow the ionization of many impurities of interest in industrial atmospheres. This is demonstrated by the listing of ionization potentials* in Tables V-XVII. Note the high (12 eV) ionization potentials for the major components of air. In addition, the choice of a sufficiently low ionization energy often permits the selective ionization of one or two components in a complex gas mixture.

While the ionization potential serves as a rough guide to whether or not a response is obtained, it does not predict what the quantitive response actually is. In some cases, a species with an ionization potential 10.3 or 10.4 eV will give a response. In these cases, however, the response is usually low because of its low ionization efficiency at 10 eV. A partial list of actual relative sensitivities obtained with a photoionization analyzer is given in Table XVIII. The use of the tables should allow a determination of the specificity of the instrument in a given application on many industrial processes; this instrument may not respond to the starting materials or by-products but will respond to a product. An example of this is seen in the vinyl chloride monomer plants where neither ethylene or dichloroethane is detected but vinyl chloride is detected.

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* Ionization potential is defined as the energy required to move an electron an infinite distance from the nucleus or more simply, the energy required to produce a positive ion and an electron.

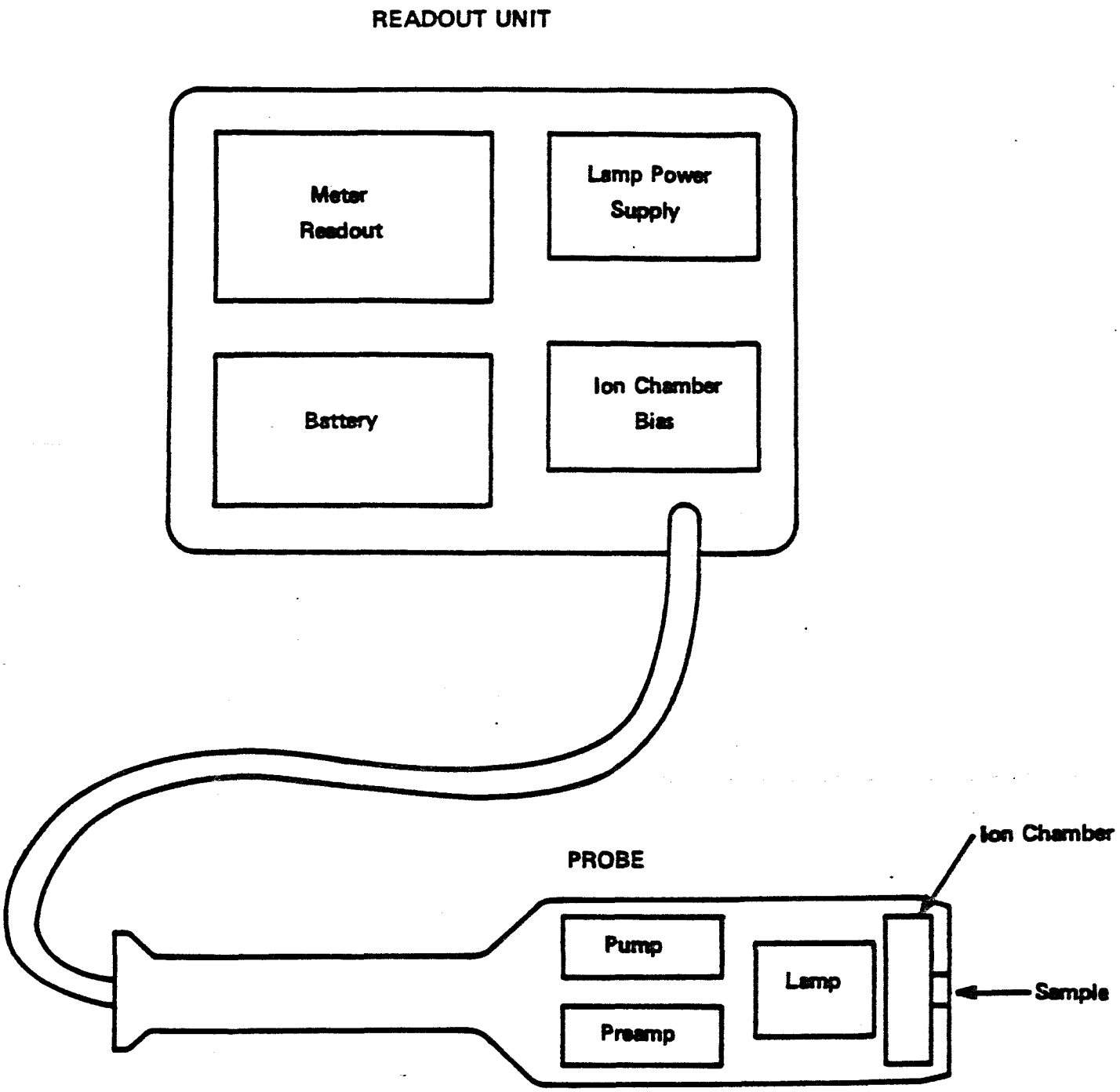


Figure 6. Block Diagram of Portable Photoionization Analyzer.

A block diagram of the major components of the photoionization analyzer is shown in Figure 6. The instrument is separated into two units interconnected by multiconductor electrical cable. The probe contains a fan for moving the air into the sensor, the ultraviolet lamp which is ignited by applying a DC voltage between the anode and cathode, the ionization chamber which contains a pair of electrodes and is adjacent to the lamp, and a signal amplifier. The photons ($\sim$ 10 eV) which are emitted from the lamp pass through a UV transmitting window and into the ionization chamber where absorption of the UV radiation by a molecule which has an ionization potential of 10 eV or less will lead to ion formation via:

$$RH + h\nu \rightarrow RH^{+} + e^{-}$$

A positively biased high voltage electrode is used to push any ions formed by absorption of UV to the collector electrode where the current (proportional to concentration) is measured. This current is then converted to a proportional voltage by the amplifier in the probe. An electrical diagram of the instrument is depicted in Figure 7. The amplifier is gain stabilized by negative feedback and provides a voltage source output to drive the analog meter readout as well as the gain control network. The sensitivity of the instrument is controlled by changing the loop gain of the amplifier. A 12 volt battery provides the primary power for a high efficiency DC-DC converter which supplies the various potentials required for instrument operation.

Figure 7. Electrical Block Diagram of Photoionization Analyzer

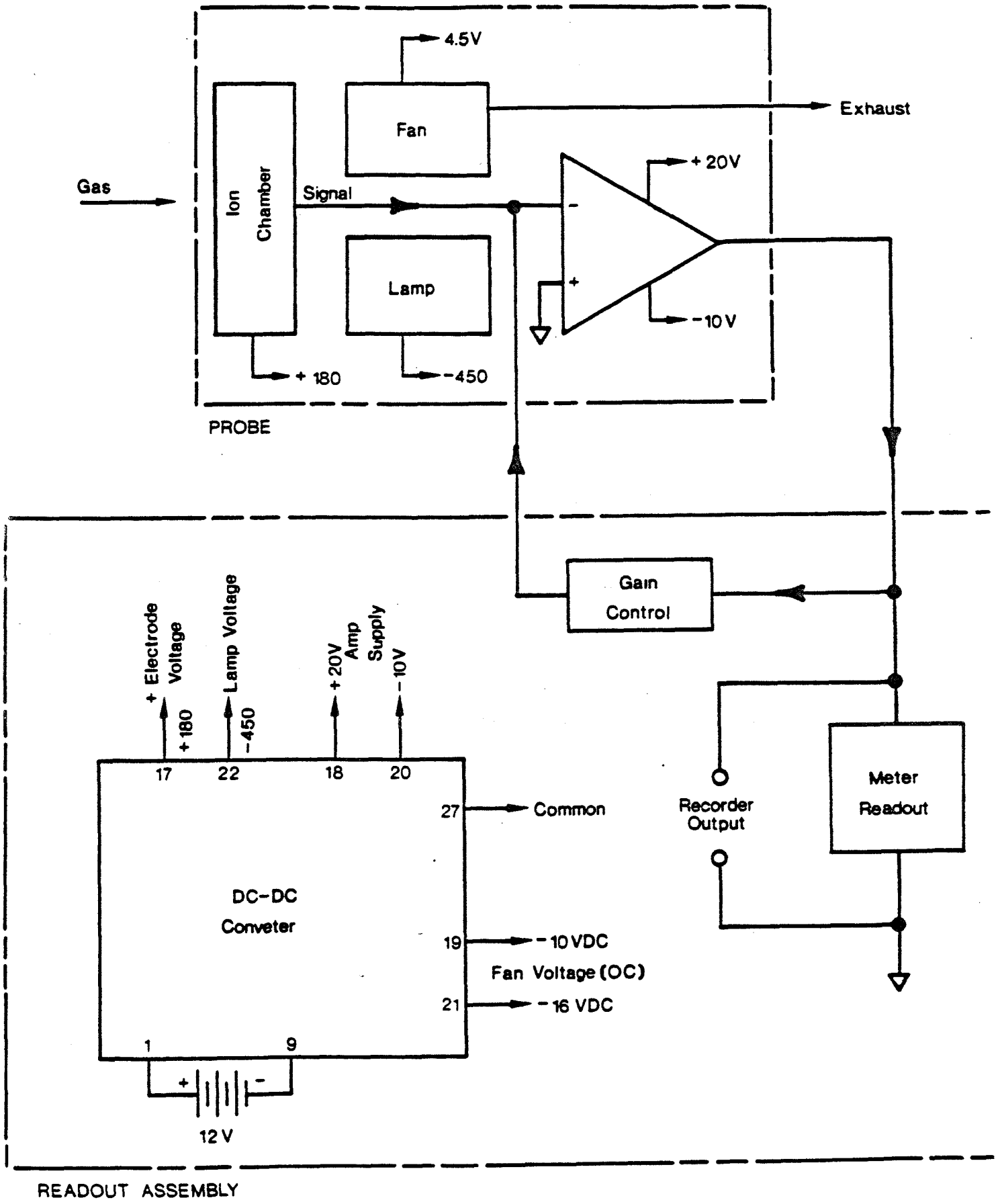


TABLE V

SOME ATOMS AND SIMPLE MOLECULES

	IP (eV)		IP (eV)
H	13.595	I_2	9.28
C	11.264	HF	15.77
N	14.54	HCl	12.74
O	13.614	HBr	11.62
Si	8.149	HI	10.38
S	10.357	SO_2	12.34
F	17.42	CO_2	13.79
Cl	13.01	COS	11.18
Br	11.84	CS_2	10.08
I	10.48	N_2O	12.90
H_2	15.426	NO_2	9.78
N_2	15.580	O_3	12.80
O_2	12.075	H_2O	12.59
CO	14.01	H_2S	10.46
CN	15.13	H_2Se	9.88
NO	9.25	H_2Te	9.14
CH	11.1	HCN	13.91
OH	13.18	C_2N_2	13.8
F_2	15.7	NH_3	10.15
Cl_2	11.48	CH_3	9.840
Br_2	10.55	CH_4	12.98

TABLE VI

PARAFFINS AND CYCLOPARAFFINS

Molecule	IP (eV)
methane	12.98
ethane	11.65
propane	11.07
n-butane	10.63
i-butane	10.57
n-pentane	10.35
i-pentane	10.32
2,2-dimethylpropane	10.35
n-hexane	10.18
2-methylpentane	10.12
3-methylpentane	10.08
2,2-dimethylbutane	10.06
2,3-dimethylbutane	10.02
n-heptane	10.08
2,2,4-trimethylpentane	9.86
cyclopropane	10.06
cyclopentane	10.53
cyclohexane	9.88
methylcyclohexane	9.85

TABLE VII

ALKYL HALIDES

Molecule	IP (eV)
HCl	12.74
Cl_2	11.48
CH_4	12.98
methyl chloride	11.28
dichloromethane	11.35
trichloromethane	11.42
tetrachloromethane	11.47
ethyl chloride	10.98
1,2-dichloroethane	11.12
1-chloropropane	10.82
2-chloropropane	10.78
1,2-dichloropropane	10.87
1,3-dichloropropane	10.85
1-chlorobutane	10.67
2-chlorobutane	10.65
1-chloro-2-methylpropane	10.66
2-chloro-2-methylpropane	10.61
HBr	11.62
Br_2	10.55
methyl bromide	10.53
dibromomethane	10.49
tribromomethane	10.51
CH_2BrCl	10.77
$CHBr_2Cl$	10.59
ethyl bromide	10.29
1,1-dibromoethane	10.19
1-bromo-2-chloroethane	10.63

TABLE VII (Continued)

Molecule	IP (eV)
1-bromopropane	10.18
2-bromopropane	10.075
1,3-dibromopropane	10.07
1-bromobutane	10.13
2-bromobutane	9.98
1-bromo-2-methylpropane	10.09
2-bromo-2-methylpropane	9.89
1-bromopentane	10.10
HI	10.38
I_2	9.28
methyl iodide	9.54
diiodomethane	9.34
ethyl iodide	9.33
1-iodopropane	9.26
2-iodopropane	9.17
1-iodobutane	9.21
2-iodobutane	9.09
1-iodo-2-methylpropane	9.18
2-iodo-2-methylpropane	9.02
1-iodopentane	9.19
F_2	15.7
HF	15.77
$CFCl_3$ (Freon 11)	11.77
CF_2Cl_2 (Freon 12)	12.31
CF_3Cl (Freon 13)	12.91
$CHClF_2$ (Freon 22)	12.45
$CFBr_3$	10.67

TABLE VII (Continued)

Molecule	IP (eV)
CF_2Br_2	11.07
CH_3CF_2Cl (Genetron 101)	11.98
$CFCl_2CF_2Cl$	11.99
CF_3CCl_3 (Freon 113)	11.78
$CFHBrCH_2Br$	10.75
CF_2BrCH_2Br	10.83
CF_3CH_2I	10.00
n-C_3F_7I	10.36
n-$C_3F_7CH_2Cl$	11.84
n-$C_3F_7CH_2I$	9.96

TABLE VIII

ALIPHATIC ALCOHOL, ETHER, THIOL, AND SULFIDES

Molecule	IP (eV)
H_2O	12.59
methyl alcohol	10.85
ethyl alcohol	10.48
n-propyl alcohol	10.20
i-propyl alcohol	10.16
n-butyl alcohol	10.04
dimethyl ether	10.00
diethyl ether	9.53
n-propyl ether	9.27
i-propyl ether	9.20
H_2S	10.46
methanethiol	9.440
ethanethiol	9.285
1-propanethiol	9.195
1-butanethiol	9.14
dimethyl sulfide	8.685
ethyl methyl sulfide	8.55
diethyl sulfide	8.430
di-n-propyl sulfide	8.30

TABLE IX

ALIPHATIC ALDEHYDES AND KETONES

Molecule	IP (eV)
CO_2	13.79
formaldehyde	10.87
acetaldehyde	10.21
propionaldehyde	9.98
n-butyraldehyde	9.86
isobutyraldehyde	9.74
n-valeraldehyde	9.82
isovaleraldehyde	9.71
acrolein	10.10
crotonaldehyde	9.73
benzaldehyde	9.53
acetone	9.69
methyl ethyl ketone	9.53
methyl n-propyl ketone	9.39
methyl i-propyl ketone	9.32
diethyl ketone	9.32
methyl n-butyl ketone	9.34
methyl i-butyl ketone	9.30
3,3-dimethyl butanone	9.17
2-heptanone	9.33
cyclopentanone	9.26
cyclohexanone	9.14
2,3-butanedione	9.23
2,4-pentanedione	8.87

TABLE X

ALIPHATIC ACIDS AND ESTERS

Molecule	IP (eV)
CO_2	13.79
formic acid	11.05
acetic acid	10.37
propionic acid	10.24
n-butyric acid	10.16
isobutyric acid	10.02
n-valeric acid	10.12
methyl formate	10.815
ethyl formate	10.61
n-propyl formate	10.54
n-butyl formate	10.50
isobutyl formate	10.46
methyl acetate	10.27
ethyl acetate	10.11
n-propyl acetate	10.04
isopropyl acetate	9.99
n-butyl acetate	10.01
isobutyl acetate	9.97
sec-butyl acetate	9.91
methyl propionate	10.15
ethyl propionate	10.00
methyl n-butyrate	10.07
methyl isobutyrate	9.98

TABLE XI

ALIPHATIC AMINES AND AMIDES

Molecule	IP (eV)
NH_3	10.15
methyl amine	8.97
ethyl amine	8.86
n-propyl amine	8.78
i-propyl amine	8.72
n-butyl amine	8.71
i-butyl amine	8.70
s-butyl amine	8.70
t-butyl amine	8.64
dimethyl amine	8.24
diethyl amine	8.01
di-n-propyl amine	7.84
di-i-propyl amine	7.73
di-n-butyl amine	7.69
trimethyl amine	7.82
triethyl amine	7.50
tri-n-propyl amine	7.23
formamide	10.25
acetamide	9.77
N-methyl acetamide	8.90
N,N-dimethyl formamide	9.12
N,N-dimethyl acetamide	8.81
N,N-diethyl formamide	8.89
N,N-diethyl acetamide	8.60

TABLE XII

OTHER ALIPHATIC MOLECULES WITH N ATOM

Molecule	IP (eV)
nitromethane	11.08
nitroethane	10.88
1-nitropropane	10.81
2-nitropropane	10.71
HCN	13.91
acetonitrile	12.22
propionitrile	11.84
n-butyronitrile	11.67
acrylonitrile	10.91
3-butene-nitrile	10.39
ethyl nitrate	11.22
n-propyl nitrate	
methyl thiocyanate	10.065
ethyl thiocyanate	9.89
methyl isothiocyanate	9.25
ethyl isothiocyanate	9.14

TABLE XIII

OLEFINS, CYCLO-OLEFINS, POLENES, ACETYLENES

Molecule	IP (eV)
ethylene	10.515
propylene	9.73
1-butene	9.58
2-methylpropene	9.23
trans-2-butene	9.13
cis-2-butene	9.13
1-pentene	9.50
2-methyl-1-butene	9.12
3-methyl-1-butene	9.51
3-methyl-2-butene	8.67
1-hexene	9.46
1,3-butadiene	9.07
isoprene	8.845
cyclopentene	9.01
cyclohexene	8.945
4-methylcyclohexene	8.91
4-cinylcyclohexene	8.93
cyclo-octatetraene	7.99
acetylene	11.41
propyne	10.36
1-butyne	10.18

TABLE XIV

SOME DERIVATIVES OF OLEFINS

Molecule	IP (eV)
vinyl chloride	9.995
cis-dichloroethylene	9.65
trans-dichloroethylene	9.66
trichloroethylene	9.45
tetrachloroethylene	9.32
vinyl bromide	9.80
1,2-dibromoethylene	9.45
tribromoethylene	9.27
3-chloropropene	10.04
2,3-dichloropropene	9.82
1-bromopropene	9.30
3-bromopropene	9.7
$CF_3CCl{=}CClCF_3$	10.36
$n\text{-}C_5F_{11}CF{=}CF_2$	10.48
acrolein	10.10
crotonaldehyde	9.73
mesityl oxide	9.08
vinyl methyl ether	8.93
allyl alcohol	9.67
vinyl acetate	9.19

TABLE XV

HETEROCYCLIC MOLECULES

Molecule	IP (eV)
furan	8.89
2-methyl furan	8.39
2-furaldehyde	9.21
tetrahydrofuran	9.54
dihydropyran	8.34
tetrahydropyran	9.26
thiophene	8.860
2-chlorothiophene	8.68
2-bromothiophene	8.63
pyrrole	8.20
pyridine	9.32
2-picoline	9.02
3-picoline	9.04
4-picoline	9.04
2,3-lutidine	8.85
2,4-lutidine	8.85
2,6-lutidine	8.85

TABLE XVI

AROMATIC COMPOUNDS

Molecule	IP (eV)
benzene	9.245
toluene	8.82
ethyl benzene	8.76
n-propyl benzene	8.72
i-propyl benzene	8.69
n-butyl benzene	8.69
s-butyl benzene	8.68
t-butyl benzene	8.68
o-xylene	8.56
m-xylene	8.56
p-xylene	8.445
mesitylene	8.40
durene	8.025
styrene	8.47
α-methyl styrene	8.35
ethynylbenzene	8.815
napthalene	8.12
1-methylnapthalene	7.96
2-methylnapthalene	7.955
biphenyl	8.27
phenol	8.50
anisole	8.22
phenetole	8.13
benzaldehyde	9.53
acetophenone	9.27
benzenethiol	8.33
phenyl isocyanate	8.77

TABLE XVI (Continued)

Molecule	IP (eV)
phenyl isothiocyanate	8.520
benzonitrile	9.705
nitrobenzene	9.92
aniline	7.70
fluoro-benzene	9.195
chloro-benzene	9.07
bromo-benzene	8.98
iodo-benzene	8.73
o-dichlorobenzene	9.07
m-dichlorobenzene	9.12
p-dichlorobenzene	8.94
1-chloro-2-fluorobenzene	9.155
1-chloro-3-fluorobenzene	9.21
1-bromo-4-fluorobenzene	8.99
o-fluorotoluene	8.915
m-fluorotoluene	8.915
p-fluorotoluene	8.785
o-chlorotoluene	8.83
m-chlorotoluene	8.83
p-chlorotoluene	8.70
o-bromotoluene	8.79
m-bromotoluene	8.81
p-bromotoluene	8.67
o-iodotoluene	8.62
m-iodotoluene	8.61
p-iodotoluene	8.50
benzotrifluoride	9.68
o-fluorophenol	8.66

TABLE XVII

MISCELLANEOUS MOLECULES

Molecule	IP (eV)
ethylene oxide	10.565
propylene oxide	10.22
p-dioxane	9.13
dimethoxymethane	10.00
diethoxymethane	9.70
1,1-dimethoxyethane	9.65
propiolactone	9.70
methyl disulfide	8.46
ethyl disulfide	8.27
diethyl sulfite	9.68
thiolacetic acid	10.00
acetyl chloride	11.02
acetyl bromide	10.55
cyclo-$C_6H_{11}CF_3$	10.46
(n-C_3F_7)(CH_3)C=0	10.58
trichlorovinylsilane	10.79
$(C_2F_5)_3N$	11.7
isoprene	9.08
phosgene	11.77

TABLE XVIII

RELATIVE SENSITIVITIES FOR VARIOUS GASES
(10.2 eV Lamp)

Species	Photoionization Sensitivity*
p-xylene	11.4
m-xylene	11.2
benzene	10.0 (reference standard)
toluene	10.0
diethyl sulfide	10.0
diethyl amine	9.9
styrene	9.7
trichloroethylene	8.9
carbon disulfide	7.1
isobutylene	7.0
acetone	6.3
tetrahydrofuran	6.0
methyl ethyl ketone	5.7
methyl isobutyl ketone	5.7
cyclohexanone	5.1
naptha (86% aromatics)	5.0
vinyl chloride	5.0
methyl isocyanate	4.5
iodine	4.5
methyl mercaptan	4.3
dimethyl sulfide	4.3
allyl alcohol	4.2

TABLE XVIII (continued)

Species	Photoionization Sensitivity*
propylene	4.0
mineral spirits	4.0
2,3-dichloropropene	4.0
cyclohexene	3.4
crotonaldehyde	3.1
acrolein	3.1
pyridine	3.0
hydrogen sulfide	2.8
ethylene dibromide	2.7
n-octane	2.5
acetaldehyde oxime	2.3
hexane	2.2
phosphine	2.0
heptane	1.7
allyl chloride (3-chloropropene)	1.5
ethylene	1.0
ethylene oxide	1.0
acetic anhydride	1.0
α pinene	0.7
dibromochloropropane	0.7
epichlorohydrin	0.7
nitric oxide	0.6
β pinene	0.5
citral	0.5
ammonia	0.3

TABLE XVIII (continued)

Species	Photoionization Sensitivity*
acetic acid	0.1
nitrogen dioxide	0.02
methane	0.0
acetylene	0.0
ethylene	0.0

*Expressed in ppm (v/v).

SECTION 5

TROUBLESHOOTING

If problems occur while using the photoionization analyzer, it is recommended that the following troubleshooting guide be followed before consulting the factory.

5.1 General Aid to Fault Determination

Check battery condition. Recharge if necessary (Section 2). Turn the instrument on. Look into the Sample Inlet of the probe unit. A violet colored glow from the UV light source should be observed in all positions of the mode switch except the standby position. If unstable readings are obtained a faulty probe cable or electrical connection could be the problem. To check, hold the probe normally and flex the cable firmly. Watch the meter for fluctuations as the cable is stressed. Individual wires in the readout can be checked in a similar way. Check the coaxial connector on the amplifier board in the probe.

In the more sensitive ranges, a fluctuation in the reading may be noted if a hand or other large object is placed in very close proximity to the probe. This is normal for the instrument and will not result in an error in the measurement as long as the probe is held stationary while the measurement is being taken.

If the probe is held close to AC power lines or power transformers an error may be observed. If measurements are to be made in close proximity to such items, their effect on measurements can be determined by the following procedure. Zero the instrument in an electrically quiet area in the standby position, then move the instrument to the questionable area involved. If AC pickup is going to be a problem, the meter (in the standby position) will indicate the magnitude of the error.

5.2 Disassembly of Instrument

PROBE - Turn the function switch to the OFF position and disconnect the probe connector from the readout unit. Remove the exhaust screw found near the base of the probe (see Figure 8.) Grasp the end cap in one hand and the probe shell in the other, and gently pull to separate the end cap and lamp housing from the shell. Loosen the screws on the top of the end cap and separate the end cap and ion chamber from the lamp and lamp housing. Care must be taken so that the ion chamber doesn't fall out of the end cap and the lamp doesn't slide out of the lamp housing. Turn the end cap over in your hand and tap on the top of it; the ion chamber should fall out in your hand. Place one hand over the top of the lamp housing and tilt slightly; the light source will slide out of the housing. The amplifier board can be removed from the lamp housing assembly by unsnapping the coaxial connection and then removing the retaining screw.

To reassemble this unit, first slide the lamp back into the lamp housing. Place the ion chamber on top of the lamp housing, checking to make sure that the contacts are properly aligned. Place the end cap on top of the ion chamber and replace the two screws. The screws should be tightened only enough to seal the "O" ring. DO NOT OVERTIGHTEN. Line up the pins on the base of the lamp housing with the pins inside the probe shell. Gently slide the housing assembly into the probe shell. DO NOT FORCE the assembly into the shell as it only fits one way.

READOUT UNIT - Turn the function switch to the OFF position and disconnect the probe from the readout unit before disassembly is conducted (see Figure 10). Remove the accessory power jack plug. Loosen the screw on the bottom of the case and, holding the instrument by the bezel, remove the case. The power supply board and control panel can be removed by unscrewing two screws and two nuts. The entire panel, including the function switch, zero and span pots is removed in this operation. Electrically disconnecting this module is simple, since all connections are made with Molex connectors.

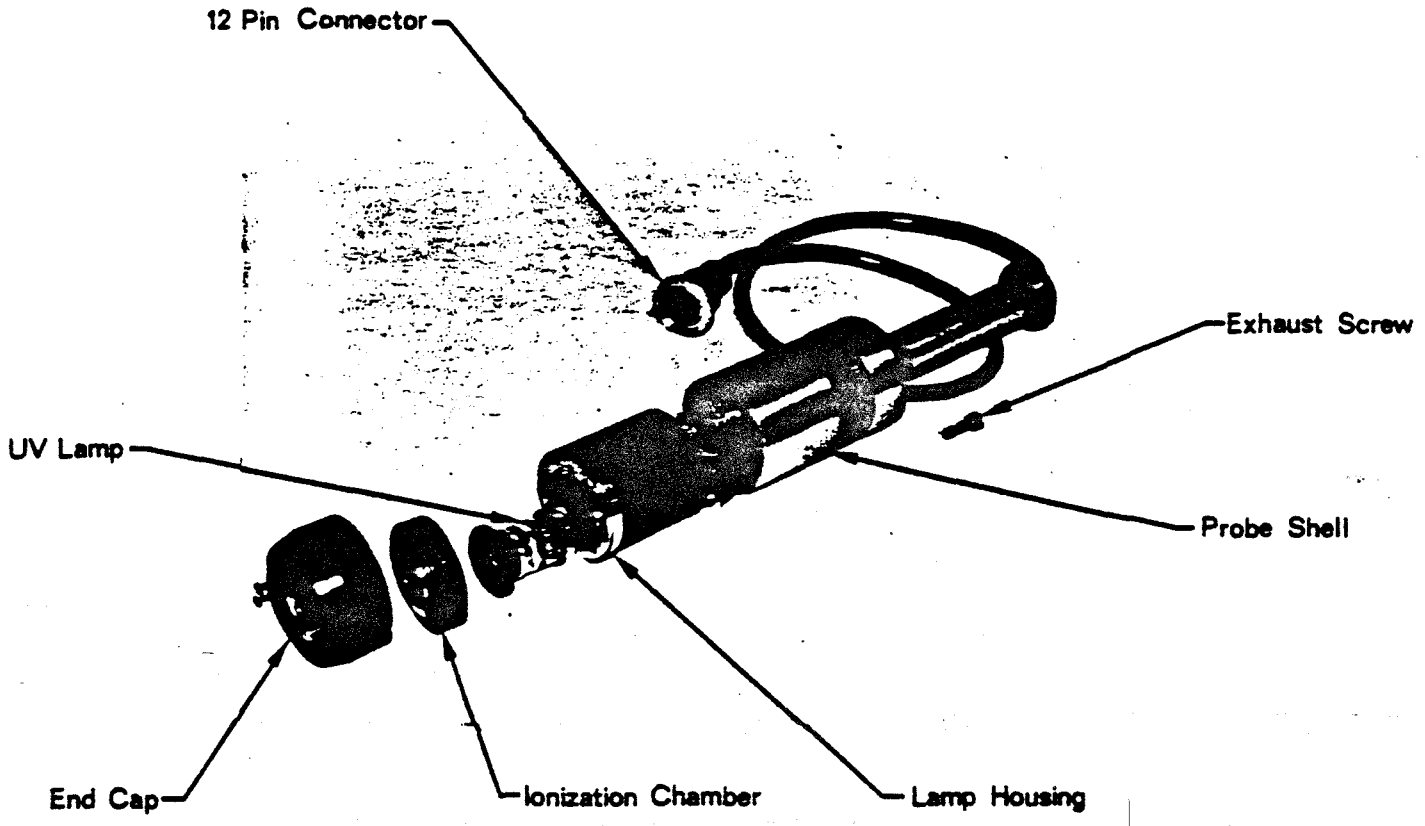


Figure 8. Component Parts of Probe

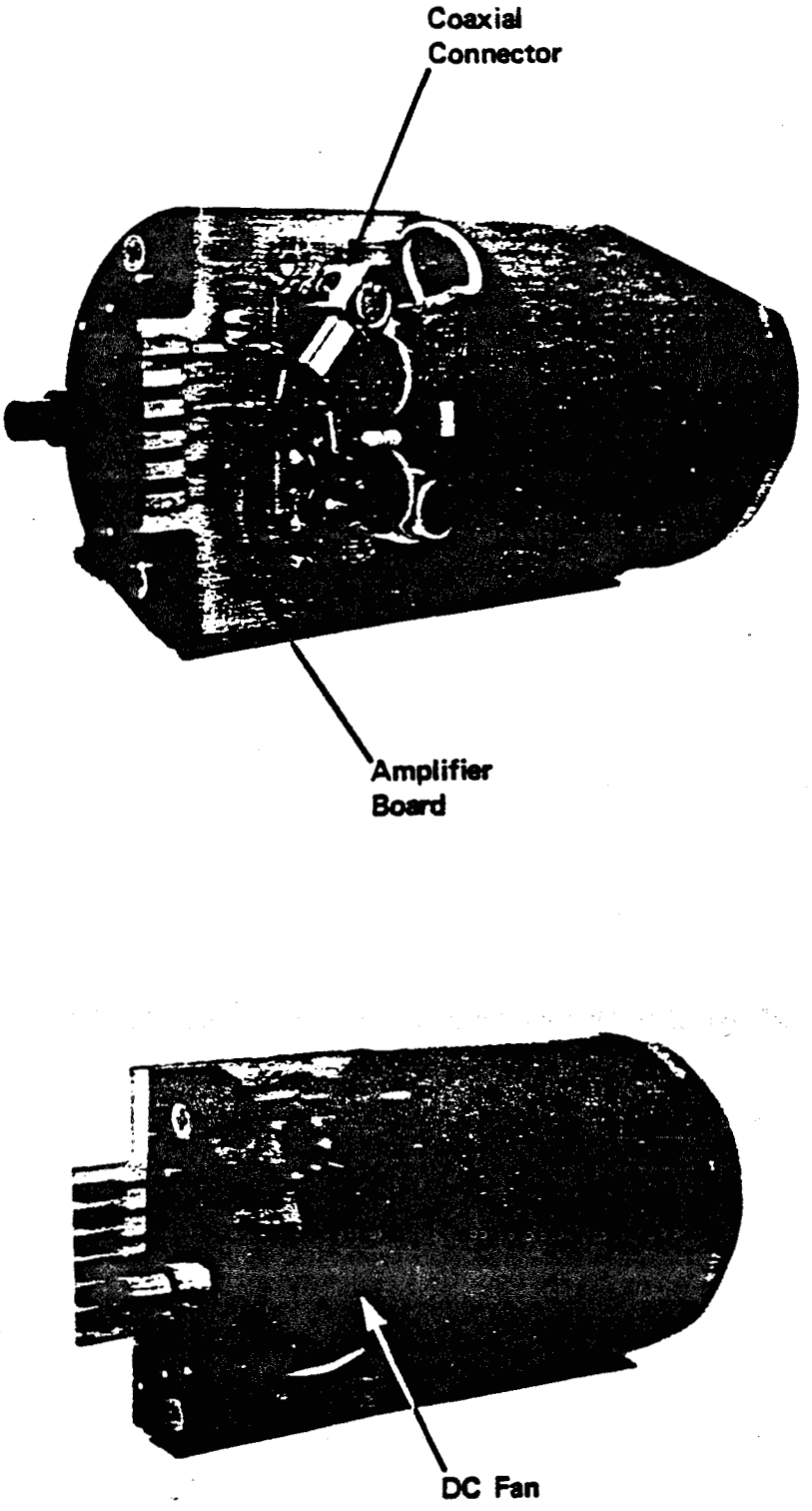


Figure 9. Component Parts of Lamp Housing.

5.3 Specific Faults

1. No meter response in any switch position (including BATT CHK)

   A. Broken meter movement

      (1) Tip instrument rapidly from side to side. Meter needle should move freely, and return to zero.

   B. Electrical connection to meter is broken

      (1) Check all wires leading to meter and clean the contacts of quick-disconnects.

   C. Battery is completely dead

      (1) Disconnect battery and check voltage with a volt-ohm meter.

   D. Check 2 amp fuse

   E. If none of the above solves the problem, consult the factory.

2. Meter responds in BATT CHK position, but reads zero or near zero for all others

   A. Power supply defective

      (1) Check power supply voltages per Figure 11. If any voltage is out of specification, consult the factory.

   B. Input transistor or amplifier has failed

      (1) Rotate zero control; meter should deflect up/down as control is turned.

      (2) Open probe. Both transistors should be fully seated in sockets

   C. Input signal connection broken in probe or readout

      (1) Check input connector on printed circuit board. Should be firmly pressed down.

      (2) Check components on back side of printed circuit board. All connections should be solid, and no wires should touch any other object.

      (3) Check all wires in readout for solid connections.

3. Instrument responds correctly in BATT CHK, AND STBY, but not in measuring mode.

   A. Check to see that light source is on (See General Faults section.)

      (1) Check high voltage power supply (see Figure 11).

      (2) Open end of probe, remove lamp and check high voltage on lamp contact ring.

      (3) If high voltage is present at all above points, light source has most likely failed. Consult the factory.

4. Instrument responds correctly in all positions, but signal is lower than expected.

   A. Check span setting for correct value.

   B. Clean window of light source

   C. Double check preparation of standards. See Section 3.

   D. Check power supply 180 V output. See Figure 11.

   E. Check for proper fan operation. Check fan voltage. See Figure 11.

   F. Rotate span setting. Response should change if span pot is working properly.

5. Instrument responds in all switch positions, but is noisy (erratic meter movement).

   A. Open circuit in feedback circuit. Consult the factory.

   B. Open circuit in cable shield or probe shield. Consult the factory.

6. Instrument response is slow and/or irreproducible.

   A. Fan operating improperly. Check fan voltage. See Figure 11.

   B. Check calibration and operation. See Sections 2 and 3.

7. Low battery indicator.

   A. Indicator comes on if battery charge is low.

   B. Indicator also comes on if ionization voltage is too high.

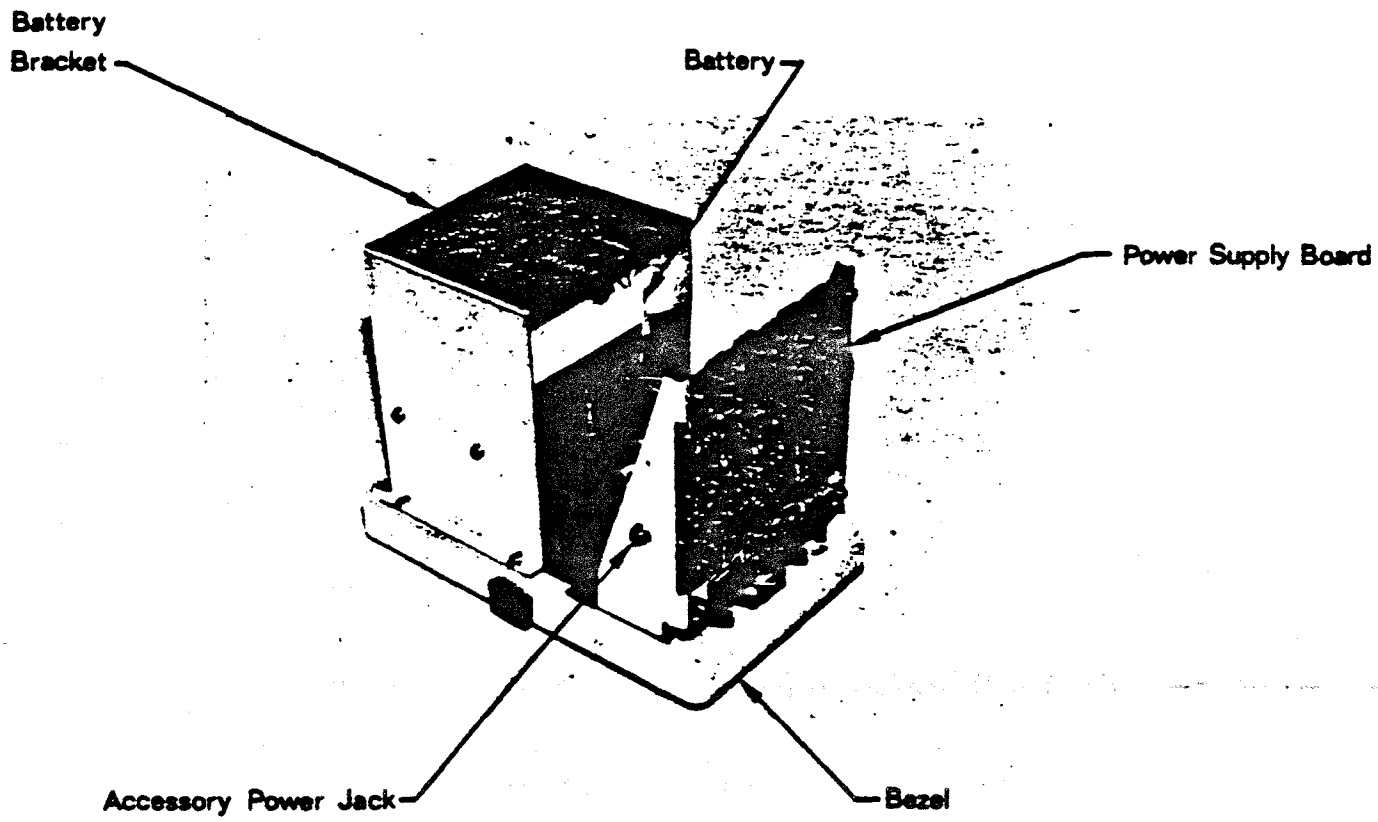
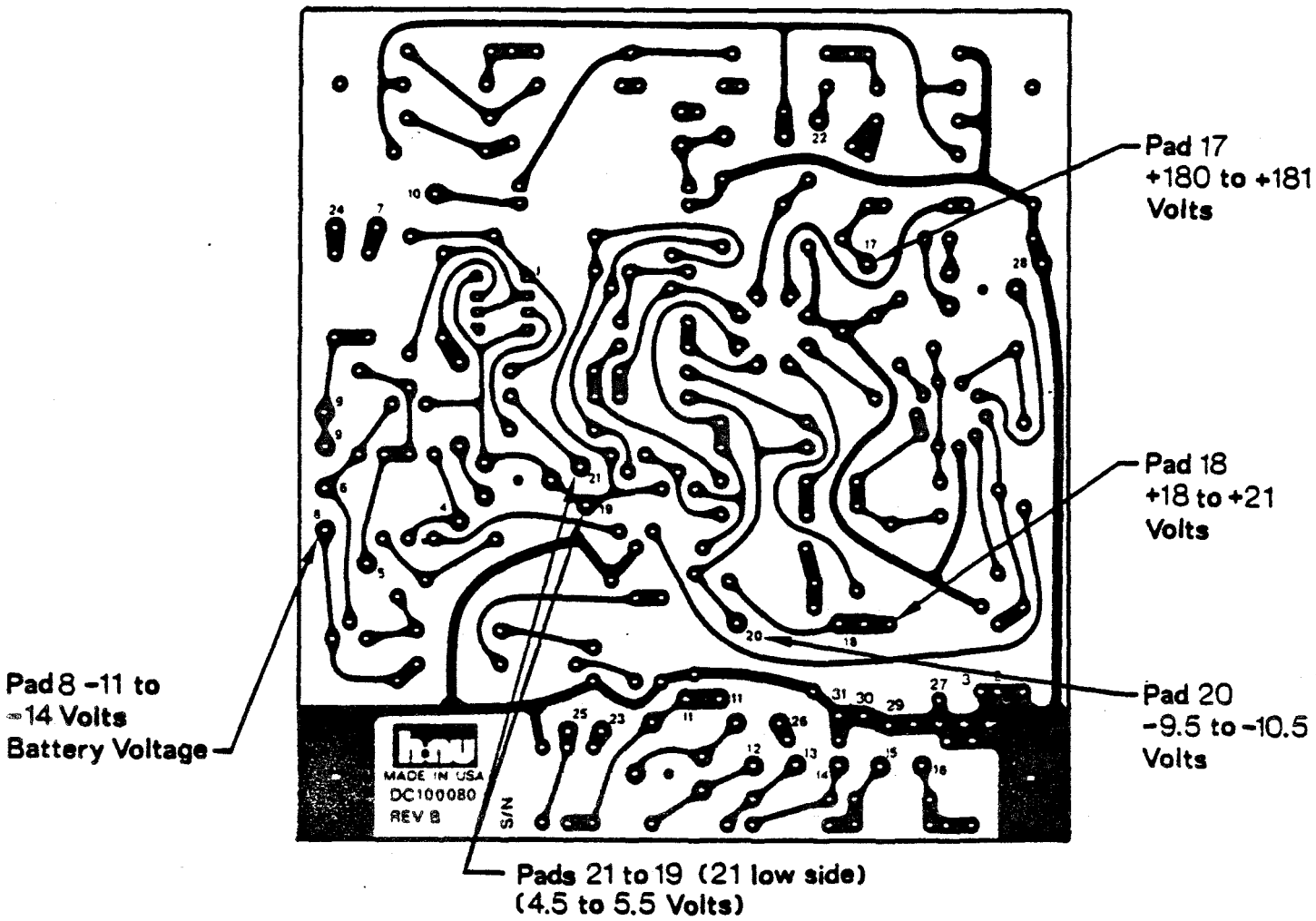


Figure 10. Component Parts Of Readout Unit.

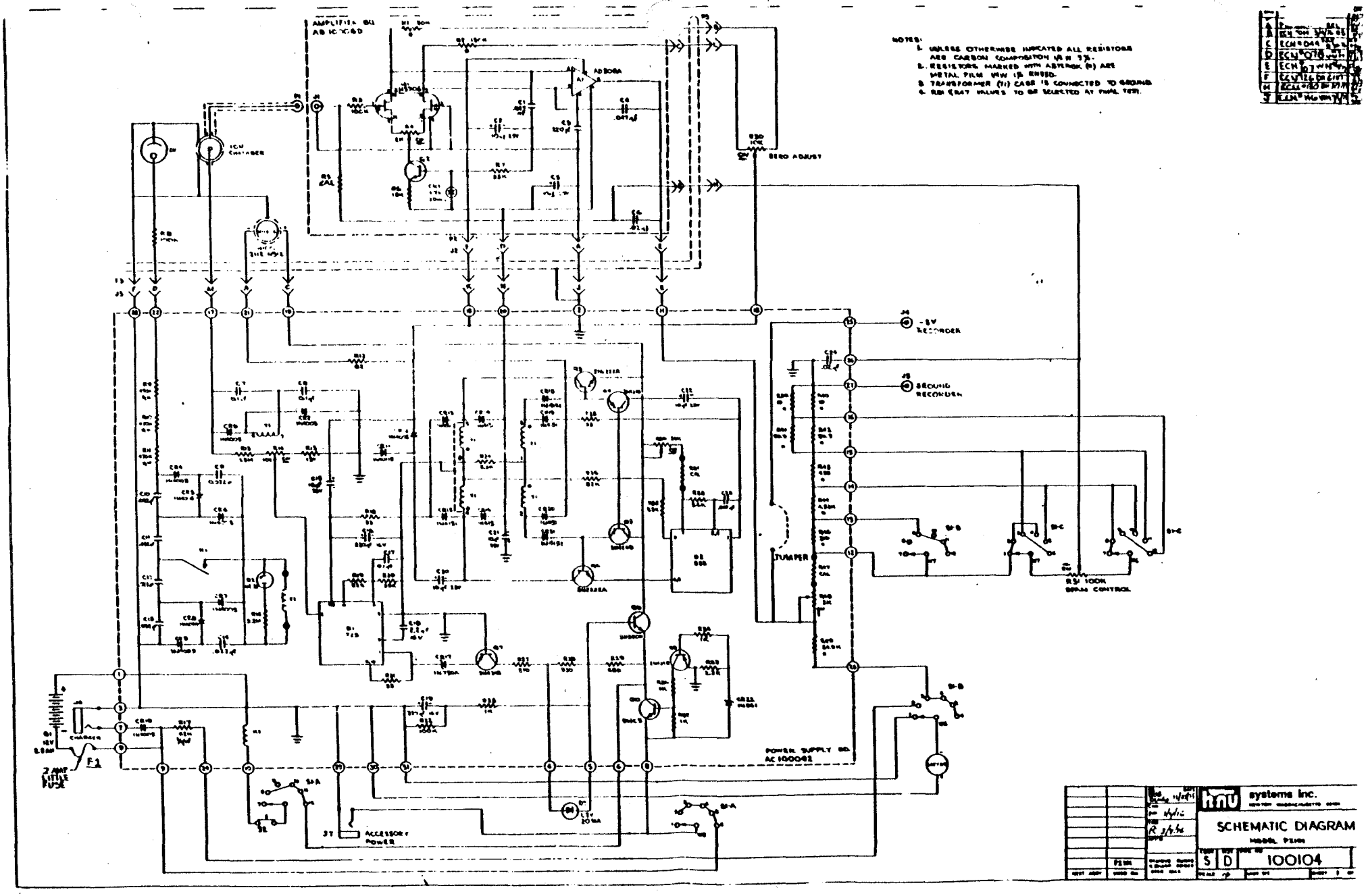
1. All voltages measured with probe connected and instrument mode switch in BATT CHK position.

2. All measurements referred to ground (pads 2,3 and 27) except pad 21 measured to pad 19 and pad 8 to pad 11.



All Voltages Respect to Ground							
pads	voltage	pads	voltage	pads	voltage	pads	voltage
1	− 5.7V	9	− 12.2V	17	180V	25	0
2	GRD	10	− 12.1V	18	− 19.4V	26	0
3	GRD	11	0	19	− 10.6V	27	GRD
4	−10 7V	12	0	20	− 9.7V	28	0
5	− 11.3V	13	0	21	−14.5V	29	GRD
6	− 12.1V	14	0	22	−400V	30	GRD
7	0	15	0	23	0	31	GRD
8	− 12.2V	16	0	24	0		

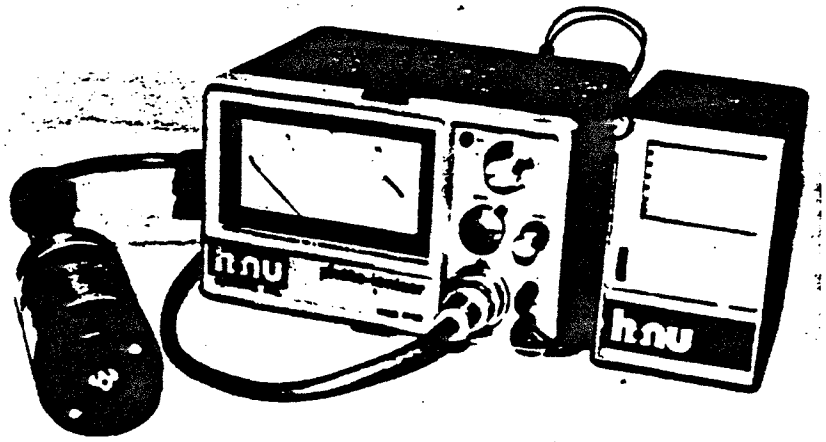
Figure 11 Power Supply PC Board


NOTES:
1. UNLESS OTHERWISE INDICATED ALL RESISTORS ARE CARBON COMPOSITION 1/4 W 5%.
2. RESISTORS MARKED WITH ASTERISK (*) ARE METAL FILM 1/4W 1% RN55D.
3. TRANSFORMER (T1) CASE IS CONNECTED TO GROUND.
4. R51 & R47 VALUES TO BE SELECTED AT FINAL TEST.
AMPLIFIER BD AB 100060
ADSORA
ZERO ADJUST
ION CHAMBER
-5V RECORDER
GROUND RECORDER
JUMPER
R51 100K SPAN CONTROL
POWER SUPPLY BD. AC 100062
CHARGER
2 AMP LITTLE FUSE
F1
ACCESSORY POWER
hnu systems inc.
SCHEMATIC DIAGRAM
S
D
100104

SECTION 6

REPLACEMENT PARTS LIST

Part No.	Assembly
00004A	Probe Shell Assembly
100005A	Ion Chamber
00006A	Fan/Light Source Housing
100007A	Amplifier Board
100008A	Fan
00009A	Light Source (10.2 eV)
100010A	"O" Ring Kit
00011A	Battery
00012A	Meter
100013A	Charger
00014A	Power Supply Unit
100015A & 00016A	Case (both halves)
100017A & 00018A	Straps
100019A	Switch
00020A	Pot (span)
4750-0001A	Pot (zero)
00074	Probe Extension

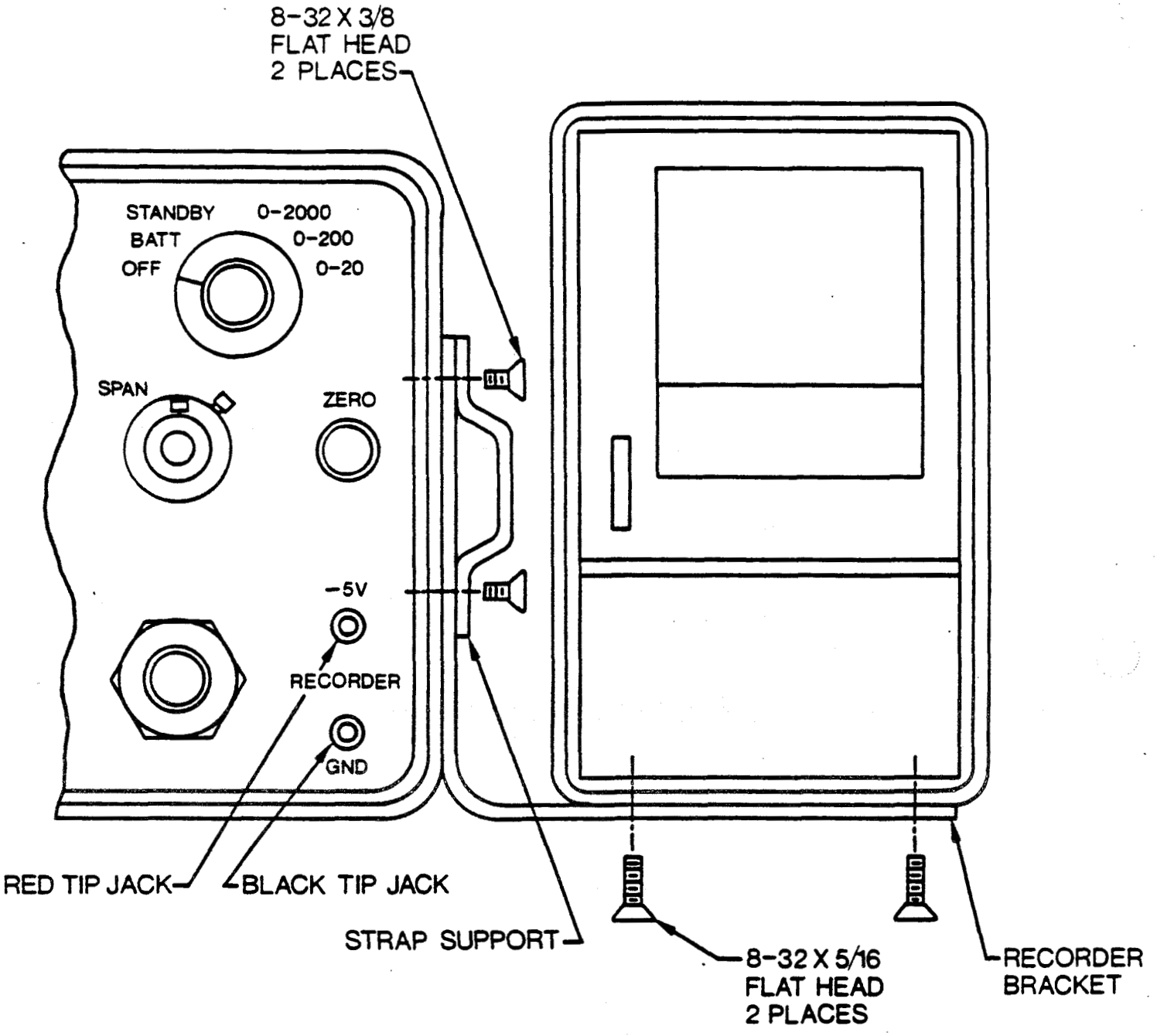


SECTION 7

MODEL PI101 PHOTOIONIZATION ACCESSORIES

101-300	Portable Recorder, having a 2" chart width with 2"/hour chart speed. Operates on 12 VDC power from Model PI101. Complete with multiconductor interface cable for battery power & signal and mounting bracket for attaching recorder to side of PI101.
101-301	Chart Paper, for portable recorder, 6 rolls.
101-320	Audible Alarm, 85 decibels, adjustable 0 to 100% of full scale on any range.
101-350	Calibration Gas Cylinder, contains 23 liters of span gas in air (300 psi) sufficient for 40-50 calibrations. (4" diameter by 12" high).
101-351	Regulator, for use with calibration gas cylinder, Model 101-350 complete with gauges for reading both cylinder pressure and flow.
101-500	Cleaning Compound, for removing deposits from window of UV lamp

SECTION 8
PI-101 RECORDER ASS'Y
INSTRUCTIONS



OTES:

1. Remove strap support on right side of PI-101 case.

. Mount recorder bracket between case & strap support using 8-32 X 3/8 long screws supplied.

3. Mount recorder to bracket using 8-32 X 5/16 screws supplied.

. Connect harness to plug on rear of recorder. Insert power plug into receptacle on side of case. Insert red pin plug into red tip jack and black pin plug into black tip jack on PI-101 front panel.

SECTION 9

WARRANTY

HNU Systems Incorporated warrants that all items delivered under this order will be free from defects in material and workmanship when used under normal operating conditions. HNU's liability hereunder shall be limited to the repair or replacement of the articles ascertained to be defective within one (1) year after date of shipment (except that the light source warranty is limited to three (3) months and does not include breakage, and battery warranty is limited to three (3) months), provided, however that the Buyer shall give notice to HNU within thirty (30) days after discovery of such defective material and provided further that all defective material be shipped prepaid to the HNU plant within a reasonable time from the date of discovery of the defect and during such warranty period. After the repair or replacement, HNU will ship the said item to Buyer, transportation charges prepaid, to any point in the United States that Buyer may designate.

THE FOREGOING IS THE SOLE EXTENT OF HNU'S WARRANTY AND NO OTHER STATEMENTS OR WARRANTIES, EXPRESSED OR IMPLIED, SHALL BE HONORED. UNDER NO CIRCUMSTANCES SHALL HNU BE SUBJECT TO ANY LIABILITY FOR SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES.

Publications on Photoionization Available from HNU Systems

(1) Driscoll, J. N. and P. Warneck, "The Analysis of ppm Levels of Gases in Air by Photoionization Mass Spectrometry," J. Air Poll. Cont. Assoc. *23*, 858 (1973).

(2) Driscoll, J. N. and F. F. Spaziani, "A New Instrument for Continuous Monitoring of Odorous Sulfur Compounds," presented at the ISA National Meeting, N.Y. (Oct. 1974).

(3) Driscoll, J. N. and F. F. Spaziani, "Trace Gas Analysis by Photoionization" presented at the ISA Analysis Instrumentation Div. Meeting, King of Prussia, Pa. (May 1975).

(4) Photoionization Detector for Gas Chromatography," presented at the Pittsburgh Conf. on Anal. Chem. and Spectroscopy, Cleveland (March 1976).

Requests for these papers should be sent to:

Publications Department
HNU Systems Inc.
30 Ossipee Road
Newton, MA 02164
USA

ADDENDUM

The following changes to the Instruction Manual should be noted for all Model 101 Photoionization Analyzers equipped with 11.7, 9.5 eV light sources, or calibrated on species other than benzene.

<u>Page</u>

3 Table I

Performance: Consult specifications sheet accompanying instrument.

11 Paragraph 2: Consult specifications sheet for span setting specific for gas on which instrument was calibrated.

NOTE: Gain settings listed apply to 10.2 eV lamp. Different gain settings are used with other lamps. Consult factory.

13 Table III

NOTE: Data obtained using 10.2 eV lamp.

14 Table IV

NOTE: Data obtained using 10.2 eV lamp.

18 Figure 4

NOTE: Data obtained using 10.2 eV lamp.

24 Paragraph 1, Line 6: "The photons which are emitted from the lamp, pass through a UV transmitting window and into the ionization chamber where absorption of the UV radiation by a molecule which has an ionization potential equal to or less than the energy of the light source will lead to ion formation via;" (continued)

25 Figure 7: For the 9.5 eV light source, the lamp voltage changes to +450 volts.

ADDENDUM A

to

Instruction Manual

for

Model PI 101

PHOTOIONIZATION ANALYZER

ION CHAMBER CLEANING PROCEDURE

Although the technique of photoionization is not sensitive to moisture, some electronic instability can be seen in the 101 portable analyzer as the result of excessive moisture. The following chart lists the symptoms expected, the possible causes, and solutions:

Symptom	Possible Cause	Solution
Loss in sensitivity	Condensation on instrument window	Avoid extreme temperature changes
		Acclimatize instrument to environment
Zero drift	Condensation on polarizing electrode	"
	Ion chamber is dirty	Clean ion chamber

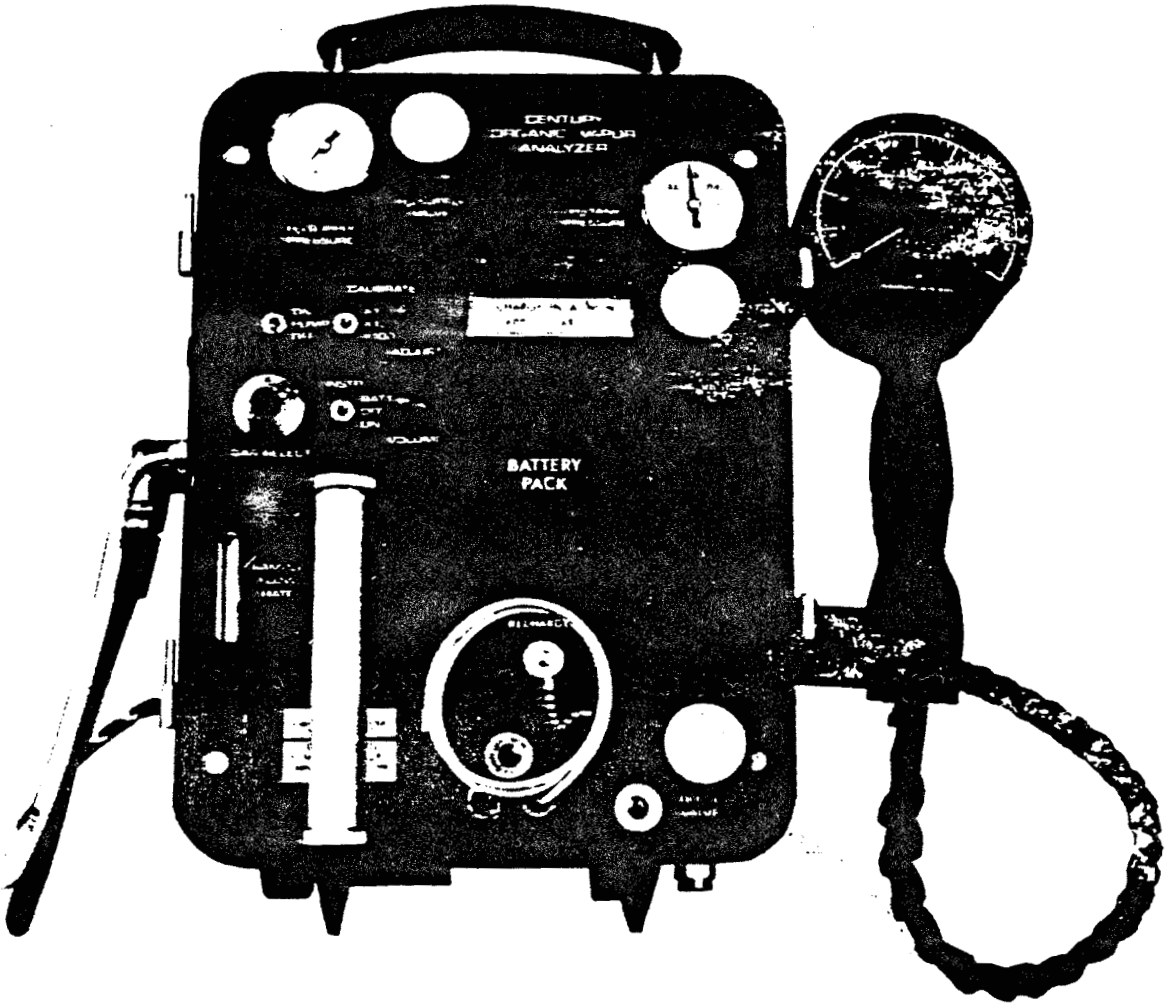
To clean the ion chamber: (See Section 5.2)

Remove the ion chamber. Remove all four screws, swing screen aside, and pull out the mesh. Using a Q-tip, gently clean the chamber with methanol to remove deposit . Dry in a vacuum oven at 90°C for 2 hours. Reassemble.

Instruction & Service Manual

MI

2R900AC



CENTURY SYSTEMS

Portable Organic Vapor Analyzer
Model OVA-128

Foxboro Analytical
A Division of The Foxboro Company

FOXBORO®

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INTRODUCTION

The Century Model OVA-128 Portable Organic Vapor Analyzer (OVA) is a highly sensitive instrument designed to measure trace quantities of organic materials in air. It is essentially a hydrogen flame ionization detector such as utilized in laboratory gas chromatographs and has similar analytical capabilities. The flame ionization detector is an almost universal detector for organic compounds with the sensitivity to analyze for them in the parts per million range (V/V) in air in the presence of moisture, nitrogen oxides, carbon monoxide and carbon dioxide.

The instrument has broad application, since it has a continuous, chemically resistant air sampling system and can be readily calibrated to measure almost all organic vapors. It has a single linearly scaled readout from 0 ppm to 10 ppm with a X1, X10, X100 range switch. Designed for use as a portable survey instrument, it can also be readily adapted to fixed remote monitoring or mobile installations. It is ideal for the determination of many organic air pollutants and in the monitoring of air in potentially contaminated areas.

The OVA-128 is certified intrinsically safe by Factory Mutual Research Corporation (FM) for use in Class I, Division 1, Groups A, B, C & D hazardous environments. Similar foreign certifications have been obtained, including BASEEFA and Cerchar approval for Group IIC, Temperature Class T4 and equivalent approval from the Japanese Ministry of Labor. This requirement is especially significant in industries where volatile flammable petroleum or chemical products are manufactured, processed or used and for instruments which are actually used in portable surveying and in analyzing concentrations of gases and vapors. Such instruments must be incapable, under normal or abnormal conditions, of causing ignition of the hazardous atmospheric mixtures. In order to maintain the certified safety, it is important that the precautions outlined in this manual be practiced and that no modification be made to these instruments.

Sections 1 through 6 herein apply to the basic instrument. Section 7 contains information relative to options which are available and which may or may not have been purchased with your OVA.

It is highly recommended that the entire manual be read before operating the instrument. It is essential that all portions relating to safety of operation and maintenance, including Section 5, be thoroughly understood.

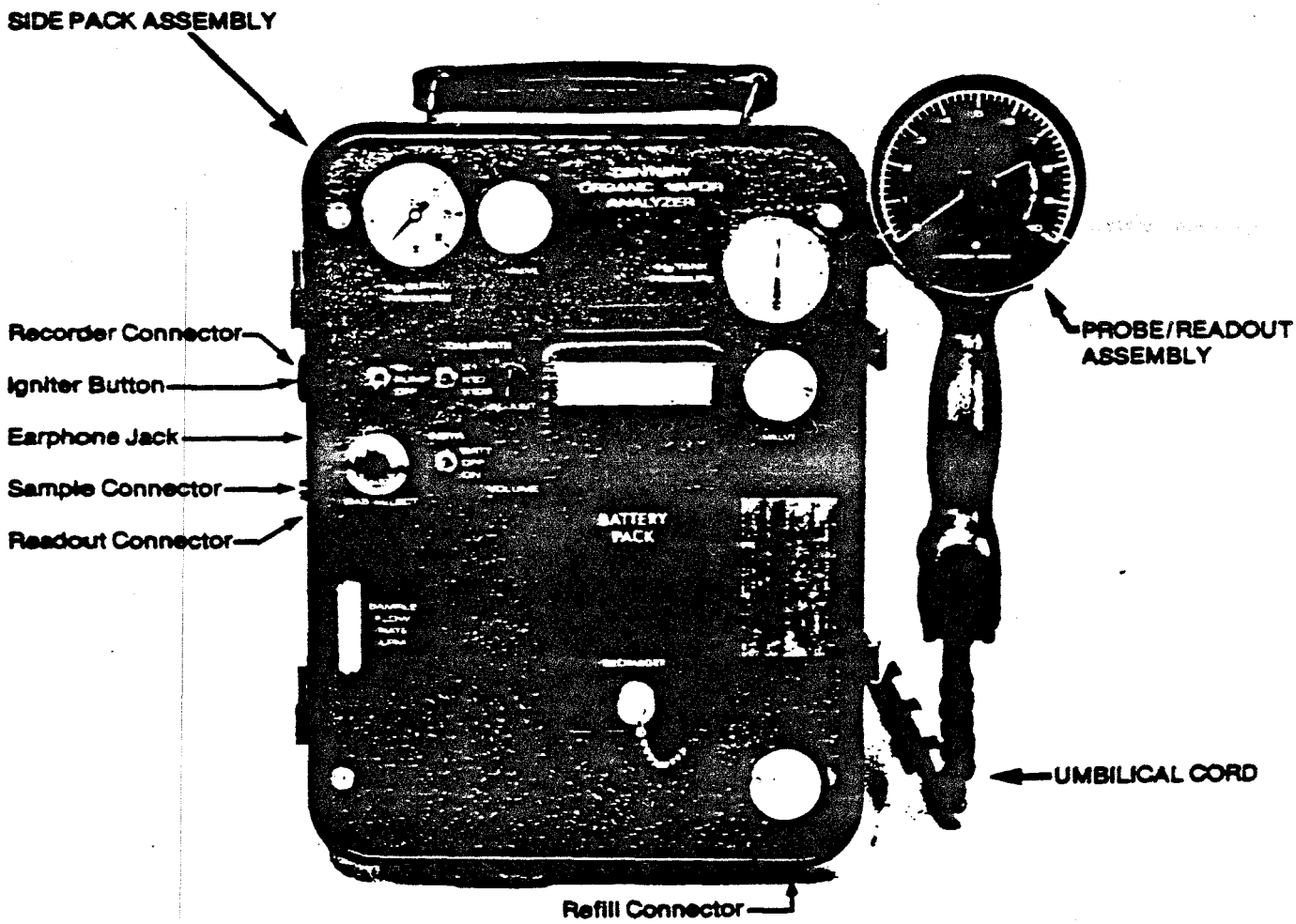


FIGURE 1-1. PORTABLE ORGANIC VAPOR ANALYZER
Model OVA-128

CENTURY SYSTEMS

SECTION 1

DESCRIPTION AND LEADING PARTICULARS

1.1 GENERAL

The Century Portable Organic Vapor Analyzer (OVA), illustrated in Figure 1-1, is designed to detect and measure hazardous gases found in almost all industries. It has broad application, since it has a chemically resistant sampling system and can be calibrated to almost all organic vapors. It is extremely sensitive and can provide accurate indication of gas concentration in one of three ranges: 0 to 10 ppm; 0 to 100 ppm; and 0 to 1,000 ppm. While designed as a lightweight portable instrument, it can readily be adapted to remote monitoring applications.

The instrument utilizes the principle of hydrogen flame ionization for detection and measurement of organic vapors. The instrument measures organic vapor concentration by producing a response to an unknown sample, which can be related to a gas of known composition to which the instrument has previously been calibrated. During normal survey mode operation, a continuous sample is drawn into the probe and transmitted to the detector chamber by an internal pumping system. The sample flow rate is metered and passed through particle filters before reaching the detector chamber. Inside the detector chamber, the sample is exposed to a hydrogen flame which ionizes the organic vapors. When most organic vapors burn, they leave positively charged carbon-containing ions which are collected by a negative collecting electrode in the chamber. An electric field exists between the conductors surrounding the flame and the collecting electrode which drives the ions to the collecting electrode. As the positive ions are collected, a current corresponding to the collection rate is generated on the input electrode. This current is measured with a linear electrometer preamplifier which has an output signal proportional to the ionization current. A signal conditioning amplifier is used to amplify the signal from the preamp and to condition it for subsequent meter or external recorder display. The meter display is an integral part of the Probe/Readout Assembly and has a scale from 0 to 10.

1.2 TYPICAL APPLICATIONS

(1) Measurement of most toxic organic vapors present in industry for compliance with Occupational Safety and Health Administration (OSHA) requirements.
(2) Process monitoring and evaluation.
(3) Evaluation and monitoring applications in the air pollution field.
(4) Leak detection in storage, transportation and handling equipment.
(5) Survey of gas distribution and transmission lines and equipment for compliance with Office of Pipeline Safety (OPS) requirements.
(6) Forensic science applications.

1.3 OTHER TYPICAL USES

(1) Controlling and monitoring atmospheres in manufacturing and packaging operationr
(2) Mudlogging, gas and mineral exploration.
(3) Leak detection related to volatile fuel handling equipment.

1.4 MAJOR FEATURES

The basic instrument consists of two majo assemblies, the Probe/Readout Assembly and the Side Pack Assembly (see Figure 1-1). The recorder is op tional on all models, but is normally used with all in struments which incorporate the GC Option. The outpu meter and alarm level adjustments are incorporated i the Probe/Readout Assembly which is operated witt one hand. The Side Pack Assembly contains the re maining operating controls and indicators, the elec tronic circuitry, detector chamber, hydrogen fuel suppl and electrical power supply. It is a quantitative type ir strument with sensitivity to 0.1 ppm methane.

Other major features are: 250° linear scale readou less than two second response time and minimum eigh hour service life for fuel supply and battery pack. A ba tery test feature allows charge condition to be read o the meter. Hydrogen flame-out is signified by an aud ble alarm plus a visual indication on the meter. The ir strument contains a frequency modulated detectio alarm which can be preset to sound at a desired co centration level. The frequency of the detection alar

varies as a function of detected level giving an audible indication of organic vapor concentration. The instrument is designed for one man, one hand operation and entire unit weighs a total of less than 12 pounds, including fuel supply and battery. An earphone is provided for "only operator" monitoring.

During use, the Side Pack Assembly can be carried by the operator on either his left or right side or as a back pack. The Side Pack Assembly is housed in a high impact plastic case and weighs less than 10 pounds. The Probe/Readout Assembly can be detached from the Side Pack Assembly and broken down for transport and storage. See Figure 1-2 for the breakdown capability of the instrument.

1.5 ADAPTABILITY FEATURES AND STANDARD ACCESSORIES

1.5.1 GENERAL

Maximum flexibility and operability features are included in the instrument design. As shown in Figure 1-2, a variety of pickup fixtures can be used. They can be installed by simply turning a knurled locking nut. Small diameter tubing can be used for remote sampling and electrically insulated flexible extensions can be used for difficult places to reach.

1.5.2 PROBE

The telescoping probe allows the length to be increased or decreased over an eight inch range to suit the individual user. A knurled locking nut is used to lock the probe at the desired length. The probe is attached to the Readout Assembly using a knurled locking nut. For measurements in close areas, the probe is replaced a Close Area Sampler, which is supplied as a standard accessory.

1.5.3 PARTICLE FILTERS

The primary filter is of porous stainless and located behind the sample inlet connector, see Side Pack Assembly drawing in Appendix "A". In addition, replaceable porous metal filters are installed in the "close area" sampler, the pickup funnel and the tubular sampler.

1.5.4 INSTRUMENT CARRYING CASE

An instrument carrying case is provided to transport, ship and store the disassembled Probe/Readout Assembly, the Side Pack Assembly and other standard equipment.

1.5.5 MOBILE INSTALLATION

The instrument is readily adaptable to a mobile application by simply plugging into vehicle power and hydrogen fuel supply and making provisions for drawing sample from the vehicle primary sampling system.

1.6 SPECIFICATIONS

Sensitivity: 0.1 ppm (methane)

Response time: Less than 2 seconds

Readout: 0 to 10 ppm, 0 to 100 ppm, 0 to 1,000 ppm, 250° linear scaled meter; external monitor connector

Sample flow rate: Nominally 2 units

Fuel supply: 75 cubic centimeter tank of pure hydrogen at maximum pressure of 2300 PSIG, fillable while in case

Primary electrical power: Rechargeable and replaceable battery pack at 12VDC

Service life: Hydrogen supply and battery power-8 hours operating time minimum

Size: Standard Unit: 8-5/8 x 11-5/8 x 4-1/4 FM Unit: 8-5/8 x 11-5/8 x 4-1/2 Probe/Readout Assembly: Variable (see Figure 1-2)

Weight: Standard Unit: Side Pack Assembly, less than 10 lbs. FM Unit: Side Pack Assembly, less than 11 lbs. Probe/Readout Assembly: less than 2 lbs.

Operator requirements: One man, one hand operation

Detection alarm: Frequency modulated audible alarm. Can be preset to desired level. Frequency varies as a function of detection level

Flame-out indication: Audible alarm plus visual meter indication

Battery test: Battery charge condition indicated on readout meter or battery recharger

Pickup fixtures: Variety of types for various applications

Probe: Telescoping adjustment over 8 inches or probe can be completely removed from Readout Assembly

Umbilical cord: Cable between readout and sidepack with connectors for electrical cable and sample hose

Filtering: In-line particle filters and optional activated charcoal filter.

Side Pack case: Molded high impact plastic case with carrying handle and shoulder strap

Electrical protection: Refer to Section 5

Standard accessories:

1) Instrument carrying and storage case
2) Fuel filling hose assembly
3) A.C. battery charger
4) Earphone
5) Various pickup fixtures

Optional accessories:

1) Gas chromatograph option
2) Portable strip chart recorder
3) Activated charcoal filter; also used with desiccant as a moisture trap
4) Dilution valve
5) Septum adapter for use with gas chromatograph option

SECTION 2

DETAILED OPERATING PROCEDURES

2.1 GENERAL

The procedures in this section are broken into five parts: (1) Starting, (2) Operating, (3) Shut Down, (4) Fuel Refilling, and (5) Battery Charging. After familiarization

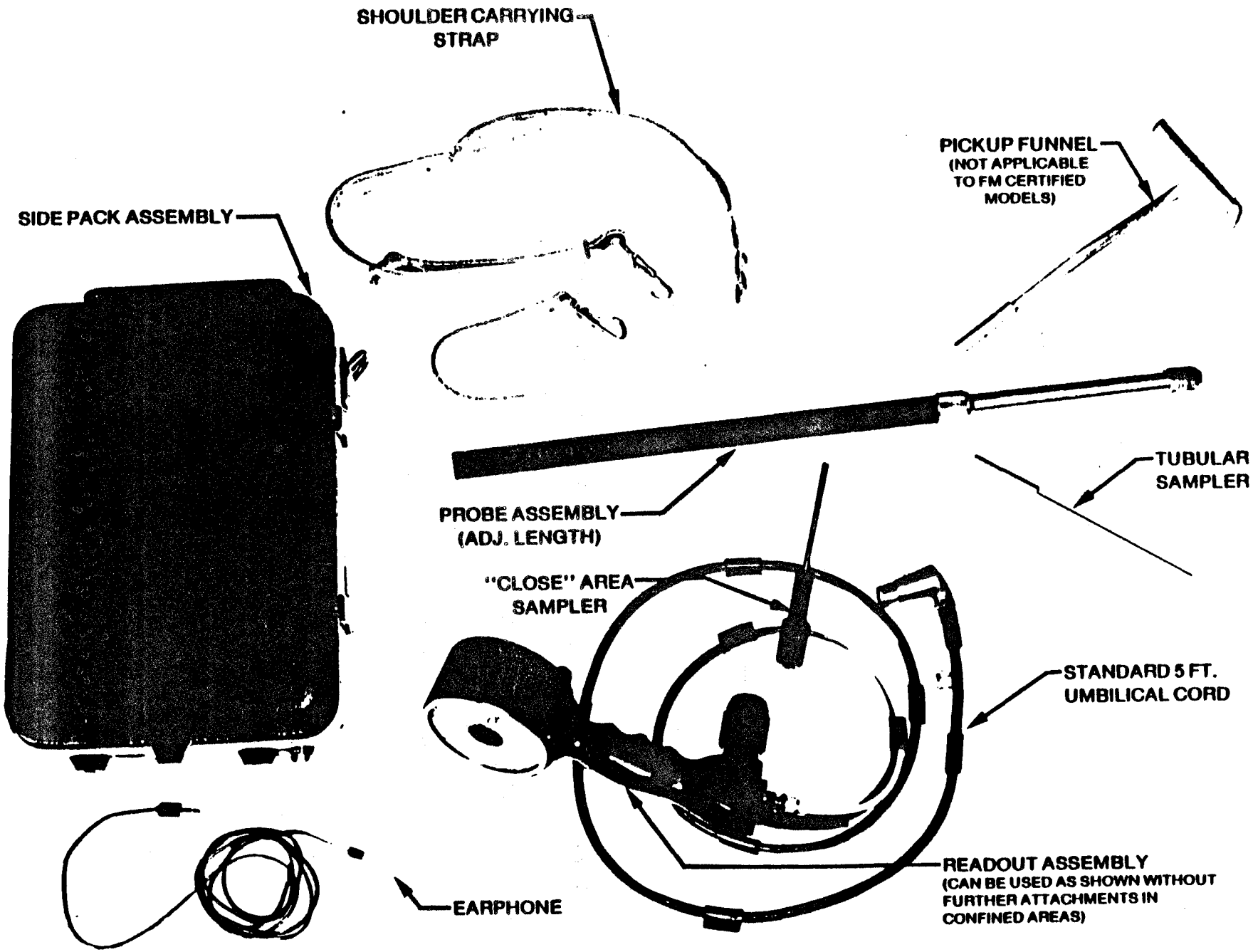


FIGURE 1-2

INSTRUM T DISASSEMBLED

Typical of All Models Except Where Noted.

with the instrument, the summarized procedures described in Section 3 may be used for simplicity. Because of the many optional applications for the instrument, the comprehensive detailed procedures described in this section may seem complex. However, in normal applications the operating procedures are quite simple. A condensed operating procedure check list is provided inside the cover of the Side Pack Assembly. Refer to Section 7 for operating procedures relative to major optional accessories such as the Gas Chromatograph Option.

2.2 SYSTEM CONTROLS, INDICATORS AND CONNECTORS

Tables 2-1 and 2-2 describe the functions of the various controls, indicators and connectors illustrated in Figure 1-1. Unless otherwise noted, the listings in Tables 2-1 and 2-2 are applicable to both the Model OVA-118 and OVA-128.

TABLE 2-1
SIDE PACK ASSEMBLY

Controls/Indicators — Function

1) INSTR/BATT Test Switch - This 3 position toggle switch turns on all instrument electrical power except the pump and alarm power and also permits display of the battery charge condition on the readout meter.
2) PUMP (ON-OFF) Switch - This toggle switch turns on power to the internal pump and audio alarms.
3) Igniter Switch - This momentary push button switch connects power to the igniter coil in the detector chamber and simultaneously disconnects power to pump.
4) CALIBRATE Switch (range selector) - This 3 position toggle switch selects the desired range: X1 (0-10 ppm); X10 (0-100 ppm); X100 (0-1,000 ppm).
5) CALIBRATE ADJUST (zero) Knob - This potentiometer is used to "zero" the instrument.
6) GAS SELECT Knob (span control) - This ten-turn dial readout potentiometer sets the gain of the instrument commonly referred to as span control.
7) Recorder Connector - This 128 series 5-pin Amphenol connector is used to connect the instrument to an external monitor with the following pin connections.

   Pin E - plus 12VDC
   Pin H - Ground
   Pin A - Signal 0-5VDC (OVA-118 only)
   Pin B - Signal 0-5VDC (OVA-128 only)

8) Recharger Connector - This BNC connector is used to connect the battery pack to the battery recharger assembly.
9) H2 TANK VALVE - This valve is used to supply or close off the fuel supply from the hydrogen tank.
10) H2 TANK PRESSURE Indicator - This high pressure gauge measures the pressure in the hydrogen fuel tank which is an indication of fuel supply.
11) H2 SUPPLY VALVE - This valve is used to supply or close off the hydrogen fuel to the detector chamber.
12) H2 SUPPLY PRESSURE Indicator - This low pressure gauge is used to monitor the hydrogen pressure at the capillary restrictor.
13) SAMPLE FLOW RATE Indicator - This indicator is used to monitor the sample flow rate.
14) Refill Connection - This 1/4" AN fitting is used to connect the hydrogen refill hose to the instrument.
15) REFILL VALVE - This valve is used to open one end of the instrument fuel tank for refilling with hydrogen.
16) Earphone Jack - This jack is used to connect the earphone; it turns off speaker when used.
17) VOLUME Knob - This potentiometer adjusts the volume of the internal speaker and earphone.
18) Readout and Sample Connectors - These connectors are used to connect the sample hose and umbilical cord from the Probe/Readout Assembly to the Side Pack Assembly.

TABLE 2-2
PROBE/READOUT ASSEMBLY

Controls/Indicators — Function

A) Meter - This 250° linear scaled meter displays the output signal level in ppm.
B) Alarm Level Adjust Knob - This potentiometer (located on the back of the Readout Assembly) is used to set the concentration level at which the audible alarm is actuated.

2.3 STARTING PROCEDURE

2.3.1 INITIAL PREPARATION FOR USE

2.3.1.1 INITIAL ASSEMBLY (Reference Figure 1-2)

a) Normal Survey Configuration
   (1) Connect the adjustable length probe to the Readout Assembly with the captive locking nut. Ensure that the probe is seated firmly in the Readout Assembly.
   (2) Select the desired pickup fixture and check that a particle filter is installed.
   (3) Connect the pickup fixture to the probe using the knurled locking nut.
   (4) Connect the umbilical cord and sample hose to the Side Pack Assembly.
b) "Close Area" Survey Configuration
   (1) Check to ensure that a particle filter is installed in the close area sampler.
   (2) Connect the close area sampler directly to the Readout Assembly.
   (3) Connect the umbilical cord and sample hose to the Side Pack Assembly.

2.3.1.2 SERVICING

a) **Fueling:** Pure, dry hydrogen can normally be

purchased locally or in a high grade from the Matheson Company of East Rutherford, New Jersey. The maximum instrument supply bottle pressure is 2300 PSIG. A high pressure hydrogen filling hose assembly is provided with the instrument. This assembly includes the proper fittings for the instrument and supply bottle, and a three-way fill/bleed valve. Initial fueling and subsequent refilling, using the Century high pressure filling hose, should be accomplished in accordance with the detailed instructions described in Section 2.6 of this manual.

b) Battery Check: Move INSTR/BATT Test Switch to the BATT position and ensure battery is charged by reading the indication on the readout meter.

c) Calibration: Standard factory calibration is performed using methane in air. The GAS SELECT (span) Control is set and locked to the position for calibration to methane (factory setting is 300). If the instrument is calibrated for other organic vapors, the reading on the GAS SELECT Control must be set for that particular vapor.

2.3.1.3 SAFETY PRECAUTIONS

Certain safety precautions must be followed in using the instrument. Hydrogen gas, when mixed with air, is highly flammable. Operating and refueling instructions should be strictly followed to ensure safe, reliable operation. Section 5 of the manual provides detailed safety precautions.

2.3.2 TURN ON PROCEDURE

The GAS SELECT control should be preset to the desired dial indication prior to turn on. The procedure for determining this setting is contained in Section 4 of this manual. The instrument, as received from the factory, is set to measure in terms of methane in air.

a) Move the INSTR Switch to ON and allow five minutes for warm up.

b) To set the audible alarm to a predetermined level, first turn the PUMP Switch to ON, then adjust the meter pointer to the desired alarm level, using the CALIBRATE ADJUST (zero) Knob. Turn the Alarm Level Adjust Knob on the back of the Readout Assembly until the audible alarm just comes on. Adjust speaker volume with VOLUME Knob. If earphone is used, plug in and readjust the volume as desired. The instrument is then preset to activate the alarm when the level exceeds that of the setting.

c) Move the CALIBRATE Switch to X10 and adjust the meter reading to zero with the CALIBRATE ADJUST (zero) Knob.

d) Ensure the PUMP Switch is ON and observe the SAMPLE FLOW RATE Indicator. Indication should be approximately 2 units.

e) Open H2 TANK VALVE one (1) turn and observe the reading on the H2 TANK PRESSURE Indicator. (Approximately 150 psi of pressure is needed for each hour of operation.)

f) Open H2 SUPPLY VALVE 1/2 to 1 turn and observe the reading on the H2 SUPPLY PRESSURE Indicator.

CAUTION

Do not leave H2 SUPPLY VALVE open when the pump is not running, as this will allow hydrogen to accumulate in the detector chamber.

g) Confirm that meter is still reading zero (readjust if required).

h) Depress igniter button. There will be a slight "pop" as the hydrogen ignites and the meter pointer will move upscale of zero. Immediately after ignition, release the igniter button. Do not depress igniter button for more than 6 seconds. If burner does not ignite, let instrument run for several minutes and try again. After ignition, the meter pointer will indicate the background concentration. This background level is nulled out using the CALIBRATE ADJUST (zero) Knob. Reference paragraph 6.2.5.1.

NOTE

Since the OVA utilizes the sample air drawn by the pump into the detector chamber as the only source of air to support the hydrogen flame, without adjustment the instrument will read the actual background concentration (ppm) of all hydrocarbons present at a given location.

i) Move instrument to an area which is representative of the "lowest ambient background concentration" (cleanest air) to be surveyed. Move the CALIBRATE Switch to X1 and adjust the meter to read 1 ppm with the CALIBRATE ADJUST (zero) Knob.

NOTE

Adjustment to 1 ppm (rather than 0) is necessary in the X1 range because of the sensitivity of the OVA. This permits minor downward fluctuations in the normal background level without dropping below 0, which would actuate the flame-out alarm. It is important, therefore, to remember during the subsequent survey that 1 ppm must be subtracted from all readings. Therefore a 1.8 ppm reading would actually be only 0.8 ppm.

j) If the alarm level is to be set above the normal background detection level, turn the Alarm Level Adjust Knob on the back of the Readout Assembly until it actuates slightly above background.

THE INSTRUMENT IS NOW READY FOR USE.

2.4 OPERATING PROCEDURES

a) Set the CALIBRATE Switch to the desire

range. Using one hand operation, survey the areas of interest while observing the meter and/or listening for the audible alarm indication. For ease of operation, carry the Side Pack Assembly positioned on the side opposite the hand which holds the Probe/Readout Assembly. For broad surveys outdoors, the pickup fixture should be positioned several feet above ground level. When making quantitative reading or pinpointing, the pickup fixture should be positioned at the point of interest.

b) When organic vapors are detected, the meter pointer will move upscale and the audible alarm will sound when the preset point is exceeded. The frequency of the audible alarm will increase as the detection level increases.

c) If the flame-out alarm is actuated, ensure that the pump is running, then press the igniter button. Under normal conditions, flame-out results from sampling a gas mixture that is above the lower explosive level which causes the H2 flame to extinguish. If this is the case, reignition is all that is required.
Another possible cause for flame-out would be restriction of the sample flow line which would not allow sufficient air into the chamber to support combustion of the H2 flame. The normal cause for such restriction would be a clogged particle filter or other restriction in the line.
It should be noted that the chamber exhaust port is on the bottom of the case and blocking this port with the hand will cause fluctuations and/or flame-out.

SHUT DOWN PROCEDURE

The following procedure should be followed for shut down of the instrument:

1) Close H2 SUPPLY VALVE.
2) Close H2 TANK VALVE.
3) Move INSTR Switch to OFF.
4) Wait 5 seconds and move PUMP Switch to OFF. INSTRUMENT IS NOW IN A SHUT DOWN CONFIGURATION.

2.6 FUEL REFILLING

a) The instrument should be completely shut down as described in Section 2.5 herein during hydrogen tank refilling operations. The refilling should be done in a ventilated area. There should be no potential igniters or flame in the area.

b) If you are making the first filling of the instrument or if the filling hose has been allowed to fill with air, the filling hose should be purged with N2 or H2 prior to filling the instrument tank. This purging is not required for subsequent fillings.

c) The filling hose assembly should be left attached to the hydrogen supply tank when possible. Ensure that the FILL/BLEED Valve on the instrument end of the hose is in the OFF position. Connect the hose to the refill connection on the Side Pack Assembly.

d) Open the hydrogen supply bottle valve slightly. Open the REFILL VALVE and the H2 TANK VALVE on the instrument panel and place the FILL/BLEED Valve on the filling hose assembly in the FILL position. The pressure in the instrument tank will now be indicated on the H2 TANK PRESSURE Indicator.

e) After the instrument fuel tank is filled, shut off the REFILL VALVE on the panel, the FILL/BLEED Valve on the filling hose assembly and the hydrogen supply bottle valve.

f) The hydrogen trapped in the hose should now be bled off to atmospheric pressure. CAUTION should be used in this operation as described in Step (g) below, since the hose will contain a significant amount of hydrogen at high pressure.

g) The hose is bled by turning the FILL/BLEED Valve on the filling hose assembly to the BLEED position. After the hose is bled down to atmospheric pressure, the FILL/BLEED Valve should be turned to the FILL position to allow the hydrogen trapped in the connection fittings to go into the hose assembly. Then, again, turn the FILL/BLEED Valve to the BLEED position and exhaust the trapped hydrogen. Then turn the FILL/BLEED Valve to OFF to keep the hydrogen at one atmosphere in the hose so that at the time of the next filling there will be no air trapped in the filling line.

h) Close the H2 TANK VALVE.

i) With the H2 TANK VALVE and the H2 SUPPLY VALVE closed, a small amount of H2 at high pressure will be present in the regulators and plumbing. As a leak check, observe the H2 TANK PRESSURE Indicator while the remainder of the system is shut down and ensure that the pressure indication does not go down rapidly, indicating a significant leak. If it does decrease rapidly (greater than 350 PSIG/hr.), there is a significant leak in the H2 supply system.

2.7 BATTERY RECHARGING

a) Plug charger BNC connector into mating connector on battery cover and insert AC plug into 115 VAC wall outlet. Never charge in a hazardous area or environment.

b) Move the battery charger switch to the ON position. The light above the switch button should illuminate.

c) Battery charge condition is indicated by the meter on the front panel of the charger; meter will deflect to the right when charging. When fully charged, the pointer will be in line with "charged" marker above the scale.

d) Approximately one hour of charging time is required for each hour of operation. However, an overnight charge is recommended. The charger can be left on indefinitely without

damaging the batteries. When finished, move the battery charger switch to OFF and disconnect from the Side Pack Assembly.

The following are special instructions relative to batteries which have been allowed to completely discharge.

It has been established that the above battery recharging procedures may not be sufficient when the operator of the instrument has inadvertently left the INSTR Switch ON for a period of time without recharging and allowed the battery to completely discharge.

When this happens and the above procedures fail to recharge the battery, the following should be accomplished:

1) Remove the battery from the instrument case.
2) Connect to any variable DC power supply.
3) Apply 40 volts at 1/2 amp maximum.
4) Observe the meter on the power supply frequently and as soon as the battery begins to draw current, reduce the voltage on the power supply at a slow rate until the meter reads approximately 15 volts. NOTE: The time required to reach the 15 volt reading will depend on degree of discharge.
5) Repeat steps a), b), c), and d) above to continue charging.

2.7.2 DC CHARGER

a) The optional DC charger is designed to both charge the battery and to provide power for operating the instrument from a 12 volt DC source, such as vehicle power.
b) Connect the DC charger cord to the connector on the battery cover of the Side Pack Assembly. Plug the line cord into the vehicle cigarette lighter or other power source connection.
c) In mobile applications, the DC charger is used to supply vehicle power to the instrument. Therefore, it may be left connected at all times.

2.8 CHARCOAL FILTERING

When it is desired to preferentially remove the heavier hydrocarbons, such as those associated with automobile exhaust, gasoline, etc., simply remove the pickup fixture from the end of the probe and install the optional charcoal filter assembly.

This same charcoal filter assembly can be installed directly into the Readout Assembly by using the adapter provided.

2.9 MOISTURE FILTERING

Filtering of moisture in the sample is not normally required. However, when moving in and out of buildings in cold weather, excessive condensation can form in the lines and detector chamber. In this case, the charcoal filter adapter can be filled with a desiccant such as "Drierite" which will filter out the moisture contained in the sample.

SECTION 3

SUMMARIZED OPERATING PROCEDURES

3.1 GENERAL

The procedures presented in this section are intended for use by personnel generally familiar with the operation of the instrument. Section 2 presents the comprehensive detailed operating procedures.

It is assumed that, prior to start up the positions of all switches and valves are in shut down configuration as described in paragraph 3.3.

3.2 START UP

a) Move PUMP Switch to ON and check ba condition by moving the INSTR Switch tc BATT position.
b) Move INSTR Switch to ON and allow five (5) minutes for warm-up.
c) Set Alarm Level Adjust Knob on back of Readout Assembly to desired level.
d) Set CALIBRATE Switch to X10 position, use CALIBRATE Knob and set meter to read 0.
e) Move PUMP Switch to ON position then place instrument panel in vertical position and check SAMPLE FLOW RATE indication.
f) Open the H2 TANK VALVE and the H2 SUPPLY VALVE.
g) Depress Igniter Button until burner lights. Do not depress Igniter Button for more than six (6) seconds. (If burner does not ignite, let instrument run for several minutes and again attempt ignition.)
h) Use CALIBRATE Knob to "zero" out ambient background. For maximum sensitivity below 10 ppm, set CALIBRATE Switch to X1 and readjust zero on meter. To avoid false flame-out alarm indication, set meter to 1 ppm with CALIBRATE Knob and make differential readings from there.

3.3 SHUT DOWN

a) Close the H2 SUPPLY VALVE and the H2 TANK VALVE.
b) Move the INSTR Switch and PUMP Swi o OFF.
c) Instrument is now in shut down configuration.

SECTION 4

CALIBRATION

4.1 GENERAL

The OVA is capable of responding to nearly all organic compounds. For precise analyses it will be necessary to calibrate the instrument with the specific compound of interest. This is especially true for materials containing elements other than carbon and hydrogen.

The instrument is factory calibrated to a methane in air standard. However, it can be easily and rapid calibrated to a variety of organic compounds. A GAS SELECT control is incorporated on the instrument panel which is used to set the electronic gain to a particular organic compound.

Internal electronic adjustments are provided to calibrate and align the electronic circuits. There are four (4) such adjustments all located on the electronics board. One adjustment potentiometer, R-38, is used to set the power supply voltage and is a one-time factory adjustment. The remaining three adjustments, R-31, R-32 and R-33 are used for setting the electronic amplifier gain for each of the three (3) calibrate ranges. Access to the adjustments is accomplished by removing the instrument from its case. Figure 4-1 indicates the lo on of the adjustments.

4.2 ELECTRONIC ADJUSTMENTS

Primary calibration of this instrument is accomplished ·e factory using methane in air sample gases.

4.2.1 GAIN ADJUSTMENT

a) Place instrument in normal operation with CALIBRATE Switch set to X10 and GAS SELECT control set to 300.

b) Use the CALIBRATE ADJUST (zero) Knob and adjust the meter reading to zero.

c) Introduce a methane sample of a known concentration (near 100 ppm) and adjust trimpot R-32 on circuit board (see Figure 4-1 for location) so that meter reads equivalent to the known sample.

d) This sets the instrument gain for methane with the panel mounted gain adjustment (GAS SELECT) set at a reference number of 300.

e) Turn off H2 SUPPLY VALVE to put out flame.

4.2.2 BIAS ADJUSTMENT

a) Leave CALIBRATE Switch on X10 position and use CALIBRATE ADJUST (zero) Knob to adjust meter reading to 4 ppm.

b) Place CALIBRATE Switch in X1 position and, using trimpot R-31 on circuit board, adjust meter reading to 4 ppm. (See Figure 4-1)

c) Move CALIBRATE Switch to X10 position again. Use CALIBRATE ADJUST (zero) Knob to adjust meter to a reading of 40 ppm.

d) Move CALIBRATE Switch to X100 position and use trimpot R-33 on circuit board to adjust meter reading to 40 ppm.

e) Move CALIBRATE Switch to X10 position and use CALIBRATE ADJUST (zero) Knob to adjust meter reading to zero.

f) Unit is now balanced from range to range, calibrated to methane, and ready to be placed in normal service.

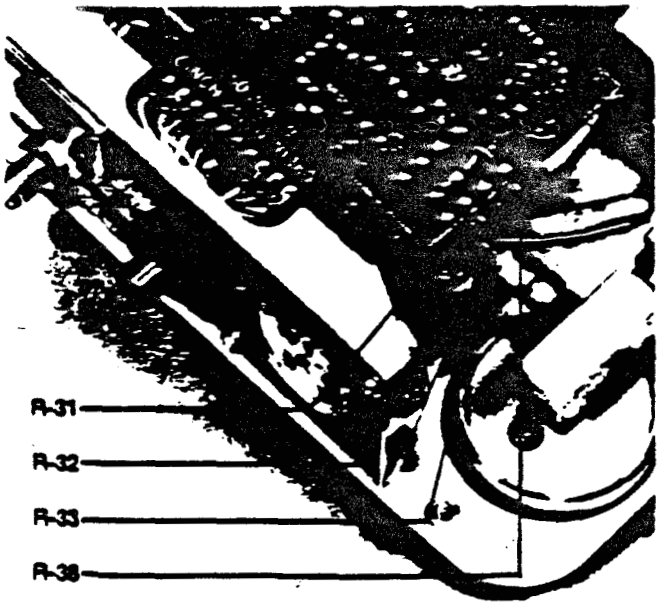


FIGURE 4-1. LOCATION OF ELECTRONIC ADJUSTMENTS
(Model OVA-118 shown; location typical to OVA-128)

4.3 CALIBRATION TO OTHER ORGANIC VAPORS

4.3.1 SETTING GAS SELECT CONTROL (Span)

Primary calibration of the instrument is accomplished using a known mixture of a specific organic vapor compound. After the instrument is in operation and the "normal background" is "zeroed out", draw a sample of the calibration gas into the instrument. The GAS SELECT Knob on the panel is then used to shift the readout meter indication to correspond to the concentration of the calibration gas mixture.

The instrument is then calibrated for the vapor mixture being used. After this adjustment, the setting on the "digidial" is read and recorded for that particular organic vapor compound. This exercise can be performed for a large variety of compounds and when desiring to read a particular compound the GAS SELECT control is turned to the predetermined setting for the compound. Calibration on any one range automatically calibrates the other two ranges.

4.3.2 USING EMPIRICAL DATA

Relative response data may be obtained, which can then be used to estimate concentrations of various vapors. With the instrument calibrated to methane, obtain the concentration reading for a calibration sample of the test vapor. The relative response, in percent, for that test vapor would then be the concentration read/concentration of the calibrated sample X 100.

4.3.3 PREPARATION OF CALIBRATION STANDARDS

4.3.3.1 COMMERCIAL SAMPLES

Commercially available standard samples offer the most convenient and reliable calibration standards and are recommended for the most precise analyses. Always remember to obtain the cylinder with the desired sample and the "balance as air". Sample should be drawn from the cylinder into a collapsed sample bag, then drawn from the bag by the instrument to prevent a pressure or vacuum at the sample inlet.

4.3.3.2 PURE GASEOUS SAMPLES

Obtain a large collapsible sample bag, preferably polyethylene such as a 40 gallon trash can liner. Insert a tube into the bag opening and tie shut around the tube. The tubing should have a shut-off valve or plug and be suitable for connecting the OVA input tube. Determine the volume of the bag by appropriate means (i.e., wet-test meter, dimensions of the bag, etc.). Forty gallon polyethylene bags provide a volume of approximately 140-160 liters. For gas samples, flush a 10 cc hypodermic syringe with the compound to be tested and then inject a 10 cc sample through the wall of the air-filled bag. Immediately after withdrawing the needle, cover the hole with a piece of plastic tape. Allow a few minutes for the sample to completely diffuse throughout the bag. Agitation will ensure complete diffusion. Connect the outlet tube to the OVA and take a reading. To verify repeatability of sampling technique, disconnect the bag and inject a second sample of the gas into the bag without emptying. Since only 2 or 3 liters will have been removed, the overall volume change will be small and the instrument reading should now be twice that of the

original. The concentration in ppm (V/V) will be equal to the sample size in cc divided by the volume of the bag in liters times 1000. For example, a 10 cc gas sample when placed in a 160 liter bag will provide a sample of 63 ppm, i.e., 10 X 1000/160 equals 63 ppm.

4.3.3.3 GASEOUS AND LIQUID SAMPLES (Alternate Method)

Obtain a five (5) gallon glass bottle and determine its volume by measuring the volume of water needed to fill it (use of a 1000 ml graduated cylinder, obtainable from scientific supply houses, is convenient). Another approach is to weigh the empty bottle, fill it with water and weigh again. The difference between the two values is the weight of water. By multiplying the weight of water in pounds by 0.455, you obtain the volume of the bottle in liters. Empty the water out and allow the bottle to dry. Place a one-foot piece of plastic tubing in the flask to aid in mixing the vapors uniformly with the air. The volume of such a bottle should be about 20 liters, which is 20,000 ml. If the volume were 20,000 ml, then a 2 ml sample of a gas placed in the bottle would be equivalent to 200 ml per 2 million ml or 100 ppm (V/V). Use of a gas tight syringe, readable in 0.01 ml, allows the preparation of mixtures in the 1 - 2 ppm range, which are sufficient for the quantitative estimation of concentrations. A rubber stopper is loosely fitted to the top of the bottle and the needle of the syringe placed inside the jug neck and the stopper squeezed against the needle to decrease leakage during sample introduction. Inject the sample into the bottle and withdraw the needle without removing the stopper. Put the stopper in tight and shake the bottle for a few minutes with sufficient vigor that the plastic tubing in the bottle moves around to ensure good mixture of the vapors with the air.

For liquid samples, use of the following equation will allow the calculation of the number of microliters of organic liquid needed to be placed into the bottle to make 100 ppm (V/V) of vapor.

V1 equals V2 X Mw/244D

- V1 - Volume of liquid in microliters needed to make an air mixture of 100 ppm (V/V)
- V2 - Volume of bottle in liters
- Mw - Molecular weight of substance
- D - Density of substance

This procedure has the advantage that you can see when all of the organic liquid has vaporized and the volume can be determined readily.

For liquid samples, an alternate procedure involves the use of a diffusion dilution device such as that described by Desty, Geach and Goldup in "Gas Chromatography", R.P.W. Scott, ed., Academic Press, New York, 1961.

4.4 THEORY

Theoretical background and empirical data related to the Century Organic Vapor Analyzer is presented in 4.4.1 and 4.4.2.

4.4.1 HYDROCARBONS

In general, a hydrogen flame ionization detector is more sensitive for hydrocarbons than any other class of organic compounds. The response of the OVA varies from compound to compound, but gives excellent repeatable results with all types of hydrocarbons; i saturated hydrocarbons (alkanes), unsaturated hydrocarbons (alkenes and alkynes) and aromatic hydrocarbons.

The typical relative response of various hydrocarbons to methane is as follows:

Compound	Relative Response (percent)
Methane	100 (reference)
Propane	64
N-butane	61
N-pentane	100
Ethylene	85
Acetylene	200
Benzene	150
Toluene	120
Ethane	90

4.4.2 OTHER ORGANIC COMPOUNDS

Compounds containing oxygen, such as alcohols, ethers, aldehydes, carbolic acid and esters give a somewhat lower response than that observed for hydrocarbons. This is particularly noticeable with those compounds having a high ratio of oxygen to carbon such as found in the lower members of each series which have only one, two or three carbons. With compounds containing higher numbers of carbons, the effect of the oxygen is diminished to such an extent that the response is similar to that of the corresponding hydrocarbons.

Nitrogen-containing compounds (i.e., amines, amides and nitriles) respond in a manner similar to that observed for oxygenated materials. Halogenated compounds also show a lower relative response as compared with hydrocarbons. Materials containing no hydrogen, such as carbon tetrachloride, give the lowest response; the presence of hydrogen in the compounds results in higher relative responses. Thus, $CHCl_3$ gives a much higher response than does CCl_4. As in the other cases, when the carbon to halogen ratio is 5:1 or greater, the response will be similar to that observed for simple hydrocarbons.

The typical relative response of various compounds to methane is as follows:

Methane	100 (calibration sample)
Ketones	
Acetone	80
Methyl ethyl ketone	80
Methyl isobutyl ketone	100
Alcohols	
Methyl alcohol	15
Ethyl	25
Isopropyl	65

Halogen compounds

Carbon tetrachloride	10
Chloroform	85
Trichloroethylene	70
Vinyl chloride	35

The OVA has negligible response to carbon monoxide and carbon dioxide which evidently, due to their structure, do not product appreciable ions in the detector flame. Thus, other organic materials may be analyzed in the presence of CO and CO_2.

SECTION 5

SAFETY CONSIDERATIONS

5.1 GENERAL

The Models OVA-108, OVA-128 and OVA-138 have been tested and certified by Factory Mutual Research Corporation (FM) as intrinsically safe for use in Class I, Division 1, Groups A, B, C & D hazardous atmospheres. Similar foreign certifications have been obtained, including BASEEFA and Cerchar approval for Group IIC, Temperature Class T4 on the Models OVA-108, OVA-128 and OVA-138, and equivalent approval from the Japanese Ministry of Labor for the Model OVA-128. Special restrictions must be strictly adhered to, to ensure the certification is not invalidated by actions of operating or service personnel.

All flame ionization hydrocarbon detectors are potentially hazardous since they burn hydrogen (H2) or H2 mixtures in the detector cell. Mixtures of H2 and air are flammable over a wide range of concentrations whether an inert gas such as nitrogen (N2) is present or not. Therefore, the recommended precautions and procedures should be followed for maximum safety. Safety considerations was a major factor in the design of the Organic Vapor Analyzer (OVA).

All connectors are of the permanent type as opposed to quick disconnect. To protect against external ignition of flammable gas mixtures, the flame detection chamber has porous metal flame arrestors on the sample input and the exhaust ports as well as on the H2 inlet connector. The standard battery pack and other circuits are internally current limited to an intrinsically safe level.

5.2 OPERATING, SERVICING AND MODIFYING

It is imperative that operation and service procedures described in this manual be carefully followed in order to maintain the intrinsic safety which is built into the OVA. No modification to the instrument is permissible. Therefore, component replacement must be accomplished with the same type parts.

5.3 ELECTRICAL PROTECTION

The 12V battery power supply circuit is current limited to an intrinsically safe level. Fuses are not utilized and all current limiting resistors and other components which are critical to the safety certification are encapsulated to prevent inadvertent replacement with components of the wrong value or specification. Under no circumstances should the encapsulation be removed.

5.4 FUEL SUPPLY & TANK

The OVA fuel tank has a volume of 75 to 85 cc which, when filled to the maximum rated pressure of 2300 PSIG, holds approximately 5/8 cubic foot of gas. The fuel used in the OVA is pure hydrogen which can be readily purchased in a highly pure form at nominal cost. The H2 tanks used in the instrument are made from stainless steel, proof-tested to 6,000 PSIG and 100% production tested to 4,000 PSIG.

5.5 H2 FLOW RESTRICTORS

Hydrogen gas gains heat when expanding and, therefore, should not be rapidly released from a high pressure tank to a low pressure environment. Flow restrictors are incorporated in the H2 refill fitting and is restricted on the output side of the tank by the flow rate control system. In addition, a special flow restrictor is incorporated in the FILL/BLEED valve of the hydrogen filling hose assembly. These precautions limit the flow rate of the H2 to prevent ignition due to self-heat from expansion.

5.6 DETECTOR CHAMBER

The OVA has a small flame ionization chamber cavity with sintered metal flame arrestors on both the input and output ports. The chamber is ruggedly constructed of teflon such that even if highly explosive mixtures of H2 and air are inadvertently created in the chamber and ignited, the chamber would NOT rupture.

5.7 H2 FILLING AND EMPTYING OPERATIONS

Precautions should be taken during H2 filling or H2 tank emptying operations to ensure that there are no sources of ignition in the immediate area. Since the instrument tank at 2300 PSIG holds only 5/8 cu. ft. of H2, the total quantity, if released to the atmosphere, would be quickly diluted to a non-flammable level. There is, however, the possibility of generating flammable mixtures in the immediate vicinity of the instrument during the filling or emptying operations if normal care is not exercised.

5.8 VENTING

The OVA case is vented to eliminate the possibility of trapping an explosive mixture of H2 and air inside case.

SECTION 6

MAINTENANCE

6.1 GENERAL

This section describes the routine maintenance schedule recommended and provides procedures for trouble shooting malfunctions or failures in the instrument.

Appendix "A" to this manual contains the assembly drawings and associated parts list for the Side Pack Assembly and two major subassemblies; the Electronic Component Assembly and the Cylinder Assembly. These drawings and parts lists may be used for locating and identifying components. Also included in Appendix "A" is a schematic wiring diagram showing interconnecting wiring between major electronic assemblies and typical signal levels at selected points on the certified instruments. The enclosed drawings and parts lists are subject to change without notice and part replacement on any certified instrument should be verified to comply with the "no modifications permitted" requirement.

CAUTION

Maintenance personnel should be thoroughly familiar with instrument operation before performing maintenance. It is essential that all portions of this manual relating to safety of operation, servicing and maintenance, including Section 5, be thoroughly understood. There should be no potential igniters or flame in the area when filling, emptying or purging the hydrogen system and the instrument should be turned off.

Extreme care should be exercised to ensure that required parts replacement is accomplished with the same parts specified by Century. This is especially necessary on the Models OVA-108, OVA-128 and OVA-138 in order that their certification for use in hazardous atmospheres be maintained. No modifications are permitted. Disassemble instrument only in a non-hazardous atmosphere.

6.2 ROUTINE MAINTENANCE

Note that Figure 6-1 is a flow diagram of the basic gas handling system.

6.2.1 FILTERS

6.2.1.1 PRIMARY FILTER

This filter is located behind the sample inlet connector (Fitting Assembly) on the Side Pack Assembly and is removed for cleaning by using a thin wall socket to unscrew the Fitting Assembly. The filter cup, "O" ring and loading spring will then come out as shown in the Side Pack Assembly drawing in Appendix "A". The porous stainless filter cup can then be cleaned by blowing out or washing in a solvent. If a solvent is used, care should be taken to ensure that all solvent is removed by blowing out or heating the filter. Reassemble in reverse order ensuring that the "O" ring seal on the Fitting Assembly is intact.

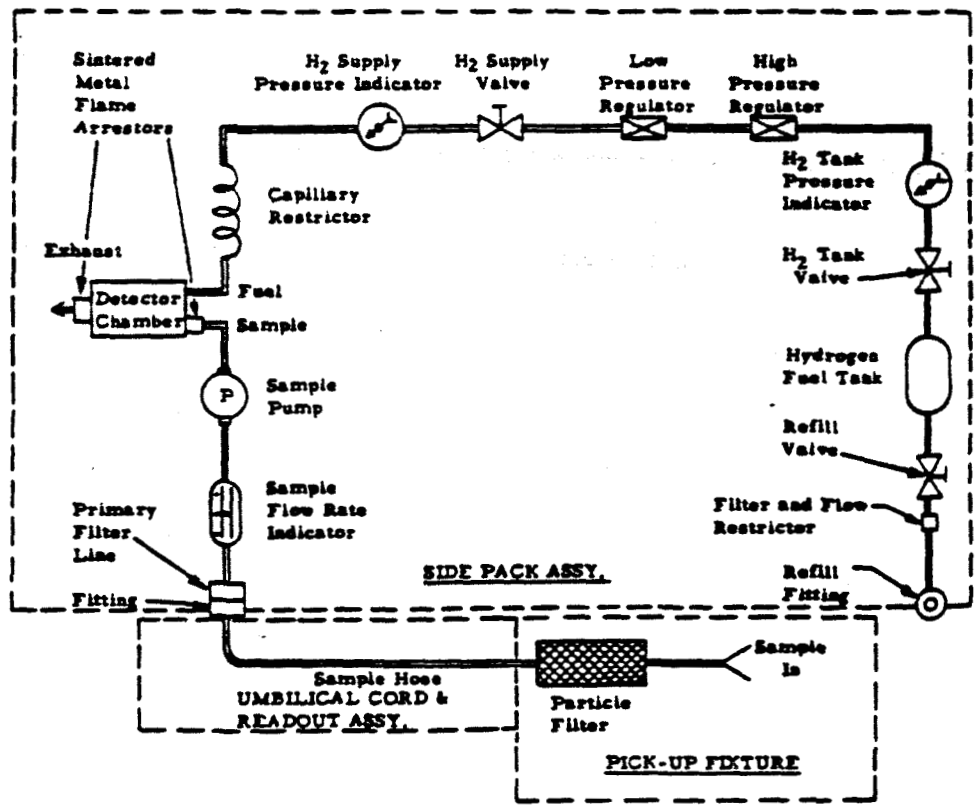


FIGURE 6-1. Flow Diagram - Gas Handling System

6.2.1.2 PARTICLE FILTERS

A particle filter is located in each pickup fixture. One of these filters must be in the sample line whenever the instrument is in use. The Models OVA-88 and OVA-138 use a disposable cellulose filter which should be changed as often as required. The Models OVA-98, OVA-108, OVA-118 and OVA-128 use a porous metal filter which can be replaced or cleaned using the cleaning procedure in paragraph 6.2.1.1.

6.2.1.3 MIXER/BURNER ASSEMBLY FILTER

Another porous metal particle filter is incorporated in the Mixer/Burner Assembly which screws into the Preamp Assembly. See Side Pack Assembly drawing. This filter is used as the sample mixer and inlet flame arrestor in the chamber. This filter should not become contaminated under normal conditions but can be cleaned or the assembly replaced if necessary.

Access to this filter for output surface cleaning is gained by simply unscrewing the exhaust port from the Preamp Assembly without removing the instrument from the case. The OVA-108, OVA-128 and OVA-138 instruments require removal of the safety cover prior to unscrewing the exhaust port. The Filter Assembly can now be seen on the side of the chamber (Preamp Assembly) and can be scrapped or cleaned with a small wire brush.

If filter replacement is required, install a new or factory rebuilt Mixer/Burner Assembly. In several OVA models, this requires removal of the Preamp Assembly.

6.2.1.4 EXHAUST FLAME ARRESTOR

A porous metal flame arrestor is located in the exhaust port of the detector chamber (Preamp Assembly). See Side Pack Assembly drawing. It acts as a particle filter on the chamber output and restricts foreign matter from entering the chamber. This filter may be cleaned, if required, by removing the exhaust port from the Preamp Assembly. The exhaust port is removed from the bottom of the case without case removal. Note that the filter is captive to the exhaust port on the Models OVA-108, OVA-128 and OVA-138. Clean the filter with a solvent or detergent but ensure that it is dry and any solvent completely baked out at 120°F before reinstalling.

6.2.2 PICKUP FIXTURES

The pickup fixtures should be periodically cleaned with an air hose and/or detergent water to eliminate foreign particle matter. If a solvent is used, the fixture should be subsequently cleaned with detergent and baked out at 120°F to eliminate any residual hydrocarbons from the solvent.

6.2.3 SEAL MAINTENANCE - CYLINDER ASSEMBLY

6.2.3.1 H2 TANK, H2 SUPPLY AND REFILL VALVES

After some time, the teflon washers under each valve packing nut can "cold flow" (move with pressure) and allow hydrogen to leak. Leakage can be determined by using Leak-Tec, Snoop or a soap solution around the valve stems. This leakage can usually be stopped by tightening the compression nut (adapter) as outlined below. See Side Pack Assembly and Cylinder Assembly drawings.

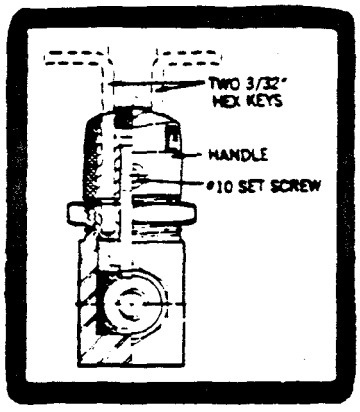
1) Remove instrument from the case by unlocking the four (4) 1/4 turn fasteners on the panel and removing the exhaust safety cover (if included), exhaust port and refill cap nut. Be sure refill valve is closed before removing refill cap nut.
2) Remove the valve knob screw and knob.
3) Loosen the panel nut with a 3/4" wrench.
4) The valve compression nut is located just under the panel. Tighten the compression nut—usually not more than 1/4 turn.

This compression is against soft material and only a small amount of force is necessary to sufficiently compress the teflon washers. If, after tightening, leakage still occurs, it would be advisable to replace the two teflon washers, as follows:

1) Drain hydrogen system slowly and to the extent necessary to work on the leaking valve(s). Observe safety precautions (see Section 5). There should be no potential igniters in the area.
2) Disconnect the capillary tube from the manifold at low pressure gauge (H2 Supply Pressure).
3) Remove all three (3) knob screws and knobs.
4) Remove the three (3) panel nuts and washers.
5) Carefully remove the tank assembly from the panel. NOTE: If OVA has GC Option installed, the GC valve assembly must be loosened or removed in order to remove the tank assembly from the panel.
6) Remove the compression nut on the valve that is not sealing properly. Remove the stem by unscrewing it from the valve body. Observe the sandwich of metal and teflon washers and note their order.
7) Visually check the Kel-F seat on the stem for cracks or foreign material. Wipe clean, if necessary, with a lint free cloth (no solvents or oils) and replace if damaged.
8) Remove the washers and replace the teflon washers (the factory procedure is a light wipe of hydrocarbon free silicone grease).
9) Replace the stem assembly in the valve body and tighten lightly.
10) Push the washers down into the compression area in the same order as noted upon removal. Replace the compression nut and tighten snugly.
11) Close the low pressure valve and fill the tank assembly. Check valves for leaks. Tighten again, if necessary, and reassemble the unit.

6.2.3.2 REFILLER VALVE PACKING ADJUSTMENT

Adjustment for the valve on the refiller can be made by loosening the set screw with a 3/32" hex key, so that the handle turns freely on the stem. Insert two (2) 3/32" hex keys through the holes provided in the handle and turn until they engage the holes in the packing adjuster. Then tighten the packing by turning the handle.



6.2.4 AIR SAMPLING SYSTEM MAINTENANCE

6.2.4.1 GENERAL

A potential problem associated with the OVA instrument is that leaks can develop in the air sample pumping system. These leaks can result in either dilution or loss of sample, causing low reading of vapor concentration and slow response time.

6.2.4.2 TESTING FOR LEAKS

The OVA's a re equipped with a flow gauge, which provides a method to check for air leaks. Assemble the pickup probe selected for use to the readout assembly and then position the sidepack vertically so the flow gauge may be observed. Cover the end of the pickup probe with your finger and observe that the ball in the flow gauge goes to the bottom, indicating no air flow (if ball has slight chatter while on bottom, this is acceptable). Cover the center of the chamber exhaust port with your thumb and again observe the ball going to the bottom. Another simple check is to expose the pickup probe to cigarette smoke or a light vapor (butane) and observe that the meter responds in approximately 1.5 - 2.0 seconds. It should be noted that slow meter response may also indicate a restriction in the air sampling system.

6.2.4.3 LEAK ISOLATION

Failure of the ball to go to the bottom when the inlet is blocked indicates a leak in the system between the probe and the pump inlet or the inlet check valve. To isolate the problem, remove parts, one at a time, and again block off the air inlet. Remove the pickup probe(s) and cover the air inlet at the Readout Assembly. If the ball goes to the bottom, check that the "readout to probe" seal washer is in place and replace the probes, holding them back against this seal while tightening the nut. Recheck, and if leakage is still present, it is probably in the probe (pickup fixture), which should be repaired or replaced.

If leakage is indicated as being past the readout handle when the connection to the sidepack is tight, disconnect the sample line at the fitting on the sidepack and cover this inlet with your finger. If the flow gauge ball goes to the bottom, the problem should be a leak in the umbilical cord/Readout Assembly, which should be investigated and repaired. There is also the possibility of a leaking check valve in the pump which would not show up on this test. If the leakage is not found in the umbilical cord, it is most likely in the pump check valve which should be repaired or replaced.

If the ball does not go to the bottom, the leak will be either in the flow gauge or it's connecting tubing. Visually check that the tubing is connected and if so, the flow gauge should be repaired or replaced. Check the "O" ring installation in the sample inlet connector (Fitting Assembly).

As an alternate approach, leaks on the inlet side of the pump can be detected by using alcohol on a "Q" Tip and lightly swabbing the connections one at a time or by directing organic vapor or smoke at the potential leakage points and observing the meter response or audible alarm.

Leaks (beyond the pump) are easier to locate, as any of the commercially available leak detection solutions can be used. Cover the exhaust port, which will place the exhaust system under pressure, and check each connection, one at a time. Replace the teflon tubing or retape the threaded connections with teflon joint tape. Check the igniter and Mixer/Burner Assembly where they screw into the detector, the high voltage terminal screw on the side of the Mixer/Burner and exhaust port itself. If after these checks, the flow gauge ball still will not go to the bottom with the exhaust blocked, the problem is likely a leaking exhaust check valve in the pump, which should be repaired or replaced.

6.2.5 CONTAMINATION CONTROL AND MAINTENANCE

6.2.5.1 GENERAL

On occasion, the background reading of the OVA may be relatively high under normal ambient conditions. Ambient background readings will vary somewhat depending on the geographical location where the instrument is being used. However, the background reading normally should be in the range of 3 to 5 ppm as methane. The acceptable background reading consists of 1 to 1-1/2 ppm of methane which is present in the normal air environment. In addition to the measurement of a normal methane background, there will normally be 2 to 4 ppm of equivalent methane background caused by acceptable levels of contamination in the hydrogen fuel and/or hydrogen fuel handling system resulting in a total equivalent methane reading of 3 to 5 ppm in clean air.

If the background reading goes above 5 ppm to 6 or 7 ppm, this is normally still acceptable since any measurement is additive to that background reading, i.e., 2 ppm on top of 5 or 2 ppm on top of 7 provides the same differential reading, however, the lower background is obviously desirable.

The background reading on the linear OVA's is zeroed out or nulled out—even though in reality the background still exists. The background reading on the

linear OVA's is measured by zeroing the meter with the flame out and noting the meter indication after the flame is on. However, on the logarithmic scaled OVA's the background reading is observed on the meter at all times. This is considered desirable since it assures the operator that the instrument is, in fact, operating properly. The background reading on the OVA's serves as a low level calibration point since it does represent the measurement of ambient levels of methane in the air, which are extremely stable and predictable any place in the world.

The cause for a high background reading is usually associated with contamination in the hydrogen fuel system. This will, of course, cause a background reading since this is the function of the basic detector "to measure contamination entering the detector chamber". In addition, contamination present in the hydrogen will many times leave a small unobservable deposit on the burner face which can continue to generate a background reading when the detector is in operation and the burner assembly is heated.

Another possible cause of contamination is the mixer/burner assembly when the contamination is trapped in the porous bronze sample filter. This is not a common problem and usually only happens when an unusually high level of contaminant is drawn into the assembly. Another possible cause of high background reading is contamination someplace in the air sample line to the detector. This is also uncommon but can be the source of the problem.

NOTE

OVA's that include the Chromatograph Option installed can also have an indication of high background related to saturation or contamination of the activated charcoal filter, which is in the line during chromatograph analysis, or of the column which is in the hydrogen line at all times.

6.2.5.2 ANALYSIS AND CORRECTION

Prior to analyzing the problem, the OVA should be checked for proper electronic operation. Check logarithmic instruments for proper high and low calibration points and for proper gas selector operation (see Section 4). On logarithmic OVA's, check Gas Selector by turning to 500 and observing the flame-out alarm comes on as the needle goes below 1 ppm. It should be ensured that the instrument is calibrated to methane as referenced.

If, after checking that the OVA is properly calibrated, the background is still higher than normal for ambient conditions, the following procedure should be followed to isolate the cause of the problem.

1) Let the OVA run for a period of time (15 to 30 minutes) and see if the background level decreases as a function of time. The background could go down and stay down as a result of clearing line contamination which is removable simply by the normal flow of air through the sample line.
2) Take a reading in a known, relatively clean air environment. Normally, outside air environment is clean enough to assess by comparison whether the background reading is internal to the instrument or is present in the laboratory office or location where the instrument is being used.
3) If the OVA includes the Gas Chromatograph Option, depress the sample inject valve so that the activated charcoal is in the line and observe whether the background reading goes down and stays steady after the elution of the air peak. The reading should always go down or stay the same but never be a higher background reading with the sample valve depressed, since the charcoal filter will take out any trace elements of organic vapors in the air heavier than a C_2. If another activated charcoal filter is available, this may be attached to the end of the probe to scrub the air so that a clean air sample would be going to the detector. The external activated charcoal can be used on any instrument, with or without chromatograph, for providing a clean air sample to assess background level.
4) If background still stays up and cannot be reduced by any of the previous steps, the safety cover (if included) and the exhaust port on the detector chamber (Preamp Assembly) on the bottom of the case should be removed and the Mixer/Burner Assembly scraped or brushed with a small wire brush. (Reference paragraph 6.2.1.3.) This will remove any small quantities of contamination that are on the Mixer/Burner Assembly which could be the source of the background vapor. After cleaning the face of the burner and tube, replace the exhaust port and safety cover (if included) and reignite the OVA. If contamination on the burner face was the cause, the problem should be immediately resolved and the ambient background will drop to an acceptable level.
5) If the background is still present, place your finger over the inlet of the probe so as to reduce the flow of air to the detector chamber. Reduced flow rate may be observed either on the sample flow gauge or can normally be observed by the sound of the pump motor.
6) If the background drops immediately in response to the reduced flow of air to the chamber, this is an indication that the contamination is in the air sample line. Therefore, the various parts of the sample flow line such as pickup probes, umbilical cord to the instrument, etc., should be investigated by the process of elimination to see if the contamination can be isolated.
7) Serious contamination in the air sample line is very uncommon. However, if very large doses of very heavy compounds are sampled, there is a possibility of a residual contamination which would eventually clear itself out but may take a considerable period of time. A typical cause for the high background from the sample line is a

contaminated Mixer/Burner Assembly. See paragraph (4) above for cleaning procedure. If heavy contamination of the Mixer/Burner is still indicated by a high background, replace the Mixer/Burner Assembly. In several OVA models, this will require removal of the Preamp Assembly. The old Mixer/Burner Assembly should be either discarded or returned to the factory for cleaning and rebuilding.

8) In the event there is contamination in the pump or other internal parts of the sample flow lines which cannot be removed, the sample flow components would have to be disassembled and cleaned. This is normally a factory type operation. However, the components such as the pump can be replaced in the field along with any contaminated tubing in the sample lines.

9) High background readings on OVA's which include the Gas Chromatograph Option can be caused by other sources of contamination. If the charcoal in the charcoal filter mounted on the panel of the instrument is contaminated or saturated, contaminated air would be supplied to the detector and raise the ambient level background. To check for this, the charcoal filter cartridge can be removed from the panel and either a bypass tube put between the two connectors or the charcoal can be removed from the charcoal cartridge and the cartridge refilled with clean activated charcoal. This would determine if the charcoal was the source of the background reading. It is possible that an apparent high background reading could be due to contamination in the column that is on the instrument. This background could be caused by compounds that are slowly eluting from a column which has become contaminated. The easiest way to check for column contamination is to replace the column with a known clean column or a short empty piece of column tubing and see if the high background reading drops.

10) If all the above steps do not correct the high background problem, the cause will normally be contamination in the hydrogen fuel system.

Contamination in the hydrogen fuel system is usually the direct result of contamination in the hydrogen gas used or contamination introduced during the filling operation. Filling hose contamination can be caused by storing the hose in a contaminated area.

To remove contamination from the hydrogen fuel system, it should be purged with hydrogen. Effective purging of the hydrogen system is accomplished by disconnecting the capillary tube fitting which attaches on to the manifold block which has the low pressure gauge (H2 Supply Pressure Gauge and H2 Supply Valve). This disconnects the capillary tubing from the hydrogen line so that hydrogen may be purged at a reasonable rate from the tank assembly through the regulators, gauges and valves. After disconnecting the capillary, the hydrogen tank can be filled in the normal manner. The tank valve and H2 supply valve can then be opened which will bleed the hydrogen from the tank through the H2 fuel system purging out the contamination which is in vapor form. There is the possibility that contamination has been introduced into the hydrogen fuel system which is not readily purged out by the hydrogen gas but this is unlikely. After purging with clean hydrogen, approximately two or three times, the capillary tube should be reconnected and the background again checked. Five or ten minutes should be allowed before assessing the background reading, since contaminated hydrogen may still have been trapped in the capillary tube.

If another tank assembly in a clean instrument is available, the fuel system from the clean instrument can be connected to the contaminated instrument to absolutely verify that it is or is not in the hydrogen fuel supply system. The interconnection should be made to the capillary tube of the contaminated instrument.

6.2.6 FUSE REPLACEMENT

This paragraph applies only to the standard (non-certified) OVA's. There are two (2) overload fuses incorporated in the Battery Pack Assembly, one is a 3AG-1 AMP Slo-Blo in the power line to the pump and igniter and the other a 3AG-1/4 AMP in the power line to the electronics. Both fuses follow the current limiting resistors which provide primary short circuit protection. However, in the event of an excessive overload, the fuses will open and prevent overheating of the current limiting resistors. It should be pointed out that the 1 AMP Slo-Blo fuse will blow in approximately 8 to 12 seconds if the igniter switch is kept depressed. Normal ignition should take place in not more than 6 seconds. Therefore, do not depress igniter button for more than 6 seconds. If ignition does not occur, wait 1 to 2 minutes and try again. If the required 1 AMP Slo-Blo fuse cannot be readily obtained, replace temporarily with a 3 AMP-3 AG standard fuse.

6.3 TROUBLE SHOOTING

Table 6-1 presents a summary of recommended field trouble shooting procedures. If necessary, the instrument can be easily removed from the case by unlocking the four (4) 1/4 turn fasteners on the panel face and removing the refill cap and exhaust port. The battery pack is removed by taking out the four (4) screws on the panel and disconnecting the power connector at the battery pack.

6.4 FACTORY MAINTENANCE

To ensure continuous trouble-free operation, Century recommends a periodic factory maintenance, overhaul and recalibration. The recommended schedule is every six (6) to nine (9) months. This maintenance program includes replacement of plastic seals and parts as required, pump overhaul, motor check, new batteries, sample line cleaning, H2 leak check, recalibration, replacement of plastic hose as required, and detailed examination of the unit for any other required maintenance and repair.

The recommended procedure for maintenance and repair beyond the scope of this manual is to send the complete instrument or subassembly to the Century factory for repairs. The assemblies will be handled expeditiously for rapid turn-around.

6.5 FIELD MAINTENANCE

Although not recommended, where field maintenance beyond that described herein is considered essential, the assembly drawings, parts lists and schematics in Appendix "A" will be of assistance.

6.6 RECOMMENDED SPARES

Century does not recommend that spares be maintained for its instruments. However, if the instrument is to be used in a remote area or spares are desired for other reasons, the following list should be used as a guide.

RECOMMENDED SPARES

Item	Description	Part No.	Recommended Quantity					
			Standard			Approved		
			88	98	118	108	128	138
1	Igniter	510027-1	2	2	2			
2	Igniter	510461-1				2	2	2
3	Pump Valve	510067-3 (10/pkg.)	1	1	1	1	1	1
4	Pump Diaphragm (Buna-N)	510091-1	1					1
5	Pump Diaphragm (Teflon)	510063-1		1	1	1	1	
6	Cup, Filter (3/8 OD, SS)	510318-1 (5/pkg.)	1	1	1	1	1	1
7	Mixer/Burner Assy	510557-2	1					
8	Mixer/Burner Assy	510557-1		1	1			
9	Mixer/Burner Assy	510513-1				1	1	1
10	Wafer, Teflon, H_2 Valve	510160-1 (10/pkg.)	1	1	1	1	1	1
11	Washer, Brass, H_2 Valve	510160-2 (10/pkg.)	1	1	1	1	1	1
12	Exhaust Port Assy	510425-1	1	1	1			
13	Exhaust Port Assy	510530-1				1	1	1
14	Battery Pack Assy	510070-1	1	1	1			
15	Battery Pack Assy	510542-1				1	1	1
16	Sample Line Assy	510316-1		1	1	1	1	1
17	Particle Filters	510114-1	1					1
18	Particle Filters	510116-1		1	1	1	1	

NOTE: Unit quantity is each unless otherwise noted.

TABLE 6-1

ROUBLE	TROUBLE SHOOTING PROCEDURE	REMEDY
1) Low sample flow rate on flow indicator. Nominally 2 units on flow gauge. (See also 6 below and refer to paragraph 6.2.4)	a) Check primary filter in sidepack and particle filters in the pickup assembly.	Replace or clean filter if clogged. (See paragraph 6.2.1)
	b) Determine assembly containing restriction by process of elimination, i.e., remove probe, remove Readout Assembly, remove primary filter, etc.	Investigate the assembly containing this restriction t determine cause of blockage. Clean or replace as re quired.
	c) If the restriction is in the Side Pack Assembly, further isolate by disconnecting the sample flow tubing at various points, i.e., pump output, chamber input, etc. Note: The inherent restrictions due to length of sample line, flame arrestors, etc., must be taken into account when trouble shooting.	If in the detector chamber, remove and clean or replac porous metal flame arrestors. If pump is found to be th problem, remove and clean or replace.
2) H2 flame will not light. (See also 6 below)	a) Check sample flow rate (see 1 above).	If sample flow rate is low, follow procedure 1 above.
	b) Check igniter by removing the chamber exhaust port and observing the glow when the IGNITE Button is depressed.	If igniter does not light up, replace the plug. If ignit still does not light, check the battery and wiring.
	c) Check for rated H2 Supply Pressure. (Listed on calibration plate on pump bracket.)	If low, remove battery pack and adjust to proper level t turning the allen wrench adjustment on the lo pressure regulator cap.
	d) Check H2 flow rate by observing the PSI decrease in pressure on the H2 Tank Pressure gauge. The flow rate should be about 130 PSI decrease in pressure per hour. (Approximately 12 cc/min. at detector.) On instruments with GC Option, disconnect column and measure H2 flow rate with a bubble meter.	The normal cause for H2 flow restriction would be blocked or partially blocked capillary tube. If flow rate marginally low, attempt to compensate by increasi the H2 Supply Pressure by one-half or one PSI. If flo rate cannot be compensated for, replace capillary tu ing.
	e) Check all H2 plumbing joints for leaks using soap bubble solution. Also, shut off all valves and note pressure decay on H2 tank gauge. It should be less than 350 PSIG per hour.	Repair leaking joint.
	f) Check to see if H2 supply system is frozen up by taking unit into a warm area.	If there is moisture in the H2 supply system and the u must be operated in subfreezing temperatures, pur the H2 system with dry N2 and ensure the H2 gas us is dry.

	g) Remove exhaust port and check for contamination. (See Figure 6-2.)	If the chamber is dirty, clean with ethyl alcohol and dry by running pump for approximately 15 minutes. If H2 fuel jet is misaligned, ensure the porous metal flame arrestor is properly seated.
	h) Check spacing between collecting electrode and burner tip. Spacing should be 0.1 to 0.15 inches.	Adjust by screwing Mixer/Burner Assembly in or out. This spacing problem should only occur after reassembling a Mixer/Burner Assembly to a Preamp Assembly.
3) H2 flame lights but will not stay lighted	a) Follow procedures 2 (a), (c), (d), (e), (g) and (h) above. Also refer to 5 below.	
4) Flame-out alarm will not go on when H2 flame is out	a) Check instrument calibration setting and GAS SELECT control setting. Refer to paragraphs 2.3.1.2 and 2.3.2.	Readjust as required to proper setting. Note that on linear OVA's the flame-out alarm is actuated when the meter reading goes below zero. On logarithmic OVA's, the alarm is actuated when the signal level goes below 1 ppm methane or equivalent.
	b) Remove exhaust port and check for leakage current path in chamber (probably moisture or dirt in chamber).	Clean contamination and/or moisture from the chamber using a swab and alcohol, dry chamber by running pump for approximately 15 minutes.
	c) If above procedures do not resolve the problem, the probable cause is a malfunction in the preamp or power board assemblies.	Return preamp chamber or power board assembly to the factory for repair.
	d) Check volume control knob is turned up.	Adjust for desired volume.
5) False flame-out alarm. (Applies to linear OVA's)	a) Flame-out alarm is actuated on linear instruments when signal goes below electronic zero (eventhough flame is still on). This can be due to inaccurate initial setting, drift or a decrease in ambient concentration. Verify if this is the problem by zeroing meter with flame out and reigniting. (See paragraph 2.3.2)	When using the X1 range, adjust meter to 1 ppm rather than zero. See paragraph 2.3.2. Be sure instrument has been zeroed to "lowest expected ambient background level".
6) Slow response time, i.e., time to obtain response after sample is applied to input. (Refer to paragraph 6.2.4)	a) Check to ensure that probe is firmly seated on the rubber seal in the readout assembly.	Reseat by holding the probe firmly against the rubber seat and then lock in position with the knurled locking nut.
	b) Check sample flow rate per procedure 1 above.	See 1 above.

7) Slow recovery time, i.e., too long a time for the reading to get back to ambient after exposure to a high concentration of organic vapor.	a) This problem is normally caused by contamination in the sample input line, requiring pumping for a long period to get the system clean of vapors again. Charcoal in the lines would be the worst type of contamination. Isolate through the process of elimination. (See 1 (b)). b) Check flame chamber for contamination.	Clean or replace contaminated sample line or assembl as required. Clean as required.
8) Ambient background reading in clean environment is too high. (Refer to paragraph 6.2.5)	a) An ambient background reading can be caused by hydrocarbons in the H2 fuel supply system. Place finger over sample probe tube restricting sample flow and if meter indication does not go down significantly the contamination is probably in the H2 fuel. b) An ambient background reading can be caused by a residue of sample, building up on the face of the sample inlet filter. If the test in 8 (a) above produces a large drop in reading, this is usually the cause. c) An ambient background reading can also be caused by hydrocarbon contamination in the sample input system. The most likely cause would be a contaminant absorbed or condensed in the sample line. Note: It should be emphasized that running the instrument tends to keep down the buildup of background vapors. Therefore, run the unit whenever possible and store it with the carrying case open in clean air.	Use a higher grade of hydrocarbon free hydrogen Check for contaminated fittings on filling hos assembly. Remove the exhaust port (it is not necessary to remov instrument from case), use small wire brush from th tool kit or a knife blade and lightly scrub surface of sar ple inlet filter. Clean and/or replace the sample input lines. Norma the lines will clear up with sufficient running.
9) Pump will not run	a) Check 1 AMP Slo-Blo fuse on the battery pack cover. NOTE: Certified OVA's do not have fuses.	Replace fuse. IMPORTANT: Note that fuse is a Slo-B type. If fuse continues to blow when igniter switch closed, check igniter for short circuit. If igniter is not t problem, there is a short in the wiring or pump mot Return OVA to factory or authorized repair facility.
10) No power to electronics but pump runs	a) Check 1/4 AMP fuse on the battery pack cover. NOTE: Certified OVA's do not have fuses.	Replace fuse. If fuse continues to blow, there is a sh in the electronics assembly. Return OVA to factory authorized repair facility.
11) No power to pump or electronics.	a) Place battery on charger and see if power is then available. Recharge in a non-hazardous area only.	If power is available, battery pack is dead or op Recharge battery pack. If still defective, replace batt pack. Reference paragraph 2.7.

SECTION 7

OPTIONAL ACCESSORIES

7.1 GAS CHROMATOGRAPH (GC) OPTION

7.1.1 INTRODUCTION

The Century Portable Organic Vapor Analyzers (OVA's), when used as described in the previous sections of this manual, are very efficient and accurate indicators of total organic compound concentrations on a continuous sampling basis for a period of eight (8) hours minimum and with a response time of one to two seconds. However, in areas where mixtures of organic vapors are present, it often becomes necessary to determine the relative concentration of the components and/or to make quantitative analysis of specific compounds.

To provide this additional capability, a built-in gas chromatograph (GC) system has been added as an option to the OVA series of instruments. See Figure 7-1-1 for the location of the major components and controls associated with the GC Option. When the GC Option is used as described in this section, the capability of the OVA will include both qualitative and on-the-spot quantitative analysis of specific components present in the ambient environment. The Strip Chart Recorder option, which is used with the GC Option, is described separately in paragraph 7.2.

This section is applicable only to OVA's with the optional gas chromatograph system. It is recommended that this entire section be read, along with the corresponding sections of the basic Operating and Service Manual, prior to operating the instrument.

7.1.2 DESCRIPTION AND LEADING PARTICULARS

7.1.2.1 GENERAL

When the GC Option is installed on a Century OVA, the OVA will have two modes of operation. The first mode is the measurement of total organic vapors in the same manner as described in the basic operating manual for the OVA instrument. This mode is referred to as the "Survey Mode". The OVA will be in the "Survey Mode" of operation whenever the Sample Inject Valve is in the "out" position.

The second mode of operation is called the "GC Mode". The OVA is in this mode of operation any time a sample has been injected into the GC system and the sample is being transported through the GC column. This section provides a brief description of how a gas chromatograph (GC) operates and specifically how the Century instruments perform the required operations. A complete, comprehensive discussion of gas chromatography theory, column selection and data analysis is beyond the scope of this manual.

It should be pointed out that the GC Option was designed to extend the capabilities of the Century OVA as a field type instrument. A "field type" instrument as used herein is defined as a fully portable, self-contained instrument capable of making direct on-site analysis of organic vapors in air. The OVA with GC Option can be utilized for many types of analysis in the outdoor or indoor ambient environment or for specific laboratory type analysis. The OVA was not designed to compete with the research or process type gas chromatograph but to compliment these instruments or eliminate their need in field type applications.

This manual is intended to provide an operato[illegible] sufficient information to operate and maintain the [illegible]tury instrument. Century further publishes Application/Technical Notes to assist the operators in applying the instrument to actual field monitoring situations. The criteria for the design of the GC Option was the same as the basic OVA, that is, simplicity, ease of operation, high reliability, field ruggedness and minimized potential for operator error.

7.1.2.2 PRINCIPLE OF OPERATION

a) GENERAL

For those not specifically trained or familiar with gas chromatography, the technique employed in the OVA during GC Mode operation is basically a separation of components in a sample gas contacted with the material in a column. When non-interference can be achieved, each component of the sample mixture elutes from the column singly into the flame ionization detector chamber to provide its own measurable response on the meter and recorder. When used as directed in this manual, the GC Option can drastically reduce and in most cases eliminate the need for elaborate grab sample and laboratory analysis techniques and the analysis can be made on-the-spot at the point of interest.

All flame ionization detector (FID) gas chromatographs require certain elements for their operation. These elements include [illegible] flow regulated gas supplies as follows: 1) A [illegible]rrier gas (normally nitrogen or helium) to transport the sample through the columns; 2) Hydrogen gas for operation of the FID; 3) A clean air or oxygen supply to support combustion of the FID. In addition, a method for injecting a known volume of sample air (aliquot) to be analyzed is required.

In standard gas chromatographs these three (3) flow regulated gases are individually supplied from pressurized cylinders equipped with regulators and flow control apparatus. The Century GC system differs in that the hydrogen (H_2) fuel for the FID is also used as the carrier gas. The clean air supply is simply the normal air sample pumped to the FID. But, during GC analysis, the air is scrubbed in a charcoal filter to provide a clean air supply. The end result is that no additional gas supplies are required to adapt the GC Option to the basic OVA instrument.

A valving arrangement is incorporated to provide a method for transferring a fixed volume of the air normally being pumped to the FID in the Survey Mode into the GC system for analysis. The sample air injected into the GC system is

the same sample being analyzed by the OVA for total organic vapor concentration. Therefore, the instrument provides the unique capability to observe the total organic vapor concentration of the sample prior to injecting it into the GC system. This operating feature is invaluable in field work where the environment is continually changing and where valuable GC analysis time must be expended only on the samples of concern.

b) SAMPLE FLOW

Figure 7-1-2 is a flow diagram illustrating the flow paths of the hydrogen (H2) fuel, sample air supply and GC injected sample aliquot. There are two push-pull valves used in the GC system, the Sample Inject Valve and the Backflush Valve.

Block D of Figure 7-1-2 illustrates the flow paths with the Sample Inject Valve in the "out" position which leaves the OVA in the Survey Mode. With this valve in the "out" position, the OVA will function in its normal manner as a total organic vapor analyzer.

Block C of Figure 7-1-2 illustrates the flow paths after the Sample Inject Valve is moved to the "in" position to initiate the GC Mode. It can be observed that the hydrogen flow path is now through the sample loop which enables the hydrogen to sweep the air sample from the loop and carry it through the GC column. It can also be observed that the sample air going to the FID chamber is now routed through the activated charcoal filter where essentially all organic vapor contamination is removed from the air. The activated charcoal filter will effectively adsorb most organic vapors with the exception of methane and ethane. The functions of the Sample Inject Valve are, therefore, to transfer a fixed volume sample of the air being monitored into the hydrogen stream and to reroute the sample air supply through a filter (scrubber).

The Backflush Valve has no prepositioning requirement to function. It can be in either the "in" or "out" position at the time a sample is injected into the GC system for analysis. The Backflush Valve simply reverses the direction of the hydrogen flow through the GC column. If the Backflush Valve is in the "out" position during sample injection and analysis, it is simply moved to the "in" position when backflushing is desired or vice versa. See blocks A and B of Figure 7-1-2.

It should be noted in Figure 7-1-2 that hydrogen is always flowing through the column and onto the FID detector and that the sample air supply is always flowing to the FID detector to provide oxygen for the hydrogen flame regardless of the operating mode.

The recommended H2 flow rate is 12 cc/min. for proper FID operation and as a standard flow rate for generating GC reference/calibration data. This H2 flow rate is adjusted by varying the H2 Supply Pressure, which is the hydrogen pressure at the input of the flow control capillary tube of the OVA. The pressure is changed by adjusting the set screw in the bonnet of the low pressure regulator, accessible by removing the battery pack from the instrument panel. To monitor the H2 flow rate, connect a bubble meter to an end of the GC column which has been disconnected from the panel fitting and move the Backflush Valve so that hydrogen is flowing out of the column. Primary H2 flow control is accomplished by the capillary tube of the OVA. However, the flow restriction of a GC column will also affect the H2 flow rate and the effect will vary with column length, type of packing and packing methods. The nominal H2 Supply Pressure is around 10 PSIG and the pressure drop across a typical 24 inch long column packed with 60/80 mesh material is approximately 1 to 1.5 PSIG. Normally, whenthe H2 flow rate is set at 12 cc/min. with a Century standard 24 inch long column, no adjustment needs to be made when using columns from three (3) inches to four (4) feet long. Longer columns may require H2 flow adjustment for proper operation. Adjustment would be required if and when precisely controlled analysis was being conducted or when the hydrogen flow was too low to keep the flame burning.

The sample air flow in the OVA is not adjustable and is nominally 1.0 liter/minute. This flow rate should remain relatively constant. A Sample Flow Gauge is provided on the OVA panel to monitor the sample flow rate. (NOTE: Panel gauge is not calibrated in LPM.) When the Sample Inject Valve is in the "in" position, there may be a slight increase or decrease in sample air flow rate (0 to 15%). This change will normally not affect operation of the instrument as long as the flow rate is consistent from analysis to analysis. Basically, if the sample air flow rate is consistent between calibration and end usage, there will be suitable precision in the measurements.

c) GC ANALYSIS

1) Sample Injection

When the Sample Inject Valve is depressed, the small volume of the input air sample which is in the sample loop is injected into the hydrogen stream which transports the sample through the column for separation of its components and on to the flame chamber for analysis. This small volume of injected sample is, therefore, qualitatively analyzed based on the retention time of the individual components of that sample while passing through the column. Quantitative analysis can then be accomplished by peak height or peak area analysis methods.

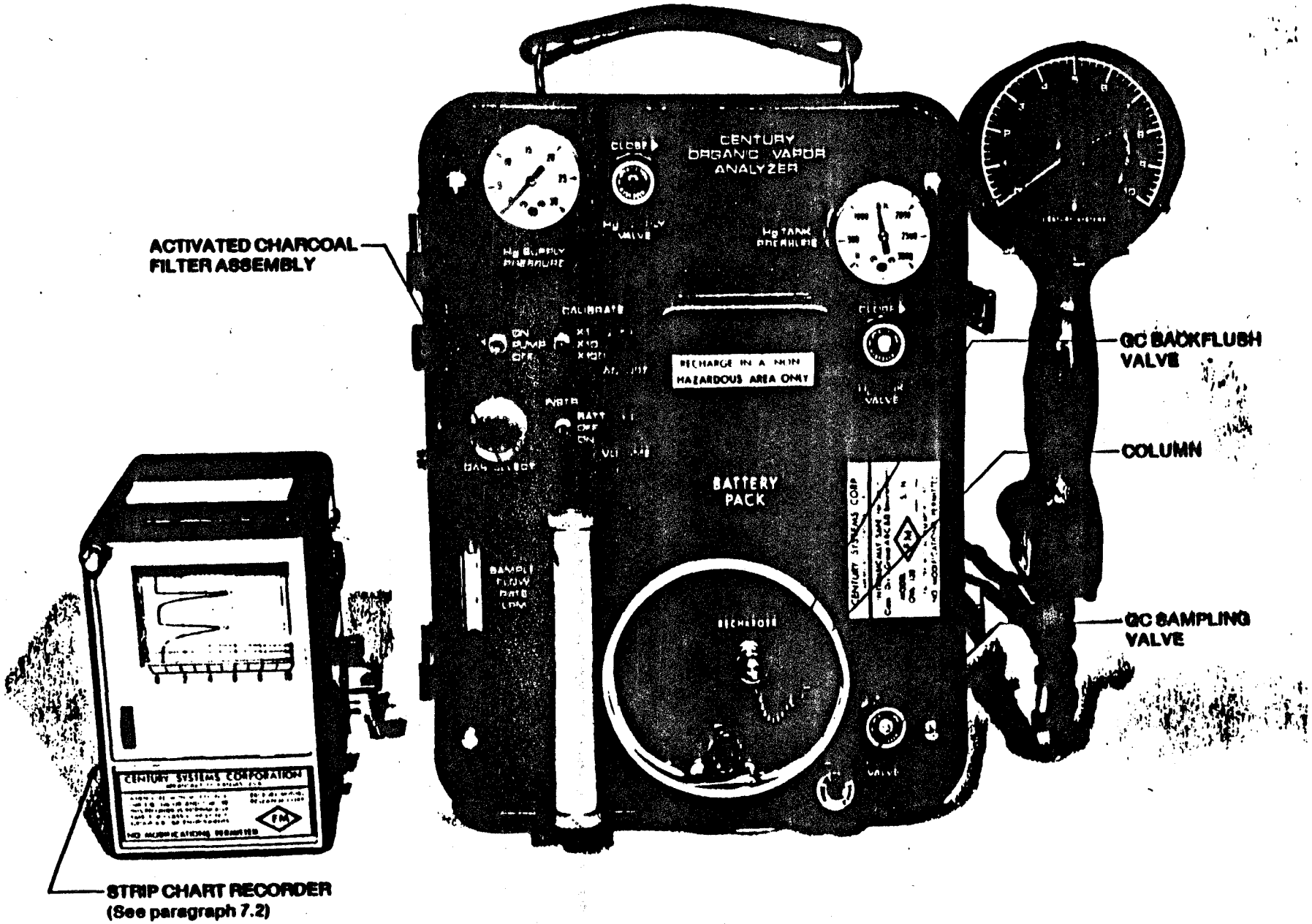


FIGURE 7-1-1. ADDITIONAL CONTROLS & COMPONENTS - GC OPTION

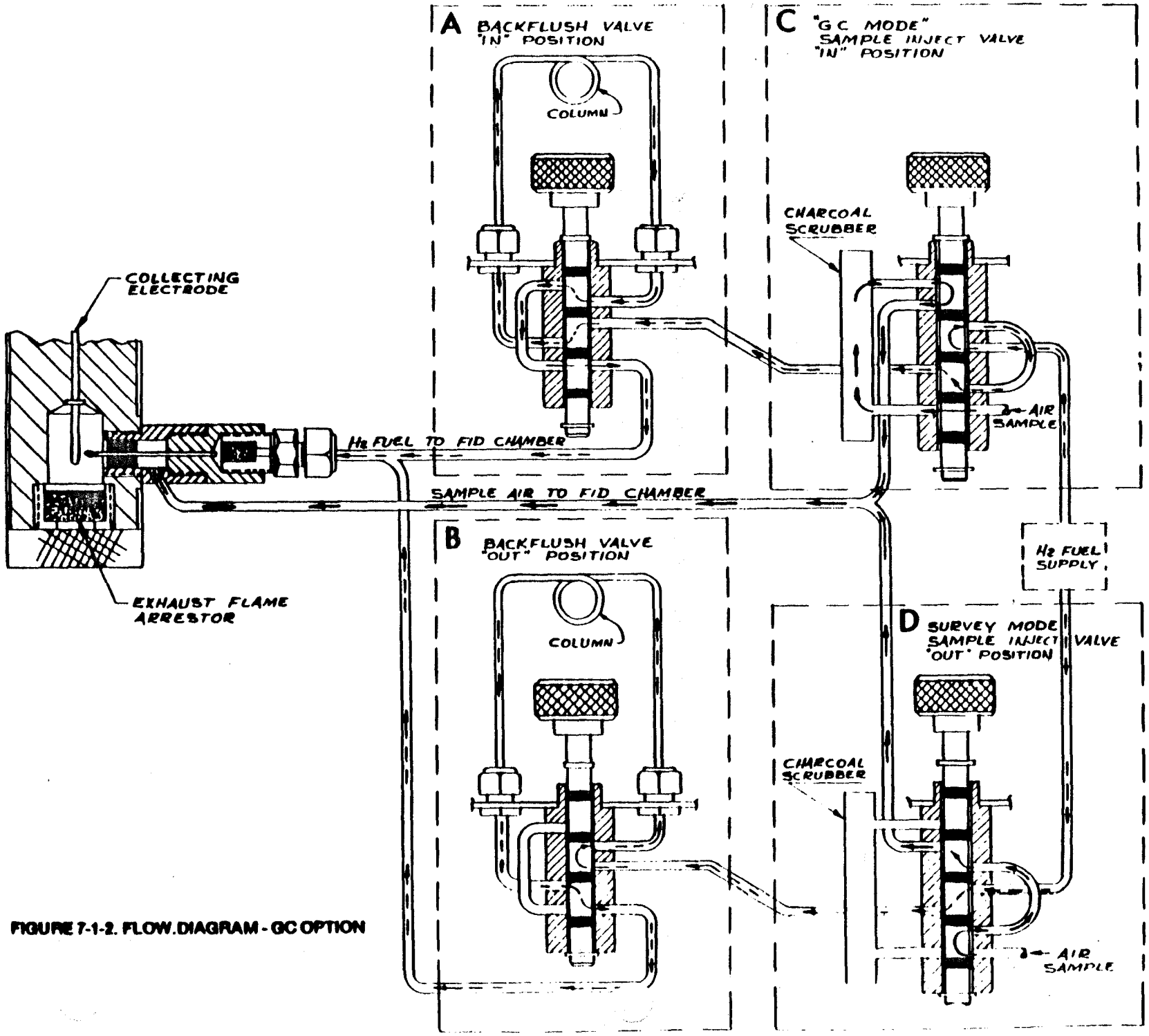


FIGURE 7-1-2. FLOW DIAGRAM - GC OPTION

2) The Column

The column consists of tubing packed with a material which physically interacts with the organic vapors in the air sample in a manner which slows down the passage of the vapors through the column. Since the packing material has a different attraction for each individual organic substance, each component in a mixture of gases will be slowed down to a different extent when passed through the column. The net effect is a separation of the gases in such a way that each component elutes from the column at a different time. The individual gases are then automatically fed to the detector which gives a response to the meter or to an external strip chart recorder. For example: Suppose that a sample containing benzene and toluene is injected onto the column containing appropriate packing material. As illustrated in Figure 7-1-3, a portion of the benzene and toluene are adsorbed on the packing material. The amounts involved depends on the relative affinities of the two components for the packing material. The carrier gas moves the gaseous phase forward a short distance, and since benzene will have less affinity than does toluene, it will be moved through the column more readily and thus a separation of these two components takes place and benzene reaches the detector at the exit of the column first.

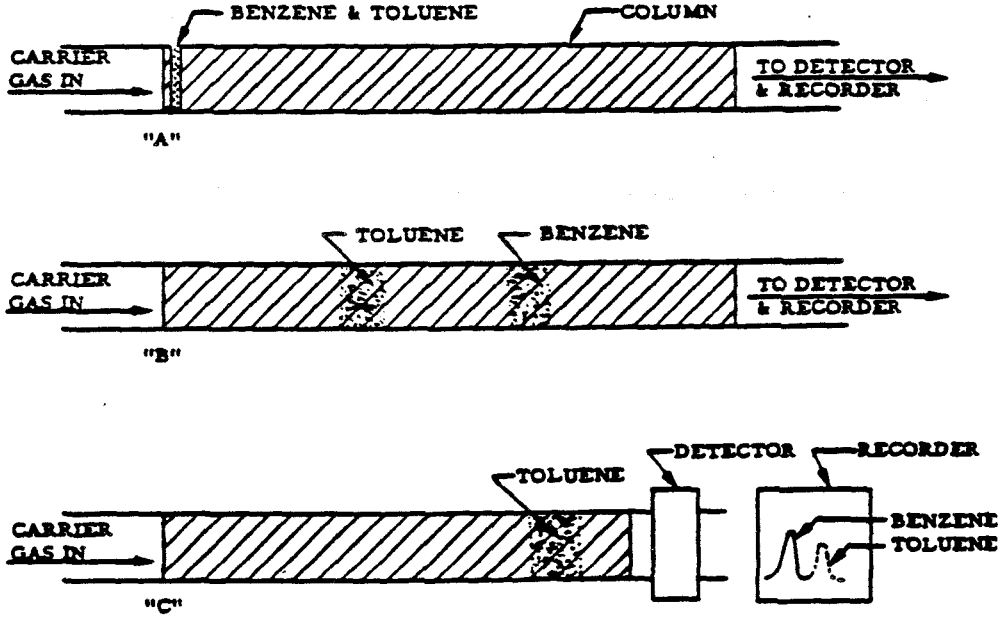
3) Qualitative Analysis

As each organic substance has a unique interaction with the column packing material, the time that the substance is retained on the column is also unique and thus characteristic of that particular substance. The "retention time" (RT) is primarily dependent on the type of packing material, the length of the column, the flow rate of the gas carrying the mixture through the column and the temperature range of the system.

When these variables are controlled, the retention times can be used to identify each of the components in a mixture. Because of these variables, it is usually necessary to establish retention times for each instrument by making a test with the pure substances of interest or to refer to established time data charts prepared in advance for that specific instrument. In those cases where retention times of the components are too close together for a good analysis, an adjustment in one or more of the operating variables will effect a sufficient difference in retention times to enable meaningful analysis.

4) Quantitative Analysis

The response of the detector to any component after it has been separated by the column is proportional to the quantity of organic material passing through the detector at any given time. However, since



PICTORIAL SEPARATION OF BENZENE AND TOLUENE - "A" AT BEGINNING OF SEPARATION; "B" DURING SEPARATION; "C" BENZENE HAS ALREADY PASSED THE DETECTOR AND IS RECORDED. TOLUENE (DOTTED LINES) WILL APPEAR ON RECORDER AS IT PASSES THE DETECTOR.

FIGURE 7-1-3. TYPICAL COLUMN SEPARATION SEQUENCE

not all of the separated components elute from the column at the same instant, but varies from low to a maximum and then falls to ambient again, it is necessary to have a means to measure the total amount of the individual component vapors. When using a strip chart recorder, the curve drawn on the paper is triangularly shaped and the area under the peak is related to the amount of substance being analyzed. For the OVA systems which have logarithmic outputs, direct measurement of areas under the peak is extremely difficult. The methods of peak height analysis described herein provide a convenient means for quantitatively interpreting peaks when operating either the logarithmic or linear readout OVA's.

5) Backflush

The column Backflush Valve is provided to reverse the flow of the carrier gas (hydrogen) through the column. It is necessary that the column be backflushed after each individual analysis except under certain special conditions. The primary purpose of the backflush function is to clear the column of heavy compounds (with long retention times) which would contaminate the column and cause interference to the total organic reading and future GC analysis. The Backflush Valve has no "sense" (prepositioning requirement). It is simply reversed from either position it was in during GC analysis. The Backflush Valve should be actuated immediately after the peak of the last compound of interest elutes. Figure 7-1-2 illustrates the functions of the Backflush Valve.

In the Century GC system, the backflush is "to the detector". This is possible due to the fact that the carrier gas and detector fuel are one in the same, i.e., hydrogen. The backflush function, therefore, provides a convenient means of quantifying the total compounds in the backflush by simply recording the peak that elutes during the backflush operation. For field type instruments, this quantitative backflush information is very valuable. The backflush to detector also provides a direct means of observing the condition of the column and seeing when the column is clean and the detector response has returned to baseline. The time required for the backflush is usually 1.2 to 1.5 times the GC analysis time.

6) Survey to GC Mode Interface

There is an inherent advantage to integrating the GC system to the basic total Organic Vapor Analyzer (OVA). The OVA provides a direct reading of total organic vapors present in the air being sampled, which provides the operator with intelligence of what he is injecting into the GC system. He can then use this information to predict and verify the peaks that result during the GC analysis, including the backflush peak.

This feature completely eliminates expending valuable GC analysis time where there is no contamination concentrations of concern (comparable to taking noise measurements in quiet corners). This "front end" intelligence also enables the operator to select the most appropriate location to conduct an analysis, which is normally the area of highest concentration.

7.1.3 OPERATING PROCEDURES

7.1.3.1 GENERAL

The Gas Chromatograph (GC) Option is a supplementary system which is built into the OVA instrument during manufacture. This system provides an additional gas chromatographic analysis (GC Mode) of operation which can be initiated at any time during a survey by simply depressing the Sample Inject Valve. After completion of the analysis and backflush operations, the Sample Inject Valve is pulled out and the survey continued or another sample injected. Note that when the Sample Inject Valve is in the out (Survey Mode) position the OVA operates in . the same manner as a standard OVA which does not incorporate the GC Option.

7.1.3.2 GC SYSTEM CONTROLS AND COMPONENTS

Refer to Figure 7-1-1 for a view of the four (4) basic controls and system components provided in the GC Option. Table 7-1-1 below describes their functions.

TABLE 7-1-1
GC OPTION-COMPONENTS

Controls/Indicators — Function

1) Sample Inject Valve - This 2 position valve (shown schematically in Figure 7-1-2) is used to select either Survey Mode (valve out) or GC Mode (valve in).
2) Backflush Valve - This 2 position valve (shown schematically in Figure 7-1-2) is used to reverse the flow of H_2 through the column to:
   a) Backflush the column for clearing
   b) Quantitatively measure total compounds after a selected point. Example: Separation of methane from non-methane hydrocarbons to read total non-methane hydrocarbon level.
3) Column - Separates components of a gas mixture so that each component of the mixture elutes from the column at a different time.
4) Activated Charcoal Filter Assembly - This assembly functions only in the GC Mode (Sample Inject Valve "in") as shown schematically in Figure 7-1-2. It removes organic compounds (except simple C_1 and C_2 hydrocarbons) by adsorption from the sample air supply.

7.1.3.3 SERVICING AND TURN ON

Place the Sample Inject Valve in the "out" position and put the OVA instrument in operation per Section 2 of this manual. NOTE: Leave the hydrogen fuel and pump "on" for three (3) to four (4) minutes before attempting ignition to enable hydrogen purging of the column.

7.1.3.4 SURVEY MODE OPERATION

When using the OVA in the Survey Mode, ensure that the Sample Inject Valve remains in the full "out" position and that the Backflush Valve is either full "in" or full "out". Note that when changing from the GC Mode to the Survey Mode the OVA output readings will continue to change as long as any compounds are still eluting from the GC column. Therefore, under normal field conditions, the GC column should be backflushed for clearing, which takes approximately 1.2 to 1.5 times the already elapsed forward analysis time. The backflush peak may be observed returning to baseline, after which the Sample Inject Valve may be moved to the Survey Mode (out) position.

When the compound(s) being analyzed are known to be the only compound(s) present in the air sample, backflushing may be omitted.

7.1.3.5 GC MODE OPERATION

In normal GC analysis, a strip chart recorder is used to record the output concentration from the OVA as a function of time. This record, called a chromatogram, is utilized for interpretation of the GC data. The Century portable strip chart recorder is further described in paragraph 7.2.

a) OPERATION

1) Turn on recorder and push Sample Inject Valve "in" with a fast, positive motion. This starts the GC analysis which is automatic up to the point of backflushing. NOTE: Rapid and positive motion should be used when moving either the Sample Inject or Backflush Valves. On occasion, the flame in the FID detector may go out, which would be indicated by a sharp and continued drop of the concentration level. If this occurs, simply reignite the flame in the normal manner and continue the analysis. NOTE: A negative "air" peak typically occurs shortly after sample injection and should not be confused as flame-out.

2) The negative air peak and various positive compound peaks will be indicated on the OVA readout meter and the strip chart recorder and represent the chromatogram of the analysis.

3) After the predetermined time for the analysis has elapsed (normally immediately after the peak of the last compound of concern), rapidly move the Backflush Valve to it's alternate position (in or out). Leave the instrument in this condition until the backflush peak printed on the recorder returns to baseline, then pull the Sample Inject Valve to the "out" position. If no backflush peak appears, pull the Sample Inject Valve out after being in the backflush condition for a period at least as long as the analysis time. The OVA is now back in Survey Mode and ready for survey us injection of another sample into the GC system.

b) INTERPRETATION OF RESULTS

Interpretation of the recorded chromatogram is always based on predetermined calibration data. A discussion of calibration methods and chromatogram interpretation is presented in paragraph 7.1.4.

7.1.4 CALIBRATION

7.1.4.1 GENERAL

The Century OVA with GC Option is a field instrument intended for applications where there are a limited number of compounds of interest and the compounds are normally known. Under these field conditions, the operator must simply know the retention time and peak height characteristics of the compounds of interest as normally presented on his OVA instrument under his specific operating conditions. Therefore, to calibrate the OVA in the GC Mode, simply determine by test the retention time and peak area (using peak height analysis) characteristics for the compounds of concern. These tests should be conducted on the column to be utilized and over the concentration and temperature range of concern. When representative characteristic data is available, such as in the Century Application/Technical Notes, a spot calibration check is normally all that is required.

It should be noted that under normal field condit the vapor concentrations vary continually as a func of time, location and conditions. Field measurements for industrial hygiene work are normally associated with a threshold level around a preestablished concentration. Surveys for locating fugative emission sources present a continually varying situation. Under these typical field conditions, it is desirable to have a fast and simple method of interpreting the GC data for on-the-spot analysis and decision making. High precision is normally not a requirement for these type analysis since the environment is continually changing. The methods presented in this section are designed to provide a means for typical field analysis. When the OVA is used under laboratory conditions, standard laboratory methodology may be used for greater precision.

7.1.4.2 TECHNICAL DISCUSSION

The chromatogram is a strip chart recorder printout of the instantaneous organic vapor concentration from the Century Organic Vapor Analyzer (OVA) as a function of time. A typical chromatogram is illustrated in Figure 7-1-4 and is seen to be a series of triangular shape peaks originating and returning to a fixed baseline. Qualitative interpretation of a chromatogram involves identifying the compound causing a peak by analyzing the time it took for the peak to appear after initial injection (referred to as retention time (RT)) and comparing this RT to

reference data. Quantitative interpretation of a peak involves analyzing the area under the peak and relating this area to calibration data of peak area versus concentration for that specific compound under the conditions present during the GC analysis.

It can therefore be seen that interpretation of a chromatogram requires the use of calibration reference data. GC reference data is always generated empirically, i.e., through tests. Century publishes Application/Technical Notes which may be used as a reference for selecting columns and interpreting chromatograms. However, in most cases, certain relatively simple tests must be conducted to obtain the required reference data. A method for obtaining this type data and applying it to a calibration chart is presented along with a typical example of the exercise.

a) QUALITATIVE ANALYSIS

Under a given set of operating conditions, the retention time is characteristic of that particular substance, and can be used to identify specific compounds. It will be necessary to calibrate retention times by making tests with the pure compounds of interest.

The retention time (RT) is defined as that period of time from injection of the sample into the GC system until the point of maximum detector response for each substance. Retention time is measured from the point of sample injection to the apex of the triangle shaped curve obtained on the strip chart recorder. (See Figure 7-1-4.)

The strip chart recorder operates on a clock mechanism such that the distance along the baseline is proportional to time. While retention times are characteristic for each compound, it is possible that two materials could have the same retention times. Thus, if there is any question as to the identity of the vapor, it may be necessary to verify identification by retention times on two different columns.

Use of a longer column will increase the retention times of those components it is capable of separating. The time between peaks will therefore also be increased. This is especially useful to know if a component to be studied comes through too fast after injecting a sample or if certain desired peaks are so close that they overlap on the strip chart.

b) COLUMN SELECTION

Two columns are normally supplied with the instrument. These are general purpose columns and are useful in a wide variety of applications. If they do not perform the separations for your particular application, it may be necessary to select other packing materials or lengths of columns to meet your needs. Century Systems will guide you in this selection or prepare a custom column to meet your needs.

If columns are made by the customer or purchased from other sources, care must be exercised to ensure that their packing density does not create too large a pressure drop as compared to columns furnished by Century. Century's method of coding it's GC columns is presented on most Century published Application/Technical Notes. Several application notes have been inserted as an appendix to this manual to illustrate typical GC separations.

c) TEMPERATURE EFFECT ON RETENTION TIME

An increase in temperature will decrease column retention time (RT) and vice versa. Normally, retention time (RT) as a function of temperature changes linearly over the range of 0 to 40°C. For complex qualitative analysis, a calibration plot of RT versus temperature will be required. In typical ambient field usage such as inside a factory, the effect of temperature can be compensated for by the operator during chromatogram interpretation. A single component tracer compound can be sampled at any time to provide a "key" for other compound identification.

d) CARRIER GAS FLOW RATE EFFECT ON RETENTION TIME

An increase in carrier gas flow rate will decrease retention time. For reproducible data, the carrier gas (hydrogen) flow rate must be recorded in association with a chromatogram. Primary control of the H2 flow rate is accomplished in the OVA by regulating the hydrogen pressure across a capillary tube. The hydrogen flow rate is also affected by the restriction of the GC column but most columns have a limited effect. The hydrogen flow rate is factory set at 12 cc/minute with a typical 24 inch column.

e) QUANTITATIVE ANALYSIS

The area under a specific peak is a function of the concentration of the compound which created the peak. This area can be calibrated by injecting known concentrations of the compound. When the base of a symmetrical GC peak remains constant, the height of the peak may be used to measure the area. Typically, as the retention time of a peak increases on the same column, the base broadens and the peak height decreases for a given sample concentration. If the hydrogen flow rate is considered to be constant, the retention time of the peak will change as a function of temperature.

In general, the more triangularly symmetrical the peak, the better the peak height analysis capability. However, many GC peaks have "tailing" as illustrated in Figure 7-1-4. Peak height calibration is still an acceptable method for quantitative analysis as long as the area under the tail is small compared with the total peak area. If severe tailing occurs, empirical calibration data generated through tests may be required to plot the peak height versus the concentration curve. If the GC Option is used on a Century "logarithmic" OVA, there will be a major apparent increase in peak tailing. This apparent tailing is the result of the logarithmic

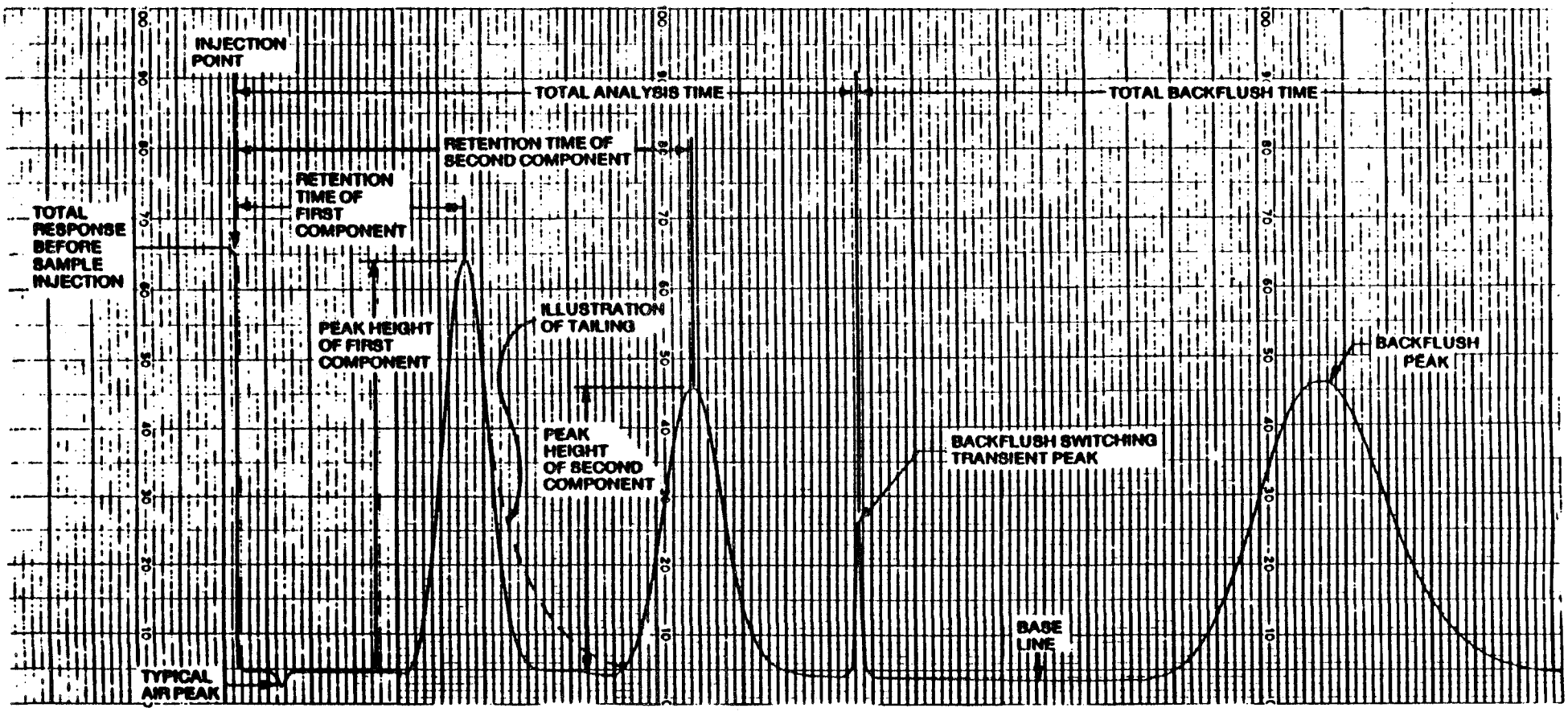


FIG. 7-1-4

TYPICAL CHROMATOGRAM (ILLUSTRATION)

scaling, which amplifies the low level signals. This apparent tailing does not appear on the "linear" OVA's, even though the same actual tailing is present.

Only peak height analysis will be discussed in this manual. The method presented is simply to inject a known concentration of the compound being tested and record the height of the peak under the test conditions. The peak height characteristics can be established for various columns and at various temperatures. Normally, both retention time and peak height characteristics will be measured simultaneously during the same test.

When peak area measurements are desired, the areas may be measured using an integrator on the OVA output signal. Other manual methods may also be used, such as counting squares, weighing curves or simple triangulation. When the GC peaks have good symmetry, triangulation (area equals 1/2 base x height) is a convenient method.

7.1.4.3 PREPARATION OF CALIBRATION SAMPLES

Samples for calibration of the GC system may be prepared with the procedures discussed in paragraph 4.3.3 of this manual. Sample mixtures are made by repeating the procedures presented for the compounds desired in the sample.

7.1.4.4 CALIBRATION DATA

When conducting tests to obtain GC calibration data, the following information should be recorded to qualify the data:

a) Column - description and serial number as applicable
b) Temperature - column temperature, normally room ambient
c) Chart speed - distance/unit time
d) Carrier flow rate - hydrogen flow rate through the column (cc/min.). (Reference paragraph 7.1.2.2 b)
e) Sample concentration - ppm for each compound
f) Sample volume - OVA by serial number or typically 0.25 cc for standard valve
g) Recorder scaling - ppm per unit deflection
h) Range - range of OVA being used, i.e., X1, X10, X100
i) OVA type and serial number

To obtain a calibration point, inject a known concentration sample into the GC system and record the resulting chromatogram peak. The retention time for the peak may be scaled from the record or timed with a stop watch. The peak height may be scaled from the record or the OVA readout meter may be observed during the elution of the peak. Figure 7-1-5 presents the format of a chart which may be used to record calibration data. Experience has indicated that the peak height response of a compound is linear up to concentrations of greater than 1,000 ppm. Therefore, a single calibration point, preferably around the concentration of most concern, is normally all that is required to plot a peak height response in ppm as a function of compound concentration. Data for other compounds on the same column may also be plotted along with their associated retention times, percent relative response in the total organic Survey Mode, TLV, etc. Note that to keep the calibration curves readable on the chart a multiplier (X) column is included. It is recommended that copies of the actual chromatograms be kept with the charts for observing the peak shapes, peak interferences, etc. It should be noted that a chromatogram can be utilized like a fingerprint for compound identification or peak height and shape comparison. Transparent overlays are sometimes an aid in chromatogram analysis.

When temperature variations are anticipated, data should be taken at several points and recorded on the chart as a new curve or as a relative change as a function of temperature as illustrated in Figure 7-1-5.

Preparing and using the calibration chart is very straightforward. As an example, once the elution sequence of a group of compounds is determined, a mixture of 100 ppm of each can be prepared and run on the GC for chart data. The retention time of each compound and the peak height of each can be read directly from the chromatogram and the data put on the chart. If temperature data is to be taken, additional chromatograms may be run with the same sample and the RT and peak height plotted as a function of temperature.

When complex mixtures such as gasoline are analyzed, it may be desirable to keep the record of the backflush peak for future reference and peak area comcomparison. It is also recommended that the total organic vapor concentration reading on the OVA be recorded for each calibration sample used. This reading should be put on the chromatogram and is used for arriving at relative response numbers and as a check on sample preparation precision.

Samples of forms for use in recording individual chromatogram data and also a sample form for the calibration chart are included in Appendix "A" and may be used as a guide or copied and used as is.

7.1.5 MAINTENANCE

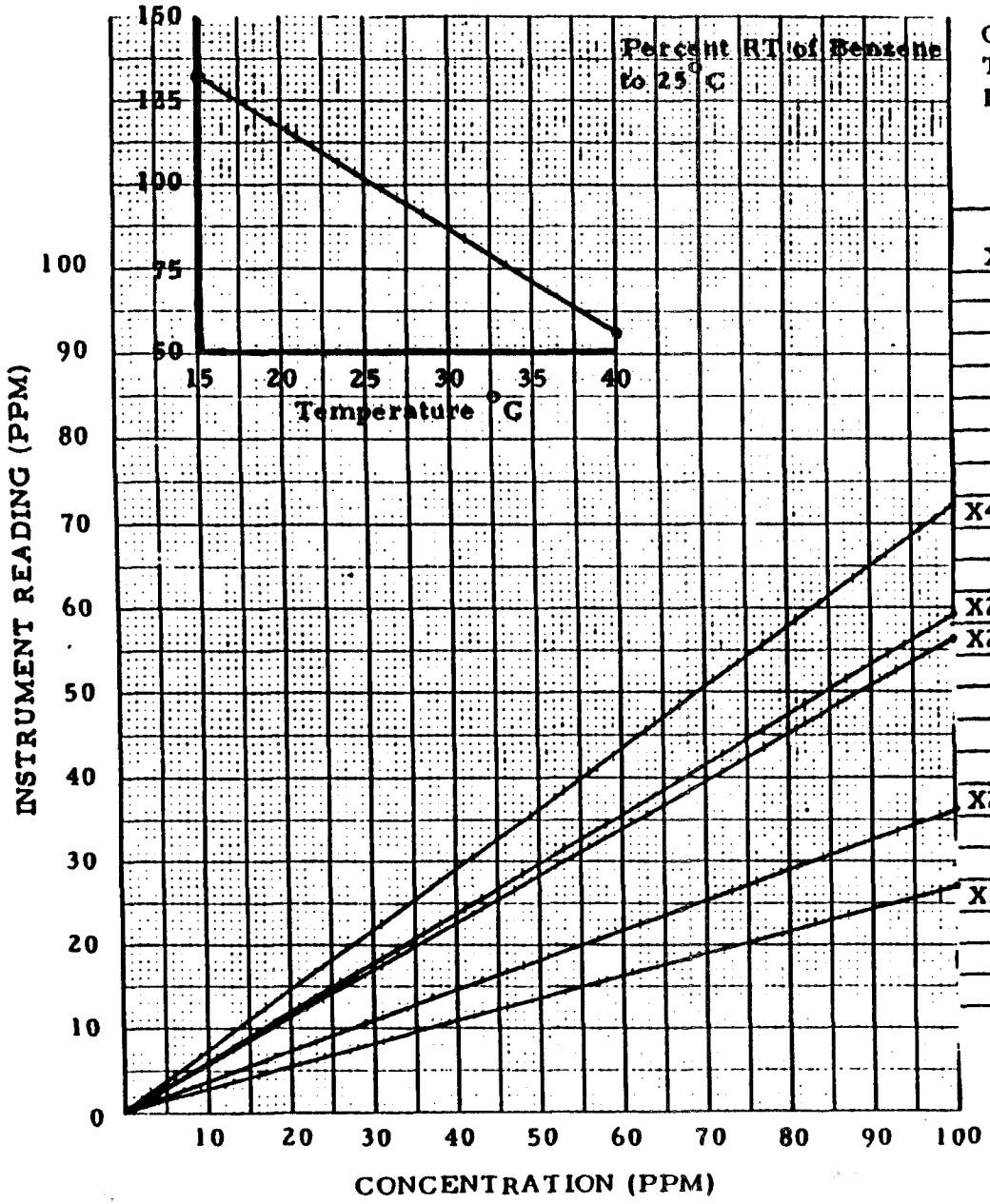
7.1.5.1 GENERAL

This section describes the routine maintenance, trouble shooting and spare parts peculiar only to the Gas Chromatograph (GC) Option.

7.1.5.2 ROUTINE MAINTENANCE

a) COLUMN

Any column can be contaminated with compounds having long retention times. This will result in high background readings. This condition can be checked by installing a new column or a blank column (tubing only). If this reduces the background reading, the contaminated column should be baked at 100°C (212°F) for three (3) to four (4) hours in a drying oven while passing nitrogen through the column. Higher



Column G-48 Chromatograph OVA-118
Temperature 25 °C Carrier Flow 12 ml/sec.
Injection: Volume 2.5 ml Type valve

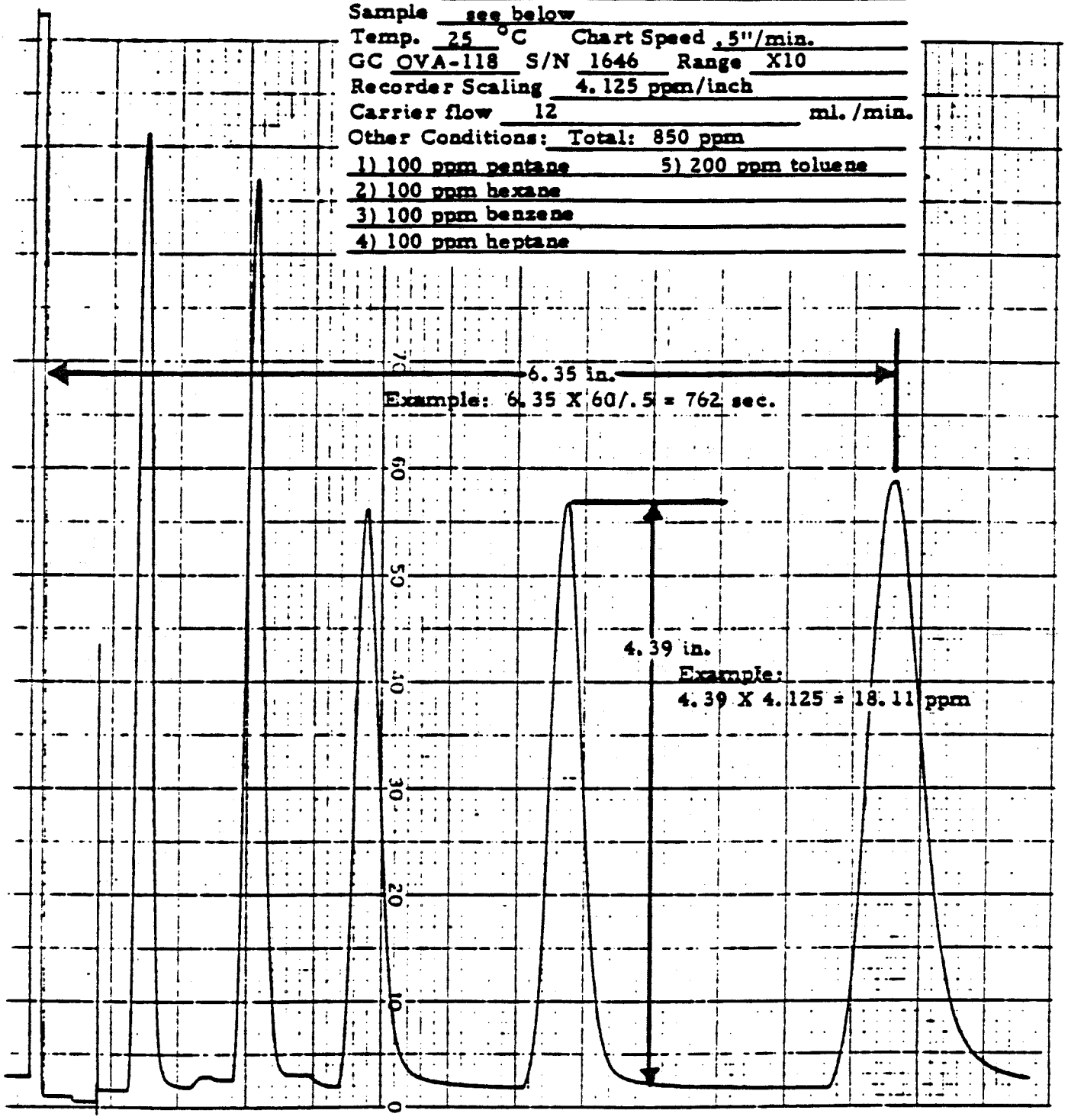
X	Compound	R. R. (%)	RT (sec)	Date	TLV (ppm)
X4	Heptane	80	471	1-31-78	400
X2	Pentane	100	90	1-31-78	1000
X2	Hexane	90	198	1-31-78	100
X2	Benzene	150	291	1-31-78	1
X3	Toluene	120	762	1-31-78	200

NOTE: Concentration used for test is 100 ppm or as indicated by marked data points.

COMMENTS:

FIGURE 7-1-5. CALIBRATION C

Date 1/31/78 Type Injection 2.5 ml valve
Column 510454-G-48
Sample see below
Temp. 25 °C Chart Speed .5"/min.
GC OVA-118 S/N 1646 Range X10
Recorder Scaling 4.125 ppm/inch
Carrier flow 12 ml./min.
Other Conditions: Total: 850 ppm
1) 100 ppm pentane 5) 200 ppm toluene
2) 100 ppm hexane
3) 100 ppm benzene
4) 100 ppm heptane



temperatures may permanently damage the column packing. Columns may be cleaned while installed on the OVA by heating the column with hot, wet towels.

When installing any column, avoid touching the ends, as this may cause contamination. Also, ensure that the fittings are tight to avoid H2 leakage.

IMPORTANT: The following simple test may be run to determine whether the GC column is contaminated. While in a clean ambient air background, place the Sample Inject Valve in the "in" (GC Mode) position. Observe the background reading on the meter or recorder. After one (1) to two (2) minutes, change the position of the Backflush Valve and again observe the background reading. If the background reading went down when the Backflush Valve was actuated and then started to increase in one (1) to two (2) minutes, the column is probably contaminated and needs to be cleaned. Note that if hydrogen is flowing into one end of the column for a period of time, the contamination is being pushed into the column and is therefore cleaning the front endportion of the column. Then when the hydrogen flow is reversed, the exhaust end of the column will be what was the input end previously. Therefore, for a period of time the now exhaust end of the column will be clean until the contamination is again pushed through. Remember that to clean a column the hydrogen or other purge gas must be run through the column in one direction until all of the contamination is removed. NOTE: Contaminated columns can be avoided by simply backflushing the column after every analysis.

b) CHARCOAL FILTER ASSEMBLY

After repeated use, the Charcoal Filter Assembly will become saturated. Periodically, the operator should check the effectiveness of the activated charcoal to perform its screening function. This can easily be done by operating the unit with the Sample Inject Valve "in" and passing the probe near a concentrated sample of the compounds being analyzed. The readout should remain nearly steady (should not rise more than 0-2 parts per million (ppm)). If rise is more than 2 ppm, remove assembly from the panel and pull the knurled cap from the end of the filter tube (pull—not twist), and replace the old charcoal with activated charcoal (Barnebey Cheney, Columbus, Ohio, Type GI or equivalent). Care should be taken to completely fill the tube so there will not be a path for the sample to bypass the charcoal. The life of the charcoal depends on the time (length) of exposure and the concentration level during that exposure. When changing charcoal, be sure that any fine particle charcoal dust is removed from the assembly.

Another simple test of the charcoal filter is to note the background reading with the Sample Inject Valve "out" and then note the baseline reading with the valve "in". The level should never be higher when the valve is in the position and the charcoal filter is in the air . . . If the reading with the valve in the "in" position is higher, the charcoal filter is probably contaminated and acting like a contamination emitter.

Characteristics of the recommended activated charcoal are provided below:

Raw Material: Coconut Shell

Nominal Mesh Size: 8 x 14 (Tyler Standard Screens)

Size Distribution: On 8 mesh, 5% maximum; through 8 on 10, 60% maximum; through 10 on 14, 60% maximum; through 14 mesh, 5% maximum

Ash: 6% maximum

Moisture Content: 3% maximum, as packed

Standard Packages: 50 lbs. net weight fiber container; 58 lbs. gross weight (typical). 1 lb. container, shipping weight approximately 1-1/2 lbs. Carton containing 12 each 1 lb. units, shipping weight approximately 16 lbs.

Applications: Removal of medium and high concentrations of organic vapors from air. Purification of gases. Safety respirators. Gas separation.

7.1.5.3 TROUBLE SHOOTING

Table 7-1-2 presents recommended field trouble shooting procedures which are peculiar to the GC system. These procedures are in addition to tr found in Table 6-1 of the basic manual.

7.1.5.4 RECOMMENDED SPARES

Spare parts and supplies which are recommended to support only the GC system (and recorder) are as follows:

Item	Description	Part Number	Quantity
1)	Quad Rings	510496-1 (10/pkg.)	1 pkg.
2)	Tubing, Teflon	.148" ID x .020 wall	12"
3)	Tubing, Teflon	.120" ID x .030 wall	12"
4)	Activated Charcoal	Type GI or equivalent	1 lb.
5)	"O" Ring	2-15	2
6)	Chart Paper (log)	Type "J" (6 rls./pkg.)	2 pkg.
7)	Chart Paper (linear)	Type "WA" (6 rls./pkg.)	2 pkg.

Activated charcoal may be purchased direct from:

Barnebey Cheney
825 North Cassady
Columbus, Ohio 43219
(614) 258-9501

Chart paper may be purchased direct from:

Gulton Recorder Systems Div.
Gulton Industrial Park
East Greenwich, Rhode Island 02818
(401) 884-6800

TABL 7-1-2

ROUBLE	TROUBLE SHOOTING PROCEDURE	REMEDY
1) Low sample flow rate on flow indicator	a) Check teflon tubing on valve assembly for kinks, etc. b) Check flow rate with valve in down position.	Straighten or replace teflon tubing Check for over restriction of charcoal filter
2) H2 flame will not light	a) Check column connections on top of unit to make sure they are tight. b) Check column for sharp bends or kinks. (Hydrogen flows through this column at all times and a sharp bend will compact packing too tightly for proper hydrogen flow.) c) Check charcoal filter fittings to make sure they are tight. d) Check H2 flow rate from the column. e) Check that the Inject and Backflush Valves are both completely in or out. A partially activated valve will block the H2 and air flow paths. f) If a new column was installed prior to problem identification, check for proper hydrogen flow rate through the column (should be approximately 12 cc/minute). Reference paragraph 7.1.4.2 d.	Tighten fittings Replace column Tighten fittings Adjust hydrogen pressure to obtain 12 cc/min. flow rat Ensure both valves are either completely in or out. Increase hydrogen pressure to obtain proper hydroge flow rate or if column is excessively restrictive, replac or repack the column.
3) Ambient background reading in clean environment is too high	a) Check for contamination in charcoal filter assembly. This can be detected if ambient reading increases when going in to the chromatographic mode. Reference paragraph 7.1.5.2 b. b) Check for contamination in column. Reference paragraph 7.1.5.2 a c) Check for contamination in column valve assembly.	Replace activated charcoal in charcoal filter assembly. Replace or clean column. Remove valve stems and wipe with clean lint-free cloth Heat valve assembly during operation to vaporize an remove contaminants.
4) Flame-out when operating either valve	a) Ensure valves are being operated with a quick, positive motion. b) Either H2 or air may be leaking around one or more of the valve quad rings. Assess by tests and "O" ring inspection. c) Damaged or worn quad rings causing leak.	Operate valve with a positive motion. Remove stems and lightly coat with silicone grease, on ly on contact surface of the "O" ring.Wipe off excess (do not remove quad rings). Replace quad rings and grease as above.
5) Excessive peak tailing	a) Change or clean GC column and see if problem disappears. b) Inspect GC valves for excessive silicone grease or contamination.	Ensure columns are clean prior to use. Refer to paragraph 7.1.5.2 a for cleaning instructions. If one of a same type of column tails worse than others, repack the column or discard. Excessive lubricant or foreign matter in the valve assembly can cause excessive tailing. Clean valve assemblies and lightly relubricate as required. Lubricant should be put only on the outside contact surface of the "O" ring. Do not get grease into "O" ring

7.2 RECORDER OPTION

7.2.1 GENERAL

A Portable Strip Chart Recorder is available from Century for use with the OVA instruments (reference Figure 7-2-1). The recorder is powered from the OVA battery pack and the output can be scaled to match the OVA readout meter, thereby providing a permanent record for subsequent analysis or reference. The recorder is available in two models. P/N 510445-1 is used with standard Models OVA-88, OVA-98 and OVA-118. P/N 510445-2 is certified intrinsically safe and is used with the certified Models OVA-108, OVA-128 and OVA-138.

7.2.2 APPLICATIONS

The recorder can be used with the OVA to provide a record of the long term monitoring profile of an area in total organic vapor concentrations, or can be used with the Gas Chromatograph Option to provide a chromatogram of the GC analysis.

7.2.3 FEATURES

The recorder prints dry (no ink) on pressure sensitive chart paper. Housed in rugged die-cast aluminum, it weighs approximately four (4) pounds and is 5-5/8" high, 3-5/8" wide and 4-1/8" deep.

The recorder is available for use with either the Century logarithmic or linear scaled OVA's by simply changing the scale and paper style. The recorder is equipped with two gain ranges and an electronic zero adjustment control. The HIGH gain position is normally used only with the logarithmic OVA to provide a means of scale expansion.

7.2.4 CONTROLS AND CONNECTIONS

Described below are the functions of the various controls and connectors. Reference Figure 7-2-1.

Controls and Connections—Function

1) HIGH-LOW Switch - This switch, located on the right hand side of the recorder, provides 2 ranges. The LOW range is set for the same full scale reading as the OVA readout meter. The HIGH range can be set to give an increased sensitivity to the recorder without effecting the OVA calibration.
2) ZERO ADJUST Knob - This potentiometer, also located on the right hand side of the recorder, permits "nulling" of the background reading on the recorder only (without affecting the calibration of the OVA as displayed on the OVA readout meter). In the full clockwise position of the knob, the recorder will display the same reading as the OVA meter. Counterclockwise rotation will reduce the reading on the recorder only.
3) Power Connector - This 126 series, 5 pin Amphenol connector provides power and signal to the recorder, as follows:

Standard 510445-1	FM 510445-2	Function
A	B	Input signal
E	E	pos. 12VDC input
H	H	Ground

7.2.5 OPERATING PROCEDURES

Connect cable between recorder and OVA. Turn recorder on by selecting either the HIGH or LOW position of the switch. (Normal is "LOW".)

When using the HIGH gain position (typically only logarithmic OVA's), it may be desirable to "null" out the background on the recorder. To accomplish this, provide clean air to the OVA or place a charcoal filter in line with the OVA input to establish a "zero" reference and use the ZERO ADJUST Knob to set the recorder needle to the zero line. Remove the filter and the instrument and recorder are ready for use. NOTE: During normal survey use, it is best to turn the recorder off to conserve paper and battery power.

7.2.6 CALIBRATION

7.2.6.1 GENERAL

Electronic and mechanical adjustments, other than the operational adjustments on the side panel, are provided to calibrate and align the recorder.

7.2.6.2 MECHANICAL ZERO ADJUSTMENT

a) Snap out the front panel nameplate (using a small blade screwdriver in the left hand slot) for access to mechanical zero adjust screw, place HIGH-LOW Switch in OFF position.
b) Unscrew knurled fastener at top left of front panel, open recorder. Pull down plastic chassis latch on right side to release sticker bar tension on paper and adjust mechanical zero as required. Replace nameplate, chassis latch and resecure front panel.

7.2.6.3 GAIN ADJUSTMENT

Separate adjustments are provided for the HIGH and LOW ranges on the recorder. (Refer to Figure 7-2-1 for location.)

a) Connect recorder to OVA and adjust OVA for full scale reading on readout (about 5 VDC).
b) Loosen knurled fastener on upper left of the front panel and pull front panel down.
c) Place HIGH-LOW Switch in LOW and adjust R1 until recorder prints full scale.
d) Place HIGH-LOW Switch in HIGH and adjust OVA to read the desired full scale with front panel CALIBRATE ADJUST Knob, typically half scale on the readout. Adjust R2 until recorder reads full scale. NOTE: Full scale adjustment of the recorder for 1/2 scale on the OVA gives a gain increase of two (2) in the height of the peak on the chromatograms. This is the factory set point for the HIGH gain range; however, other points can be set as desired with 30 ppm full scale on the logarithmic units and a gain of three (3) on the linear units being the maximum obtainable without amplifier loading.

7.2.7 SAFETY

Due to the low power requirements of the recorder, one model has been approved for use with Century's line of certified intrinsically safe instruments. The only difference between the two models is a heavy blue

epoxy powder coat on the certified model and different power connector pin arrangement to prevent accidental interchange of the recorders.

7.2.8 MAINTENANCE AND ROUTINE OPERATIONS

Refer to the manufacturer's (Gulton) manual on the recorder which is enclosed with each recorder when shipped.

7.2.8.1 CHANGING CHART SPEEDS

The recorder is equipped with a 16 RPM motor which gives a writing speed of four (4) strikes per second. The chart advance speed is determined by the gear train assembly number used. The inches per hour for each gear train is given in the table on page 9 of the Gulton recorder manual. Refer to the bottom line of the chart adjacent to drive motor 16 and note for example that a number 1 gear train has a chart speed of 8"/hour.

a) To change the paper speed, open the recorder, remove gear box spring (on left side), move gear box in direction of arrow on its case and lift out from top. Do not force out from bottom. Insert new gear, bottom first, slide into position against arrow direction. Replace gear box spring.

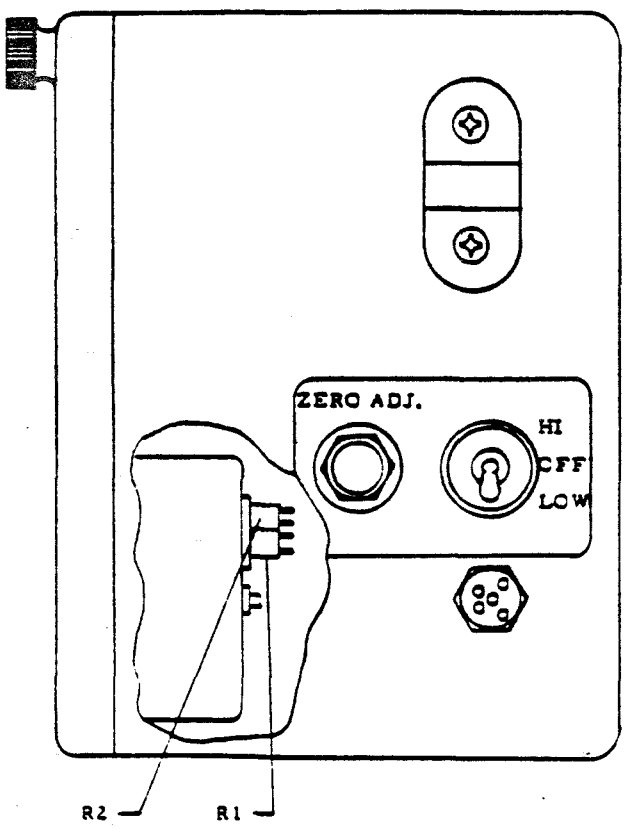


FIGURE 7-2-1. RECORDER CONTROLS AND ADJUSTMENTS

7.3 ACTIVATED CHARCOAL FILTER ASSEMBLY

The Activated Charcoal Filter Assembly, P/N 510085-1, is an optional accessory that can be used with any of the Century portable OVA's. The filter can be installed on the OVA Readout Assembly or attached at the end of the telescoping probe. The filter assembly is typically filled with activated charcoal which acts as an adsorbent and effectively filters out most non-methane or non-ethane organic vapors. A screw cap on the probe end is removed for refilling the filter with activated charcoal or any other filtering media desired.

Applications of the filter include:

1) Obtaining a clean air sample for zero baseline check and adjustment on linear OVA's or for a background check on logarithmic OVA's.
2) Running "blank" chromatograms to assess instrument contamination.
3) Rapid screening of methane and non-methane organic vapors.
4) Selective screening for natural gas surveys.
5) As a moisture filter when filled with a desiccant such as silica gel.

A press fit, large adapter on the back of the filter assembly is removed when installing the unit on the telescoping probe. When replacing the cap end after refilling, one wrap of 1/4 inch teflon tape should be used to seal the threads. The recommended activated charcoal for use in the filter is Barnebey-Cheney, Type GI-8579.

The life of the filter will depend on the time in use and the concentrations of the compounds being filtered. Under typical industrial air monitoring conditions, the filter will last for many days of continuous sampling.

7.4 OVA SAMPLE DILUTOR

An adjustable Sample Dilutor Assembly, P/N 510825-1, is available as an optional accessory for use on all Century portable Organic Vapor Analyzers. The dilutor may be adjusted over the range of 5:1 to 50:1 in OVA response. In operation, the dilutor is attached to the end of the telescoping probe or may be connected by external tubing to the input fitting of the OVA side pack case. Dilution of the air being monitored is accomplished by stream splitting through the use of a needle valve on the sample input. An activated charcoal scrubber is inserted in the main air supply line to the OVA and scrubs the air clean of organic vapors and also creates a slight vacuum at its output side of the scrubber and the vacuum at this point draws the sample air through the needle valve where it mixes with the main air supply going to the OVA detector.

This dilution valve provides a means of sampling vapor levels above the lower explosive level (LEL) and in oxygen deficient atmospheres. These conditions can occur in normal leak or source survey as the operator gets close to the leak or vapor source or in monitoring various manufacturing or material handling processes. Approximately 14% oxygen is required to sustain operation of the FID in the OVA.

7.4.1 SETTING DILUTION RATE

Prepare a sample in a bag at a high level, typically 1,000 to 5,000 ppm. Any suitable gas can be used, such as butane from a cigarette lighter; however, a compound similar to those to be measured provides greater accuracy. The actual concentration of the gas does not have to be known, since the dilution rate is simply a relative level.

Obtain an OVA reading on the vapor sample with the dilution valve removed. Then install the valve, loosen the jam nut and turn the needle valve until the meter reading corresponds to the original reading divided by the dilution factor desired. Retighten the jam nut.

It should be noted that when the dilution valve is used for natural gas leak survey and pinpointing that the charcoal filter will not remove the methane from the dilution air supply. Care should be taken so that natural gas is not allowed to enter the main air inlet.

7.5 OVA SEPTUM ADAPTER

A Septum Adapter, P/N 510645-1, is available for direct on-line sample injection to the GC column inlet. The Septum Adapter mounts directly on the OVA front panel and sample injections from .025 to 2.5 cc may be made using a gas tight syringe. This provides a range of sensitivity of approximately 10% to 1000% of the OVA standard valve, which has a sample loop volume of approximately 0.25 cc. Syringe injection can cause a flame-c however, the OVA may be reignited after the injectio made. The air in the sample must elute from the column before reignition can be made. The time for the air peak to elute will be a function of the column length and the volume of the sample injected. For example, a 1 cc sample into a 12" column will require waiting approximately 5 seconds; and, a 2.5 cc sample into a 48" column will require approximately 20 seconds.

The Septum Adapter also provides a means whereby samples can be taken from oxygen deficient atmospheres or process streams and injected directly into the chromatograph. Headspace analysis may also be accomplished using the Septum Adapter and a syringe.

When the Septum Adapter is installed on the OVA, the normal GC sample valve may still be used alternately with the syringe injection. In addition to variable sample size and sensitivity, syringe injections will normally provide greater symmetry and reduced tailing of chromatogram peaks as compared with the standard valve injection.

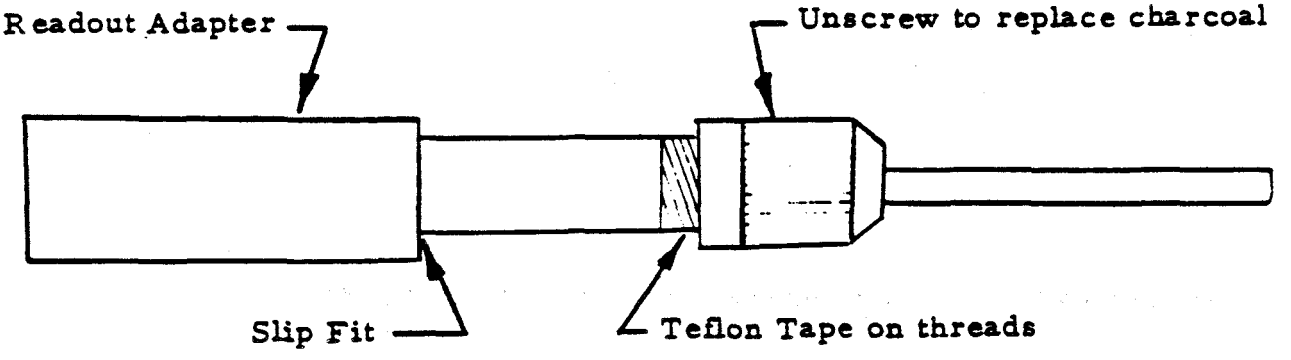


FIGURE 7-3-1. ACTIVATED CHARCOAL FILTER ASSEMBLY

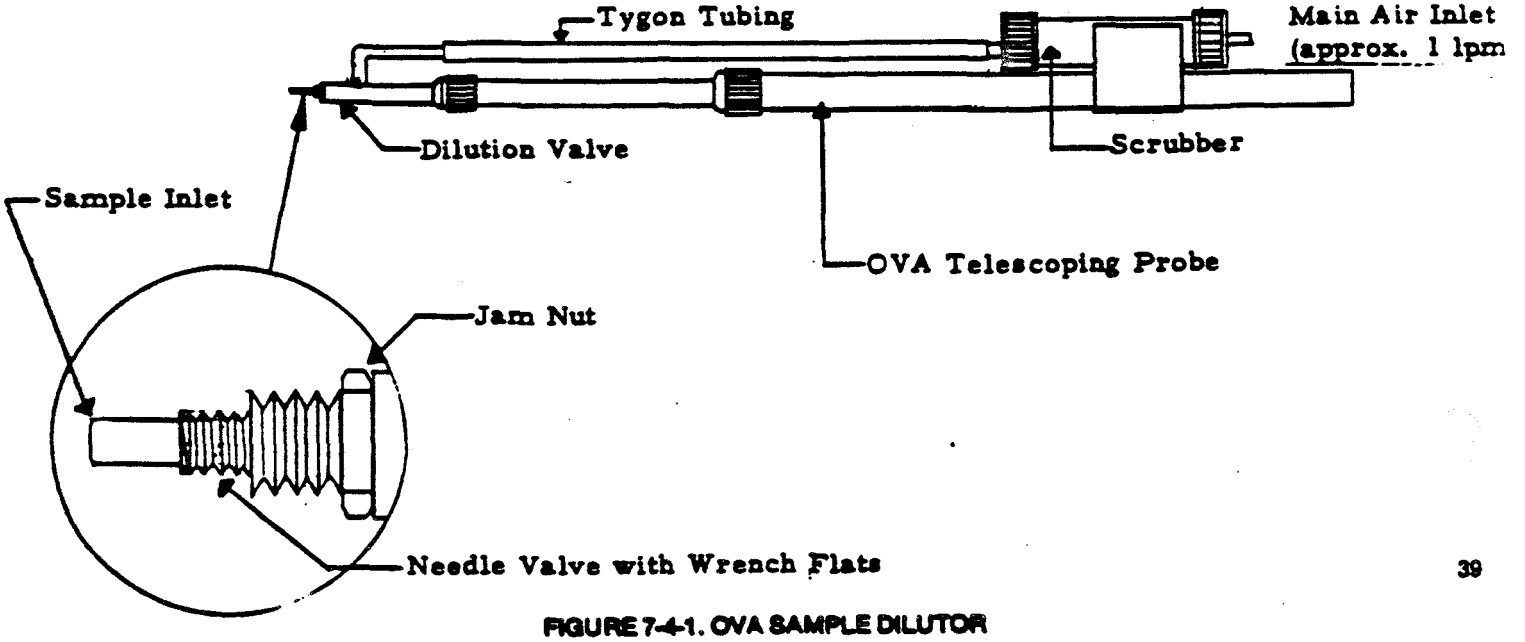


FIGURE 7-4-1. OVA SAMPLE DILUTOR

Date _____ Type Injection _____
Column _____
Sample _____
Temp. _____ °C Chart Speed _____
GC _____ S/N _____ Range _____
Recorder Scaling _____
Carrier flow _____ ml. /min.
Other Conditions: _____
_____
_____
_____
_____

APPENDIX "A"

OVA-128

This Appendix includes the following:

Sample forms and typical Application/Tech Notes

Side Pack Assy Dwg. No. 510605
Side Pack Assy Parts List No. LM510605

Electronic Component Assy Dwg. No. 510570
Electronic Component Assy Parts List No. LM510570

Cylinder Assy Dwg. No. 510055
Cylinder Assy Parts List No. LM510055

Schematic Wiring Diagram Dwg. No. 510555

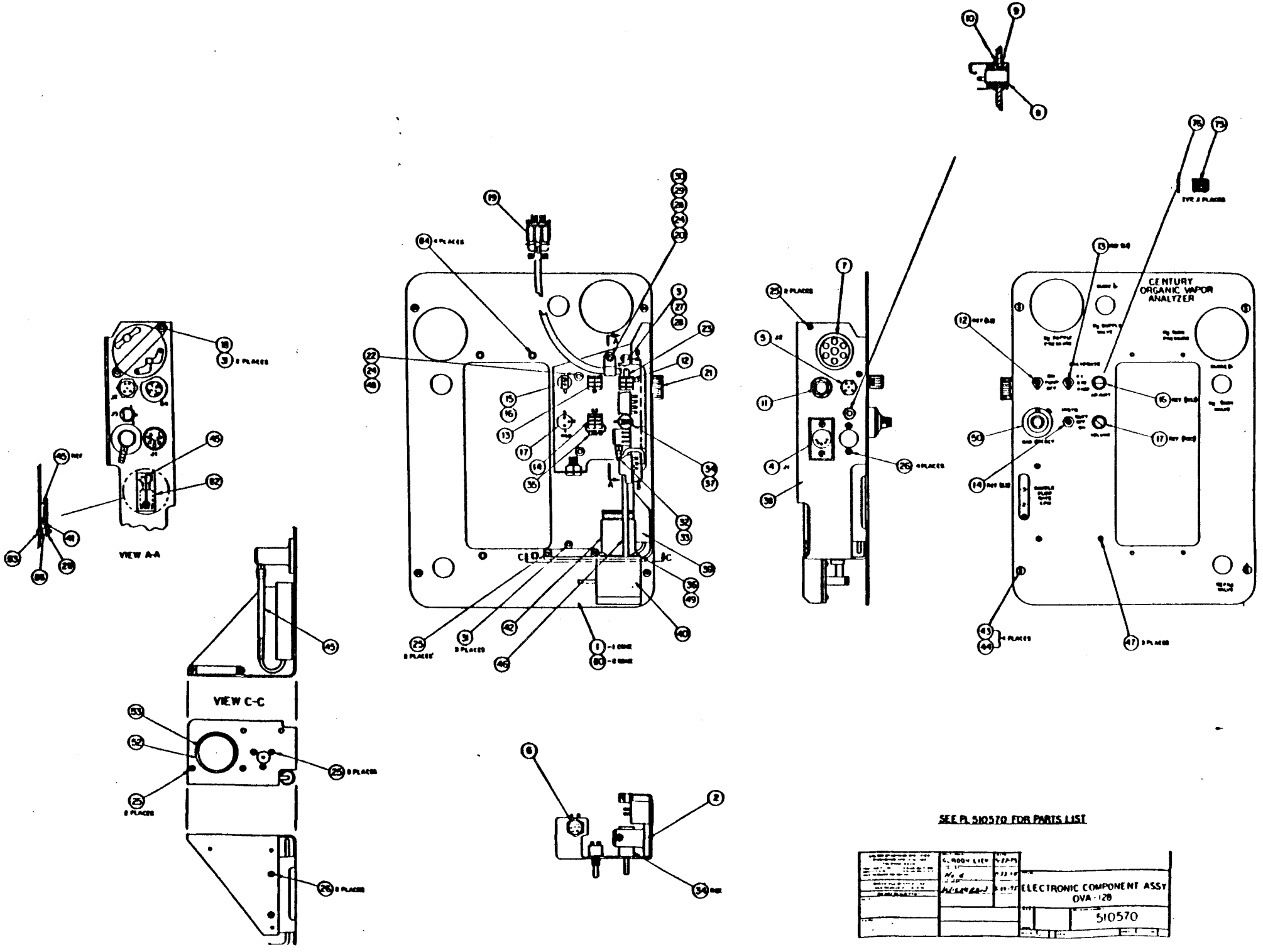
The assembly drawings and parts lists provide location/identification information necessary for maintenance, trouble shooting and parts ordering. The drawings are furnished only for reference and are subject to change without notice. The schematic wiring diagram is for use in trouble shooting for possible electronic or wiring problems. Note that components that are not accessible for safety reasons on the certified instruments are not shown on the schematic. However, typical signal levels at selected points are shown.

In using the drawings and parts list to locate items described in the Maintenance Section of this manual, it may first be necessary to identify the item in the parts list (by nomenclature), then refer to the corresponding item number on the drawing for location.

CENTURY SYSTEMS	TITLE SIDEPACK ASSY/COLUMN OVA-128
-1 Conf. OVA-128 -2 Conf. OVA-128 w/column	LM 510605

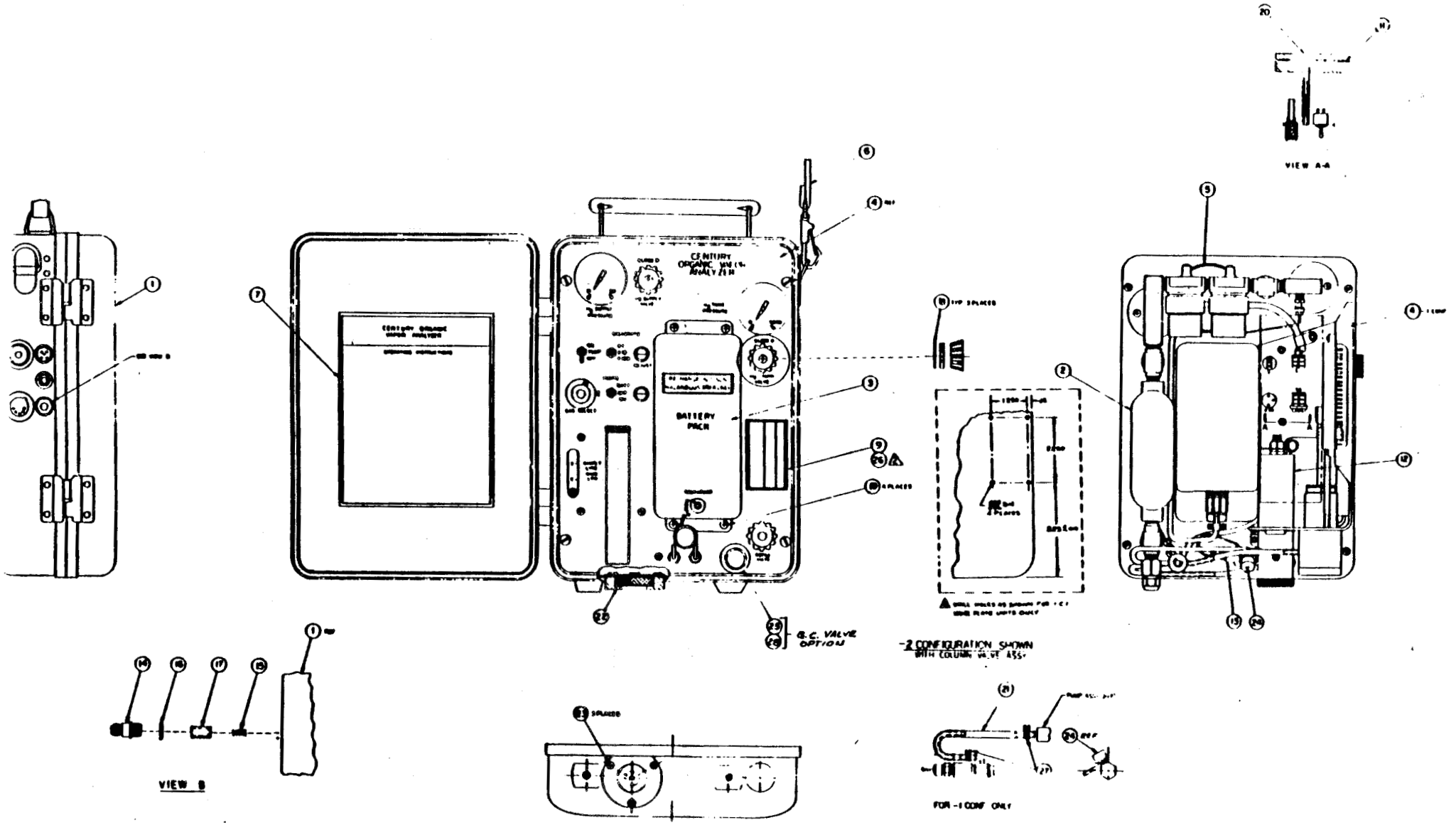
1	1	1					510508-1	Case Assy.
2	1	1					510055-1	Cylinder Assy.
3	1	1					510542-1	Battery Pack Assy.
4	1	/					510570-1	Electronic Component Assy.
5	1	1					510073-1	Capillary Tube
6	1	1					510094-1	Carrying Strap Assy.
7	1	1					510295-1	Ident. Plate, Operating Instr.
8	1	1					510137-1	Ident. Plate, Calib. Rate
9	1	1				1	510577-2	Ident. Plate, OVA Assy.
10	/	1					510545-1	Ident. Plate, Column
11	1	1					510590-1	Printed Wiring Board Assy.
12	1	1					510600-1	Preamp Assy.
13	1	1					510513-1	Mixer & Burner Assy.
14	1	1					510382-1	Fitting Assy.
15	1	1					LC-032C-4SS	Spring
16	1	1					568-013	O-Ring
17	1	1					510318-1	Filter, Cup
18	3	3					510164-1	Washer
19	4	4					MS35206-226	Screw, 6-32 x 1/4, Pan Hd. Phillips (Blk. C
20	2	2					MS35206-223	Screw, 4-40 x 1 1/2 Lg. Pan Hd. Phillips
21	1	/					510420-1	Tubing Assy.
22	1	1					510622-1	Cover
23	3	3					MS35457-4	Screw 4-40 x 3/4 Socket Head, Cad.
24	1	1					3305-11-46	Thermostat, 75°C
25								
26	A/R	A/R					1	Identification Plate
27	2	/					510568-1	Spring

ITEM NO.	QTY. REQ. PER DASH NO.						PART OR IDENT. NO	DESCRIPTION
	-1	-2	-3	-4	-5	-6		
35	/	1					510435-1	Charcoal Filter Assy.
36	/	1					510630-1	Valve Assy.
37	/	2					510436-1	Union, Mod.
38	/	1					510430-1	Reducer Tube Assy.
39	/	1					510430-2	Reducer Tube Assy.
40	/	1					510454-A-18	Column Assy.
41	/	1					510454-A-3	Column Assy.
42	/	A/R					Type 0113	Tubing, Teflon, .148(I.D.)x.020 Wall
43	/	A/R					Type 0113	Tubing, Teflon, .120(I.D.)x.030 Wall
44	/	2					MS35337-45	Washer, Helical, Lock, # 5/16
45	/	2					MS35333-74	Washer, Lock, Internal, # 1/4
46	/	2					17-215-NP	Nut, Hex, Brass, N.P. 5/16-24
47	/	1					510570-2	Electronic Component Assy.



SEE PL 510570 FOR PARTS LIST

		ELECTRONIC COMPONENT ASSY OVA-128
		510570



SIDEPACK ASSY/COLUMN
MODEL 1/4 LINEAR
510605

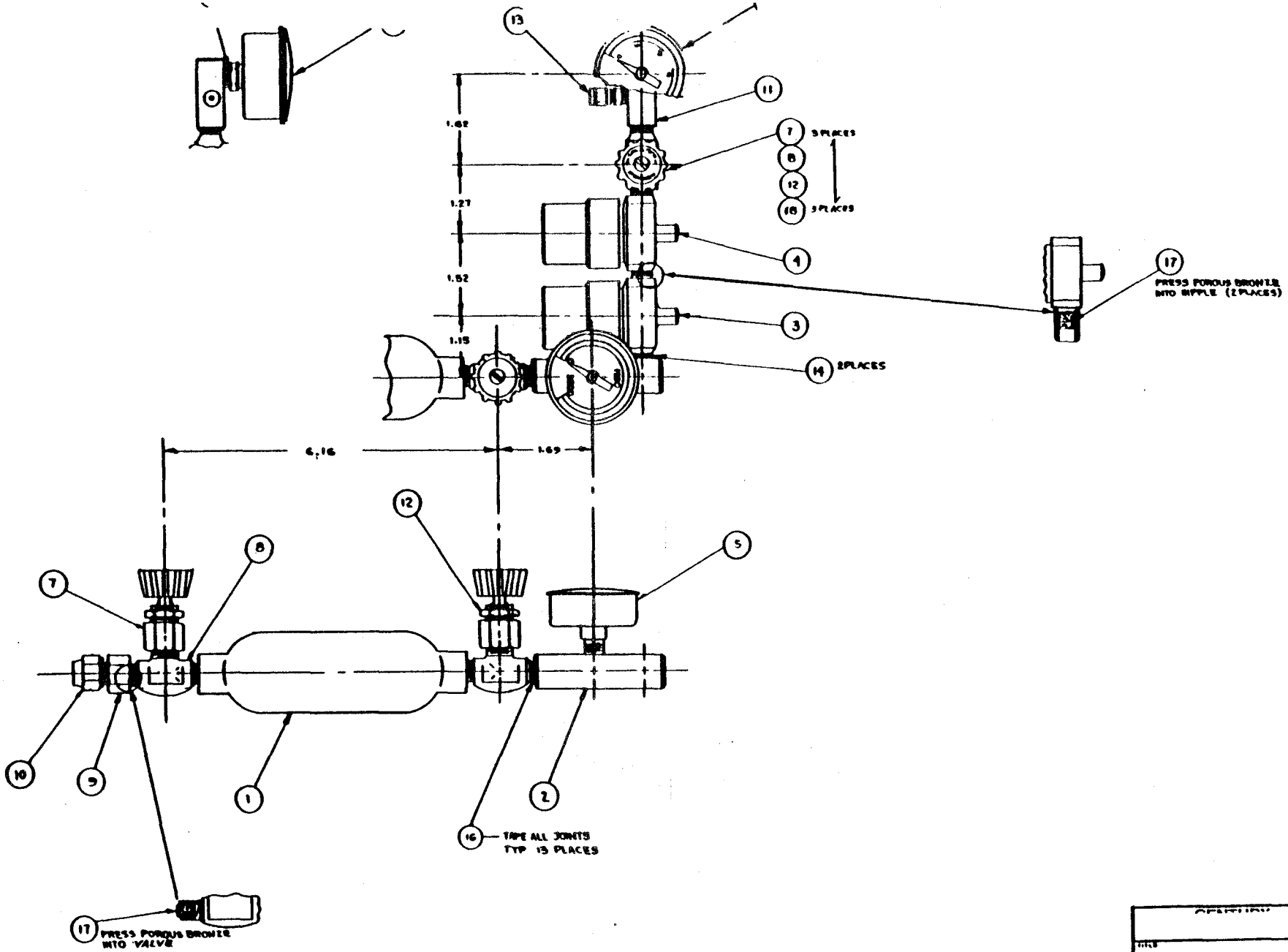
CENTURY SYSTEMS	TITLE ELECTRONIC COMPONENT ASSY
-1 Conf. OVA-128 -2 Conf. OVA-128 w/column	LM 510570

1	1						510386-4	Panel	
2	1	1					510379-1	Housing, Filter	
3	1	1					SAC-22D/1-2	Connector	
4	1	1					D5M	Connector	J1
5	1	1					126-011	Connector, 5 Pin, Female	J2
6	1	1					126-192	Connector, 7 Pin Female	
7	1	1					75547	Speaker	
8	1	1					42A	Tina - Jax	
9	1	1					510362-1	Washer, Nylon	
10	1	1					2154	Washer, Shoulder	
11	1	1					510567-1	Switch, Push Button	S4
12	1	1					8A2011	Switch, Toggle	S2
13	1	1					8A2101	Switch, Toggle	S1
14	1	1					8A2051	Switch, Toggle	S3
15	2	2					510540-3	Spacer	
16	1	1					510193-1	Potentiometer Assy., 50K	R53
17	1	1					510053-1	Potentiometer	R50
18	1	1					510389-1	Clamp	
19	1	1					510519-1	Cable Assy.	
20	1	1					8942	Clamp, 1/4"	
21	1	1					510052-2	Shield	
22	2	2					8327	Spacer	
23	1	1					1468-1/4	Terminal Lug	
24	3	3					MS35190-223	Screw, 4-40X3/8 Ft. Hd. Phillips	
25	6	6					MS35206-213	Screw, 4-40X1/4, Pan Hd. Phillips	
26	9	9					MS35190-221	Screw, 4-40X1/4, Ft. Hd. Phillips	
27	2	2					MS35206-214	Screw, 4-40X3/8, Pan Hd. Phillips	
28	5	5					MS15795-4	Washer, No. 4, Flat	
29	2	2					MS35649-4	Nut, Hex, 4-40	
30	1	1					MS35337-4	Washer, Split Lock, No. 4	
31	5	5					511-041800-00	Nut, Hex, 4-40	
32	1	1					11761-1	Washer	

ITEM NO.	QTY. REQ. PER DASH NO. -1	-2	-3	-4	-5	-6	PART OR IDENT. NO	DESCRIPTION
33	1	1					11752-1	Fitting
34	1	1					510193-2	Potentiometer Assy, 100K (R52)
35	1	1					RN55D5621F	Resistor, 5.62K, 1%, M.F. (R54)
36	2	2					MS35206-226	Screw, 6-32X1/4 Lg., Pan Hd Phillips
37	1	1					510540-3	Spacer
38	1	1					510499-1	Bracket
39	1	1					510539-1	Flow Gauge Assy.
40	1	1					510223-6 ⚠1	Pump Assy.
41	1	1					7806UC	Regulator
42	1	1					PL11-213-8 ⚠1	Motor, 12 VDC
43	4	4					12S1-11-1AA	Stud Assy.
44	4	4					5 S 3-1	Washer
45	1	1					NY334R	Capacitor, .33UF
46	A/R	A/R					Type 0113	Tubing, Teflon, .148 I.D. X .020 Wall (Blk. Oxide)
47	3	3					MS35190-221	Screw, 4-40X1/4 Lg. Ft. Hd. Phillips
48	A/R	A/R					35-31	Loctite, Retaining Compound
49	2	2					MS35337-6	Washer, Helical, No. 6
50	1	1					11-1-11	Dial, 10 Turn, 1" Dia.
51								
52	1	1					510537-1	Support, Preamp
53	1	1					510538-1	Clamp, Preamp
54	A/R	A/R					8505-10	Wire, Awg 26 Black, Stranded, Tinned
55							-1	Brown
56							-2	Red
57							-3	Orange
58							-4	Yellow
59							-5	Green
60							-6	Blue
61							-7	Violet
62							-9	White
63	A/R	A/R					8505-14	Wire, Awg 26 Wht/Blk, Stranded, Tinned

ITEM NO.	QTY. REQ. PER DASH NO. -1	-2	-3	-4	-5	-6	PART OR IDENT. NO	DESCRIPTION
64	A/R	A/R					8505-15	Wire, Awg 26 Wht/Red, Stranded, Tinned
65							-20	Wht/Orange
66							-17	Wht/Yellow
67							8505-18	Awg 26 Wht/Blue, Stranded, Tinned
68								Awg 22 Wht/Blk, Type 44A0311, 2500V
69								Wht/Brn.
70								Wht/Red.
71								Wht/Orng.
72								Wire, Awg 22 White, Type 44A0311, 2500V
73							299/1	Wire, Buss, Awg 26, Tinned
74	A/R	A/R					PVC-105-14	Sleeving, 3/32
75	2	2					KN-500-1/8(Blk)	Knob, Black, 1/8" Shaft
76	2	2					568-8	O-Ring
77	1	1					4976	Lug, Spade
78	1	1					CL-2	Clip
79	1	1					510581-1	Wire List
80	/	1					510386-5	Panel
81	A/R	A/R						Wire, Awg 20, White, Type 44A0311, 2500V
82	1	1					510574-1	P.W.B. Motor Regulator
83	1	1					MS35206-217	Screw, 4-40 x 1/2, pan hd. Phillips
84	4	4					CL-632-2	Nut, 6-32
85	A/R	A/R					FIT-105-1/8	Sleeving, Shrink, 1/8 PVC
86	1	1					8480	Spacer, .250 dia. x 1/8 thk.

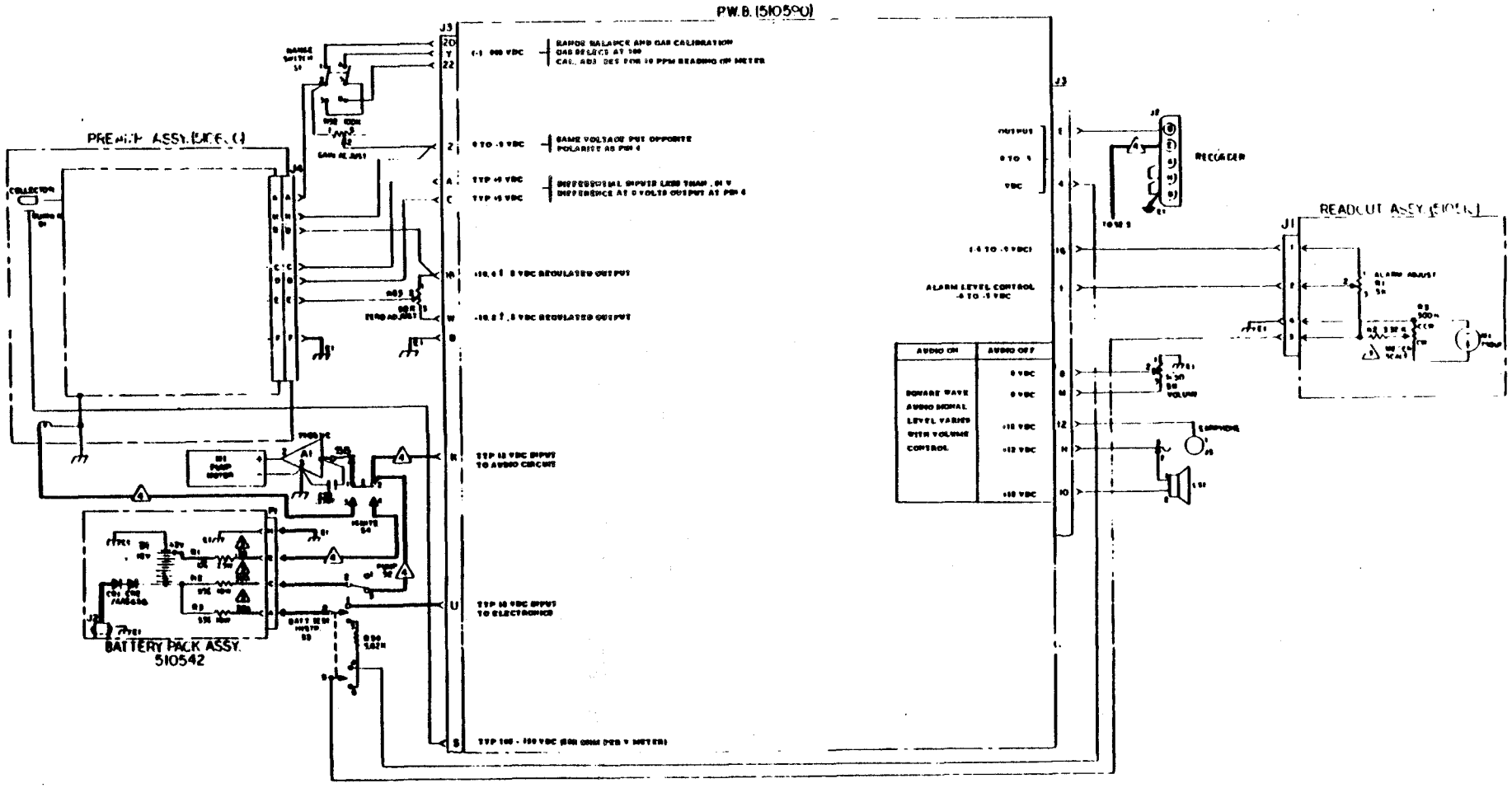
1 -6 to be used effective S/N 1400 and up with Escap Motor #PL-11-213-35.



TITLE	CYLINDER ASSY
SIZE D	00214 — 510055
SCALE 1/4	SHEET 1 OF 1

CENTURY SYSTEMS	TITLE CYLINDER ASSY
-1 Conf. OVA-88, 98, 118, 108, 128, 138	LM 510055

1	1						510056-1	Cylinder
2	1						510057-1	Manifold
3	1						510100-1	Regulator Assy., High Pressure
4	1						510100-2	Regulator Assy., Low Pressure
5	1						510008-1	Gauge H.P.
6	1						510007-1	Gauge L.P.
7	3						510059-1	Adapter Panel
8	3						510058-1	Valve
9	1						646F 1/4	Coupling, Female 1/4 Tube x 45°
10	1						640-FB-1/4	Nut, Cap, 1/4" x 45°, Brass
11	1						510108-1	Manifold
12	3							Nut, 5/8" - 24, Brass
13	1						510283-1	Connector, Filter Assy
14	2						112-B-1/8	Nipple, Close, 1/8" Brass
2 15	1						510109-1	Connector (MOD)
16	A/R						A69007	Tape, Pipe Thread, 1/4" Teflon
17	3							Filter, Porous Bronze, 1/4 dia.
								x 1/4 Lg., Grade 30
*	A/R						510160-1	Wafer, (Teflon)
								* Use only if required
18	3						510152-1	Ident. Plate Hydrogen Knob



SCHEMATIC
ORGANIC VAPOR ANALYZER
OVA-128

D

510555

INSTRUCTION MANUAL
YSI MODEL 51B
DISSOLVED OXYGEN METER

Scientific Division
Yellow Springs Instrument Co., Inc.
Yellow Springs, Ohio 45387 • Phone 513-767-7241 • Telex 20-5437

PRICE INCLUDING HANDLING $5.00

SUMMARY OF OPERATING INSTRUCTIONS

1. CALIBRATION

A. Switch instrument to OFF and adjust meter mechanical zero.
B. Switch to ZERO and adjust to "0" on mg/l scale.
C. Switch to FULL SCALE and adjust to "15" on mg/l scale.
D. Prepare probe for operation, plug into instrument, wait up to 15 minutes for probe to stabilize. Probe can be located in calibration chamber or ambient air.
E. Switch to CALIB. O_2 and adjust CALIB. control until meter indicates local altitude on short scale in upper right corner of meter.
NOTE: It is desirable to calibrate probe in a high humidity environment. See instruction manual for more detail on calibration and other instrument and probe characteristics.

2. MEASUREMENT

A. Place probe in sample and stir.
B. Allow sufficient time for probe to stabilize to sample temperature and dissolved oxygen.
C. Switch to READ TEMP AND SET DIAL. Set O_2 SOLUBILITY FACTOR dial to sample temperature. Take care to properly index salinity on sloped white bar.
D. Switch to READ O_2 and read mg/l, dissolved oxygen while stirring.
E. We recommend the instrument be left on between measurements to avoid the necessity to re-polarize the probe.

3. GENERAL CARE

A. Replace batteries after 1000 hours of operating or if full scale adjustment cannot be made. Use Eveready 935 "C" size or equal.
B. Membranes will last indefinitely depending on use. Average replacement is 2-4 weeks. Probe should be stored in humid environment to prevent drying out.
C. Calibrate daily.

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SCHEMATIC DIAGRAM ..... CENTER SPREAD

GENERAL DESCRIPTION

The YSI Model 51B Dissolved Oxygen Meter is intended for dissolved oxygen and temperature measurement in water and wastewater applications, but are also suitable for use in certain other liquids. Dissolved Oxygen is indicated in mg/l (milligrams per liter) on a 0-15 mg/l scale. Temperature is indicated in °C on a -5° to +45°C scale. The dissolved oxygen range is automatically temperature compensated for permeability of the probe membrane, and manual by direct dial for changes in water temperature.

The probes use Clark-type membrane covered polarographic sensors with builtin thermistors for temperature measurement and compensation. A thin, permeable membrane stretched over the sensor isolates the sensor elements from the environment, but allows oxygen and certain other gases to enter. When a polarizing voltage is applied across the sensor, oxygen that has passed through the membrane reacts at the cathode, causing a current to flow.

The membrane passes oxygen at a rate proportional to the pressure difference across it. Since oxygen is rapidly consumed at the cathode, it can be assumed that the oxygen pressure inside the membrane is zero. Hence, the force causing the oxygen to diffuse through the membrane is proportional to the absolute pressure of oxygen outside the membrane. If the oxygen pressure increases, more oxygen diffuses through the membrane and more current flows through the sensor. A lower pressure results in less current.

SPECIFICATIONS

I. Instrument

Oxygen Measurement

Range: 0-15 mg/l
Accuracy: Better than ± 0.2 mg/l when calibrated with ±5°C of actual sample temperature.
Readability: Better than 0.1 mg/l

Temperature Measurement

Range: -5° to +45°C
Accuracy: ±0.7°C, including probe
Readability: 0.25°C

Compensation

Temperature compensation for oxygen probe membrane coefficient is automatic.

Temperature compensation for oxygen solubility is manual by direct dial from 0°C to 45°C for fresh water and -5°C to +37°C for sea water.

Altitude compensation is manual by direct dial from 0 to 11,000 feet.

Salinity compensation is manual by direct dial from fresh water to sea water of 20,000 mg/l chloride concentration.

System Response Time

Typical response for temperature and DO readings is 90% in 10 seconds at constant temperature of 30°C.

DO response at low temperature and low DO is typically 90% in 30 seconds

If response time under any operating conditions exceeds two minutes, probe service is indicated.

Instrument Ambient Range

Satisfactory operation from -5°C to +45°C.

Power Supply

YSI Model 51B is powered by four disposable "C" size carbon zinc batteries, providing approximately 1000 hour operation. Replace with Eveready 935C or equal.

II. Probe

Cathode: Gold
Anode: Silver
Membrane: .001" FEP Teflon
Electrolyte: Half saturated KCl
Temperature Compensation: (See SPECIFICATIONS, I. Instrument)
Pressure Compensation: Effective 1/2% of reading of pressures of 100 psi (230 ft. water)
Polarizing Voltage: .75 volts nominal
Probe Current: Air at 30°C = 19 microamps nominal
Nitrogen at 30°C = .15 microamps or less

III. Accessories and Replacement Parts

YSI 5720A — Self Stirring B.O.D. Bottle Probe
YSI 5750 — Non Stirring B.O.D. Bottle Probe
YSI 5739 — Oxygen Temperature Probe for field use. Combine with one of the following cables for desired lead length.

Detachable leads for use with YSI 5739.

YSI 5740- 10	10' cable
YSI 5740- 25	25' cable
YSI 5740- 50	50' cable
YSI 5740-100	100' cable
YSI 5740-150	150' cable
YSI 5740-200	200' cable

YSI 5492A — Battery Pack operates YSI 5791A Submersible Stirrer.
YSI 5791A — Submersible Stirrer for field use with YSI 5739 and 5740 probe cable assembly.
YSI 5795A — Submersible Stirrer for field use with YSI 5739 probe. (Convenient single cable design does not require YSI 5740 probe cable.)
YSI 5075A — Calibration Chamber for use with field probe.
YSI 5890 — Carrying Case
YSI 5775 — Membrane and KCl Kit Standard — includes 2 each 15 membranes packets (.001" thick standard membranes) and a 30 ml bottle KCl with Kodak Photo Flo.
YSI 5945 — "O" Ring Pack — includes (6) "O" rings for each YSI D.O. Probe.
YSI 5486 — Beater Boot Kit — includes (1) A-05486 Boot — (1) A-05484 Tip, (2) A-05485 Springs. Use only on YSI 5720A and discontinued YSI 5420A and 5720.
YSI 5986 — Diaphragm Kit for use only with YSI 5739 D.O. Probe.
YSI 5735 — Adaptor makes it possible to use YSI 5739, YSI 5720A and YSI 5750 Probes with discontinued YSI Model 51A.

OXYGEN PROBES AND EQUIPMENT

There are three oxygen probes for use with the YSI Model 51B Dissolved Oxygen Meter. Descriptions of where they are used are contained in the following paragraphs.

I. YSI 5739 D.O. Probe

The YSI 5739 Probe, with built-in lead weight and pressure compensation, is an improved design that replaces the discontinued YSI 5101, 5418, 5419, 5718 and 5719 Probes. (See Figure 1)

For user convenience the probe is equipped with a disconnecting cable to facilitate changing cable lengths and replacing damaged cables or probes. The probe and cable assembly is held together with a threaded retaining nut. The connection is *not* designed for casual disconnection and should only be disconnected when necessary.

To disconnect the cable unscrew the retaining nut and slide it down the cable to expose the connector. Pull gently on the cable and connector until the con*nector comes away from the probe body.*

To reassemble, inspect the connector and "O" ring for cleanliness. If the "O" ring is frayed or damaged remove it by squeezing it in the groove causing it to bulge, then roll it out of the groove and off the connector. A replacement "O" ring is supplied with the cable.

Push the connector into the probe body, rotating it until the two halves mate. A light coating of vaseline or silicone grease on the "O" ring will make reasssembly easier. Air trapped between the connector halves which may cause them to spring apart slightly, is normal. Screw on the retaining nut, *hand tight only.* NOTE: If erratic readings are experienced, disconnect the cable and inspect *for water. If present, dry out and reconnect, replacing the "O" ring, if necessary.*

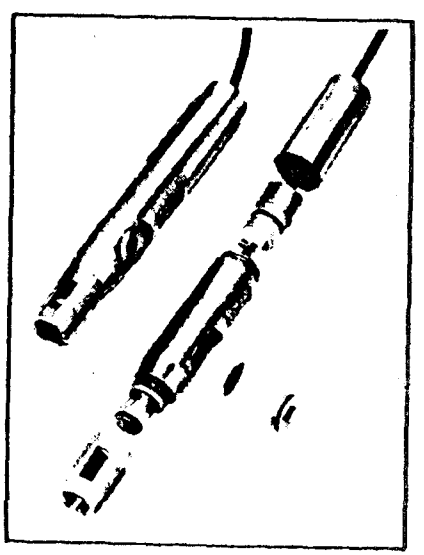


FIGURE 1

Pressure Compensation

The vent on the side of the probe is part of a unique pressure compensating system that helps assure accurate readings at great depths of water. Pressure compensation is effective to 1/2% of reading with pressures to 100 psi (230 ft. water). *The quantity of air bubbles trapped under the membrane determines how* serious the pressure error will be, which is why proper preparation of the probe is essential. (See OPERATING PROCEDURES.) The system is designed to accommodate a small amount of trapped air and still function properly, but the amount should be kept to a minimum

The compensating system normally does not require servicing and should not be taken apart. However, if electrolyte is leaking through the diaphragm or if there is an obvious puncture, *the diaphragm must be replaced.* A *spare* is supplied with the probe. Using a coin unscrew the retaining plug and remove the washer and the diaphragm, flush any salt crystals from the reservoir, install the new diaphragm (convolution side in), replace the washer, and screw in the retaining plug.

II. YSI 5720A B.O.D. Bottle Probe

The YSI 5720A B.O.D. Bottle Probe replaces the discontinued YSI 5420A B.O.D. Bottle Probe for measuring dissolved oxygen and temperature in standard B.O.D. bottles. *It is provided with an agitator for stirring the sample solu*tion, available in models for 115VAC (95-135VAC, 50-60 Hz) or 230VAC (190-250VAC, 50-60 Hz) operation. (See Figure 2)

When using the probe, plug the agitator power supply into line power and the probe plug into the instrument. With the agitator turned off place the tapered *probe end into the B.O.D. bottle and switch agitator "ON" with switch on top of* probe. The probe should be operated with a minimum of trapped air in the B.O.D. bottle. A slight amount of air in the unstirred region at the top of the bottle may be neglected, but no bubbles should be around the thermistor or oxygen sensor.

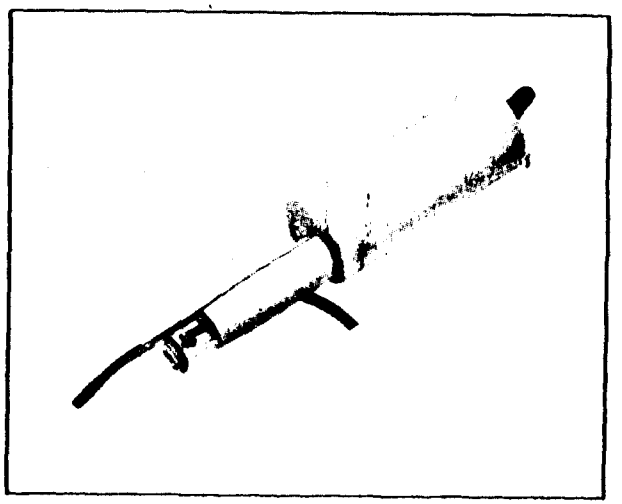


FIGURE 2

Stirrer Boot

The probe uses a flexible stirring boot to transmit motion from the sealed motor housing to the sample. If the boot shows signs of cracking or other damage likely to allow leaking into the motor housing, the boot must be replaced.

In fresh water applications boot life is normally several years, but this may be shortened by exposure to hydrocarbons, moderate to strong acids or bases, ozone, or direct sunlight. For maximum life rinse the boot after use in contaminated samples. (See Figure 3)

Boot replacement is as follows:

1. Pull off old assembly and clean shaft.
2. Slide on new assembly making sure the back spring is on the grooved area of the shaft. A small amount of rubber cement may be used.
3. Check that there is sufficient clearance between the tip and the end of the shaft to permit turning without binding.

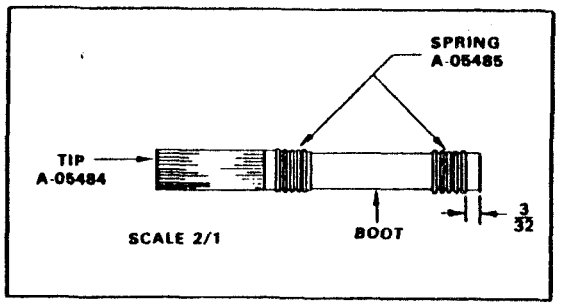


FIGURE 3

III. YSI 5750 B.O.D. Bottle Probe

The YSI 5750 B.O.D. Bottle Probe replaces the discontinued YSI 5450 B.O.D. Bottle Probe. It is similar to the YSI 5720A B.O.D. Bottle Probe, except that it does not have a stirrer. Agitation of the sample must be provided by other means, such as a magnetic stirrer. (See Figure 4)

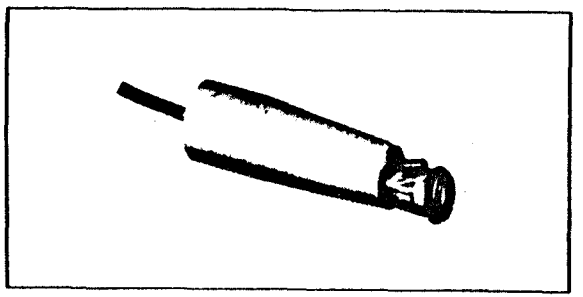


FIGURE 4

IV. Cable Adaptors

All YSI 5700 Series Probes are designed for direct use with the YSI Model 51B Dissolved Oxygen Meter. However, to use YSI 5700 probes with the discontinued YSI Model 51A, cable adaptor YSI 5735 is required.

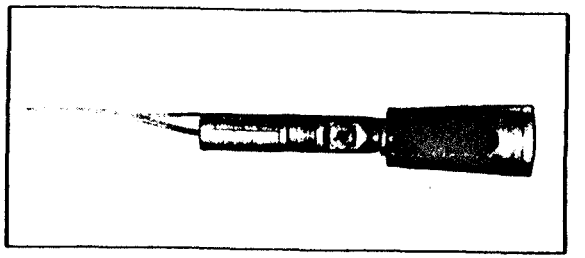


FIGURE 5

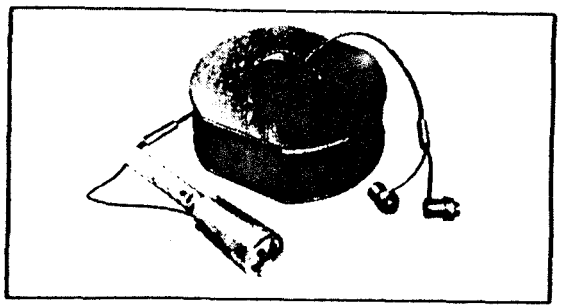


FIGURE 6

V. YSI 5791A and 5795A Submersible Stirrers

The YSI submersible stirrers are accessories that perform the function of stirring the sample being studied when making dissolved oxygen measurements in the field. The YSI 5791A stirrer can be used with the following dissolved oxygen probes: YSI 5101, 5418, 5419, 5718, 5719, and 5739. The YSI 5795A stirrer is only for use with the YSI 5739 Probe. (See Figure 6)

When a stirrer and probe are assembled, the stirrer agitates the sample directly in front of the sensor by means of a rotating eccentric weight which causes the spring-mounted hermetically sealed motor housing to vibrate. An impeller on the end of the motor housing flushes the media across the oxygen sensor. (See sales literature and instruction sheets for further information)

VI. YSI 5492A Battery Pack

The YSI 5492A Battery Back is designed to attach to the case of the YSI Model 51B Dissolved Oxygen Meter to provide power for operating the submersible stirrers. (See sales literature and instruction sheets for further information)

OPERATING PROCEDURES

I. Preparing the Probe

All YSI 5700 Series Probes have similar sensors and should be cared for in the same manner. They are precision devices relying on good treatment if high accuracy measurements are to be made. Prepare the probes as follows. (See Figure 7)

ALL PROBES ARE SHIPPED DRY — YOU MUST FOLLOW THESE INSTRUCTIONS

1. Prepare the electrolyte by dissolving the KCl crystals in the dropper bottle with distilled water. Fill the bottle to the top.
2. Unscrew the sensor guard from the probe (YSI 5739 only) and then remove the "O" ring and membrane. Thoroughly rinse the sensor with KCl solution.
3. Fill the probe with electrolyte as follows:
   A. Grasp the probe in your left hand. When preparing the YSI 5739 probe the pressure compensating vent should be to the right. Successively fill the sensor body with electrolyte while pumping the diaphragm with the eraser end of a pencil or similar soft, blunt tool. Continue filling and pumping until no more air bubbles appear. (With practice you can hold the probe and pump with one hand while filling with the other.) When preparing the YSI 5720A and 5750 probes, simply fill the sensor body until no more air bubbles appear.
   B. Secure a membrane under your left thumb. Add more electrolyte to the probe until a large meniscus completely covers the gold cathode. NOTE: Handle membrane material with care, keeping it clean and dust free, touching it only at the ends.
   C. With the thumb and forefinger of your other hand, grasp the free end of the membrane.
   D. Using a continuous motion *stretch* the membrane *UP, OVER,* and *DOWN* the other side of the sensor. Stretching forms the membrane to the contour of the probe.
   E. Secure the end of the membrane under the forefinger of the hand holding the probe.
   F. Roll the "O" ring over the end of the probe. There should be no wrinkles in the membrane or trapped air bubbles. Some wrinkles may be removed by lightly tugging on the edges of the membrane beyond the "O" ring.
   G. Trim off excess membrane with scissors or sharp knife. Check that the stainless steel temperature sensor is not covered by excess membrane.
4. Shake off excess KCl and reinstall the sensor guard.
5. A bottomless plastic bottle is provided with the YSI 5739 probe for convenient storage. Place a small piece of moist towel or sponge in the bottle and insert the probe into the open end. This keeps the electrolyte from drying out. The YSI 5720A and 5750 probes can be stored in a B.O.D. bottle containing about 1" of water.
6. Membranes will last indefinitely, depending on usage. Average replacement is 2-4 weeks. However, should the electrolyte be allowed to evaporate and an excessive amount of bubbles form under the membrane, or the membrane become damaged, thoroughly flush the reservoir with KCl and install a new membrane.
7. Also replace the membrane if erratic readings are observed or calibration is not stable.

8. "Home brew" electrolyte can be prepared by making a saturated solution of reagent grade KCl and distilled water, and then diluting the solution to half strength with distilled water. Adding two drops of Kodak Photo Flo per 100 ml of solution assures good wetting of the sensor, but is not absolutely essential.
9. The gold cathode should always be bright and untarnished. To clean, wipe with a clean lint-free cloth or hard paper. NEVER USE ANY FORM OF ABRASIVE OR CHEMICAL. Rinse the sensor several times with KCl, refill, and install a new membrane.
10. Some gases contaminate the sensor, evidenced by discoloration of the gold. If the tarnish cannot be removed by vigorous wiping with a soft cloth, lab wipe, or hard paper, return the probe to the factory for service.
11. H_2S, SO_2, Halogens, Neon, Nitrous Oxide and CO are interfering gases. If you suspect erroneous readings, it may be necessary to determine if these are the cause. These gases have been tested for response.

100% Carbon Monoxide-Less than 1%	100% Helium-none
100% Carbon Dioxide-Around 1%	100% Nitrous Oxide-1/3 O_2 response
100% Hydrogen-Less than 1%	100% Ethylene-none
100% Chlorine-2/3 O_2 response	100% Nitric Oxide-1/3 O_2 response

12. If the probe has been operated for extended periods with a loose or wrinkled membrane the gold cathode may become plated with silver. In this event return the probe to the factory for refinishing.

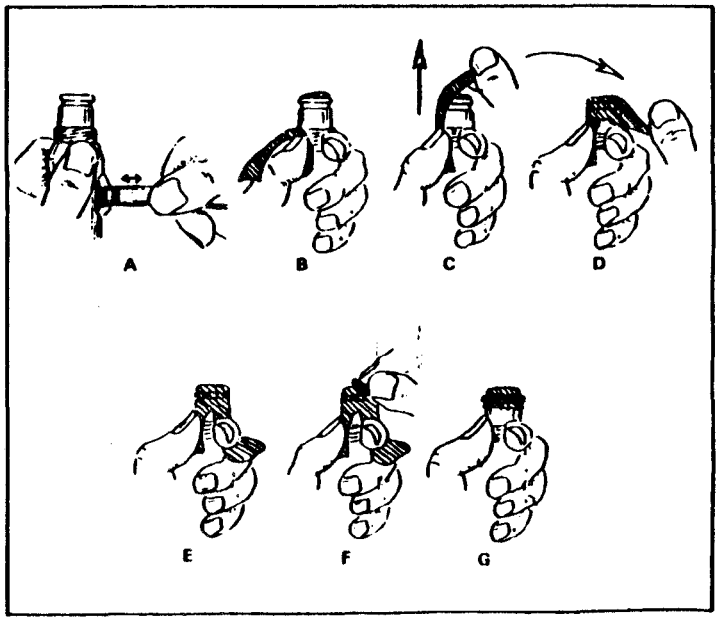


FIGURE 7

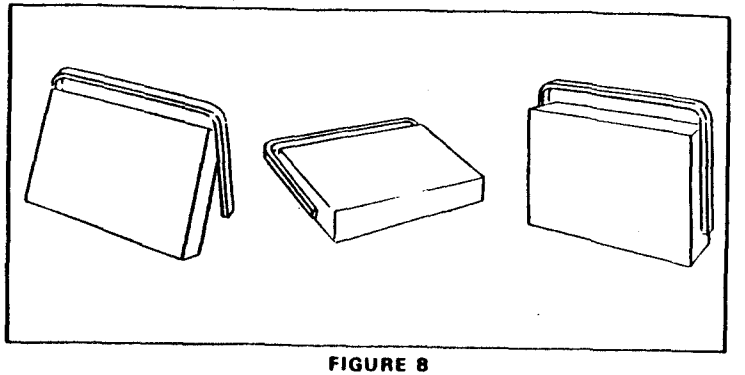


FIGURE 8

II. Preparing the Instrument

It is important that the instrument be placed in the intended operating position vertical, tilted, or on its back — before it is prepared for use and calibrated. (See Figure 8). Readjustment may be necessary when the instrument operating position is changed. *After preparing the probe proceed as follows:*

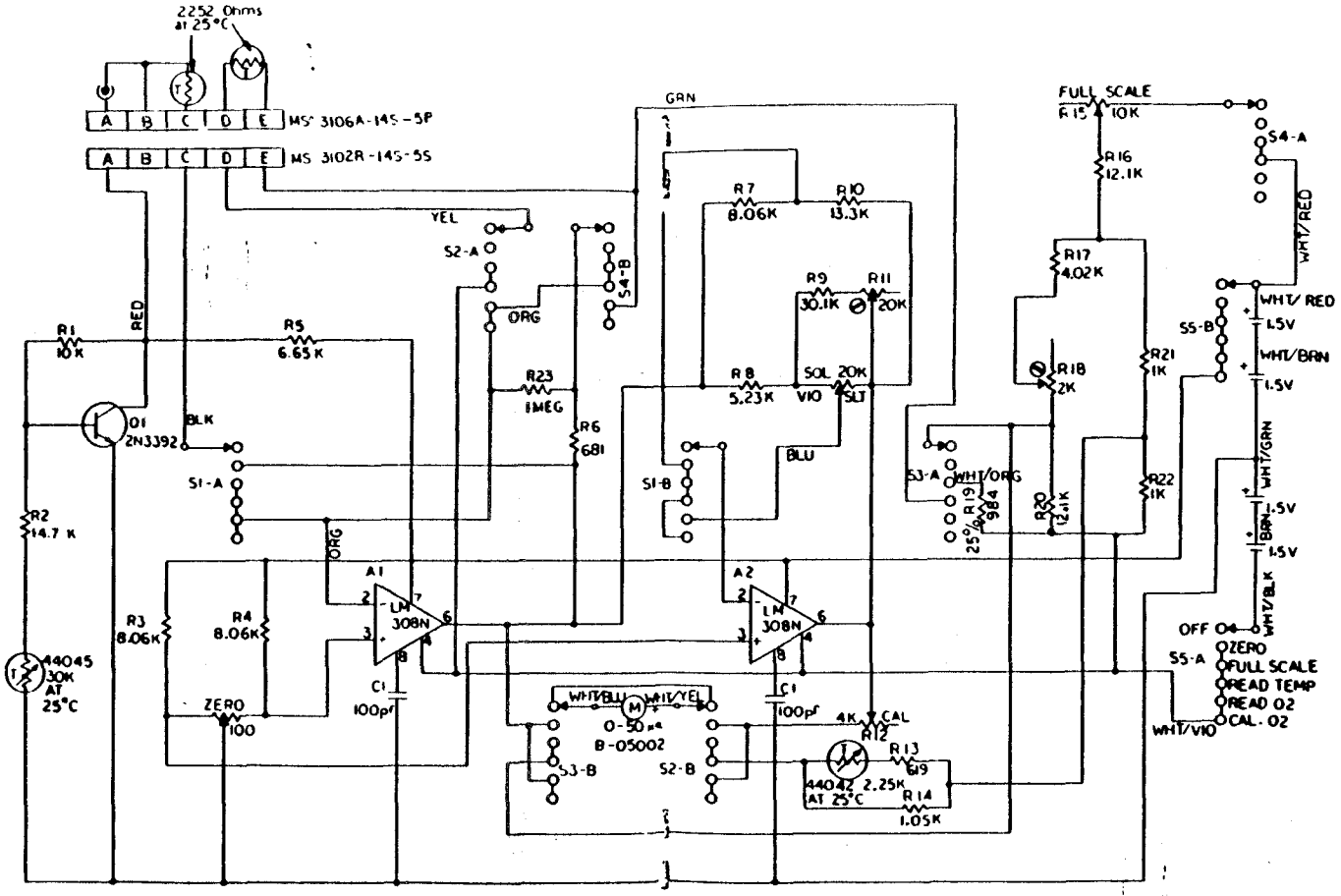
1. With switch in the OFF position, adjust the meter pointer to Zero with the screw in the center of the meter panel. Readjustment may be necessary if the instrument position is changed.
2. Switch to ZERO and adjust to zero with zero control knob.
3. Switch to FULL SCALE and adjust the FULL SCALE knob until the meter needle aligns with the "15" mark on the mg/l scale.
4. Attach the prepared probe to the PROBE connector of the instrument and adjust the retaining ring finger tight.
5. Before calibrating allow 15 minutes for optimum probe stabilization. Repolarize whenever the instrument has been OFF or the probe has been disconnected.

III. Calibration

The operator has a choice of three calibration methods — Winkler Titration, Saturated Water, and Air. Experience has shown that air calibration is quite *reliable, yet far simpler than the other two methods. The three methods are described in the following paragraphs.*

Winkler Titration

1. Draw a volume of water from a common source and carefully divide into four samples. Determine the oxygen in three samples using the Winkler Titration technique and average the three values. If one of the values differs from the other 2 by more than 0.5 mg/l, discard that value and average the remaining two.
2. Place the probe in the fourth sample and stir.
3. Read temperature of calibration sample and set solubility dial to sample temperature. Observe correct salinity. Allow the probe to remain in the sample at least two minutes before setting temperature.
4. With switch in READ O_2 position, set CALIB O_2 Knob to the average value determined in Step 1. Leave in the sample for an additional two minutes to verify stability.



NOTES:

1. Resistor values are in OHMS. K = 1,000. Unless otherwise specified, all resistors are 1/4W 1%.
2. 4 batteries are required. Use Eveready 935 cells or equivalent.
3. All switch sections are ganged.
4. The values shown on the schematic may differ from those in the instrument, if so other value may be used for replacement purposes.

MODEL 818 OXYGEN METER
C-05230-P

Saturated Water

1. Air saturate a volume of water (300-500cc) by aerating or stirring for at least 15 minutes at a relatively constant temperature.
2. Place the probe in the sample and stir.
3. With the switch in the CALIB O_2 position, adjust the CALIB Knob to the mark for the local altitude. Leave probe in sample for 2 minutes to verify stability.

Air Calibration

1. Switch to CALIB O_2 position.
2. Place the probe in moist air. B.O.D. probes can be placed in partially filled B.O.D. bottles. Other probes can be placed in YSI 5075A Calibration Chamber (Refer to the following section describing CALIBRATION CHAMBER) or the small calibration bottle (the one with the hole in the bottom along with a few drops of water. The probe can also be wrapped loosely in a damp cloth taking care the cloth does not touch the membrane. Wait approximately 10 minutes for temperature stabilization. This may be done simultaneously while the probe is stabilizing.
3. With the CALIB Knob set the meter pointer to the mark for the local altitude. Be sure reading is steady. For calibration at altitudes higher than 7000 feet above sea level, see Table II. Recalibration is recommended when altitude is changed. A 1000 ft. altitude change can result in a 3% reading error — 0.3 mg/l at 10.0 mg/l.

The probe is now calibrated and should hold this calibration value for many measurements. Calibration can be disturbed by physical shock, touching the membrane, or drying out of the electrolyte. Check calibration after each series of measurements and in time you will develop a realistic schedule for recalibration. For best results when not in use, follow the storage procedures recommended for the various probes described under OXYGEN PROBES AND EQUIPMENT. This will reduce drying out and the need to change membranes.

Calibration Chamber

The YSI 5075A Calibration Chamber is an accessory that helps obtain calibrating conditions when air calibrating in the field and is also a useful tool when measuring in shallow water (less than 4 ft). As shown in Figure 9, it consists of a 4-1/2 ft. stainless steel tube (1) attached to the calibration chamber (5) and the measuring ring (7). For calibration insert the solid rubber stopper (6) into the bottom of the calibration chamber (5). Push the probe (4) through the hollow rubber stopper (3) as shown in Detail A. For maximum accuracy wet the inside of the calibration chamber (5) with fresh water. This creates a 100% relative humidity environment for calibration. Insert the probe-stopper assembly in the top of the calibration chamber.

During calibration hold the calibration chamber under water and calibrate as described in the Air Calibration procedure. Keep the handle above the water at all times. After calibration the chamber can be used as a measuring aid by removing the probe-stopper assembly from the calibration chamber (5) and placing it in measuring ring (7). (See Detail C). Slowly stir the water with the wand when measuring.

IV. Dissolved Oxygen Measurement

With the instrument prepared for use and the probe calibrated, place the probe in the sample to be measured and provide stirring.

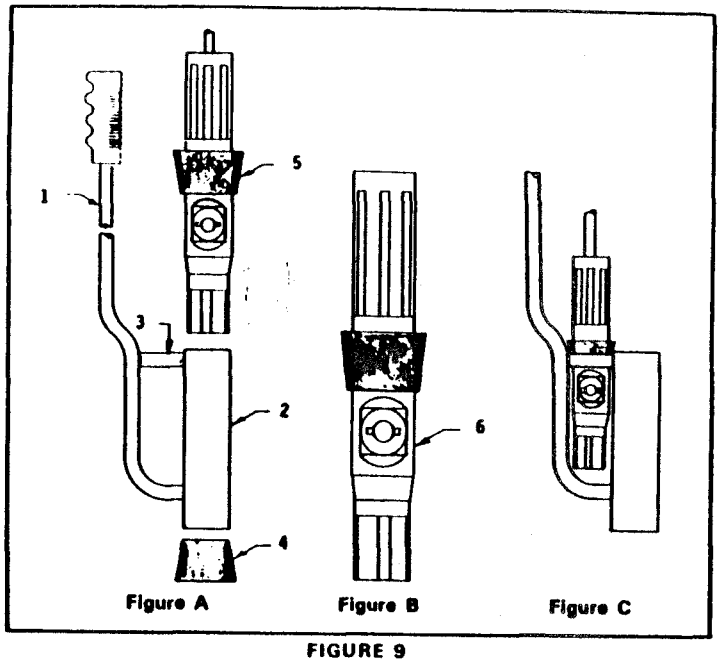


FIGURE 9

1. Stirring for the 5739 Probe can best be accomplished with a YSI Submersible Stirrer. If the Submersible Stirrer is not used, provide manual stirring by raising and lowering the probe about 1 ft. per second. If the 5075A Calibration Chamber is used, the entire chamber may be moved up and down in the water at about 1 ft. per second.
2. The YSI 5720A has a built-in power driven stirrer.
3. With the YSI 5750 sample stirring must be accomplished by other means such as with the use of a magnetic stirring bar.
4. Allow sufficient time for probe to stabilize to sample temperature and dissolved oxygen.
5. Turn the switch to TEMP and read temperature from the lower meter scale. Set the O_2 SOLUBILITY FACTOR dial to the observed temperature, taking care to use the appropriate salinity index (See SALINITY CORRECTION).
6. Turn the switch to READ O_2 and read the dissolved oxygen value in mg/l directly from the meter.

Salinity Correction

Less oxygen can be dissolved in salt water than in fresh water. The amount varies directly with the degree of salinity and, at constant temperature, the relationship can be considered linear for the range of fresh water to sea water, which corresponds to the instrument range of 0 to 20,000 mg/l Chloride.

It is necessary for the operator to determine salinity by suitable means (such as with the YSI Model 33 S-C-T Meter) and then to choose the correct position along the index scale when dialing in the temperature. (See Figure 10)

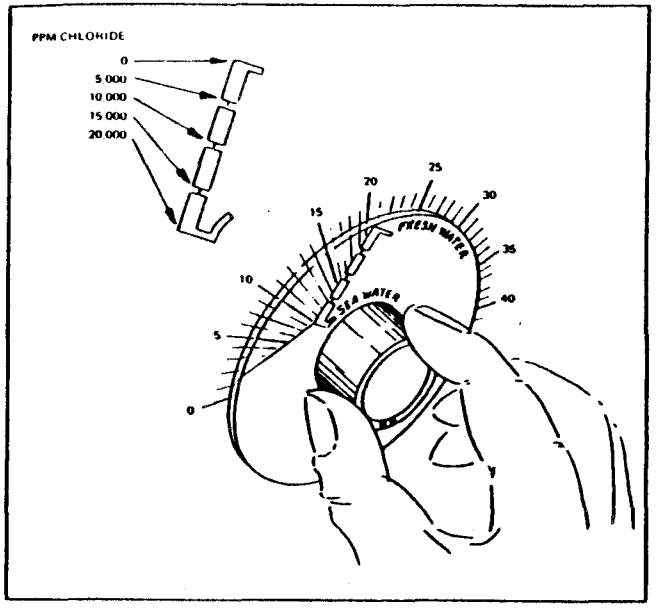


FIGURE 10

Each section of the bar on the O_2 SOLUBILITY FACTOR dial represents 5,000 mg/l Chloride concentration over a range from 0 to 20,000 mg/l. The line leading to the correct temperature should intersect the left edge of the bar at the proper salinity concentration. The drawing shows the dial set for 0 mg/l Chloride at 20°C, or 10,000 mg/l Chloride at 15°C, or about 18,000 mg/l Chloride at 10°C, etc.

Multiple Measurements

If a series of measurements are made in a short time at about the same temperature (within 5°C of calibration temperature) performance will not be degraded and recalibration is not required, simply:

1. Read temperature of new sample.
2. Reset O_2 SOLUBILITY FACTOR DIAL.
3. Read oxygen concentration. Experience is the best guide for deciding how often recalibration is required. Careful probe maintenance and storage aid stability of calibration.

V. % Oxygen & % Air Saturation Measurements

Occasionally it is desirable to measure the % oxygen in a sample or the % air saturation of a sample. The YSI Model 51B can be used for these measurements with any of the YSI 5700 Series Probes with an altered calibration technique as follows:

% Oxygen Readings Calibration Procedure (0-45%)

1 Prepare the probe for operation as previously discussed
2 Connect the probe to the instrument
3 With the instrument OFF adjust the meter to zero on *upper scale* using the adjustment screw
4 Switch to FULL SCALE and adjust the meter to the full scale position
5 Switch to READ O_2 position and leave the instrument on up to 20 minutes to stabilize the probe
6 Set O_2 SOLUBILITY FACTOR dial to 25°C position
7 Switch to ZERO position and adjust meter to zero on the *lower scale* with the ZERO knob
8. Switch to READ O_2 and with the probe in air adjust the meter to 21 on the *lower scale* using the CALIB knob.
9 Repeat Steps 7 and 8 until no further adjustment is required
10 Transfer the probe to the measurement sample and read on the lower scale with the instrument still in the READ O_2 position All readings will be in $\%O_2$ Accuracy will be ±1% O_2, worst case

NOTE. Temperature readings may be made with the switch in TEMP position The SOLUBILITY FACTOR dial must be left in the 25°C position.

% Air Saturation Readings (0-100%)

1 thru 4 Same as in % Oxygen Readings
5. Turn the selector switch to ZERO and adjust the meter to zero on the *upper scale* using the ZERO adjustment knob.
6. Switch to CALIB O_2 and with the probe in air adjust the meter to 10 on the upper scale using the CALIB knob
7. Transfer the probe to the measurement sample and read on the upper scale with the instrument still in the CALIB O_2 position. Multiply by 10 to obtain % air saturation. For example, if the meter reads 8.5, multiply by 10 for an answer of 85% air saturation.

NOTE: Temperature readings may be made with the switch in the TEMP position The O_2 SOLUBILITY FACTOR dial is inoperative and unnecessary when making % air saturation readings.

NOTE: When $\%O_2$ or % air saturation measurements are to be made in water, greatest accuracy will be achieved if the probe is calibrated *in moist air* by suspending it in a bottle containing a small amount of water, or by wrapping it in a damp cloth during calibration steps.

VI. Recording Data

Although the YSI Model 51B is not designed with recorder output, it is possible for the user to modify the instrument slightly in order to record % O_2 and % air saturation Connect a 100 mV recorder with minimum 50K ohm input impedance across the meter terminals Set up the recorder according to the manufacturer's instructions and operate the YSI Model 51B as described.

Dissolved oxygen measurements in mg/l cannot be recorded accurately except under constant temperature conditions This is because the solubility of oxygen in water is temperature dependent and instrument correction is manual If recording of dissolved oxygen is required in your application, we recommend either the YSI Model 54 A or Model 57 Dissolved Oxygen Meter, which have

automatic temperature compensation and are designed with recorder output terminals.

VII. Calibration Tables

The mg/l tables in accordance with standard practice include the vapor pressure of water in the indicated pressure The sample of air used for calibration should be saturated with water vapor for greatest calibration accuracy

The error which may result from use of completely dry air (extreme condition) is small and is maximum at higher temperatures and altitudes. At 25°C and 760 mm pressure the extreme error would be 0.3 mg/l, for 50% RH, 0 15 mg/l If the error is of concern, wet the inside of the sampler cup before use to provide 100% RH. Then no error will occur using the tables provided.

Table I
SOLUBILITY OF OXYGEN IN WATER (Saturated with Air) IN mg/l AT VARIOUS TEMPERATURES AND PRESSURES

TEMPERATURE IN DEGREE CENTIGRADE	P mm P inches	775 30.51	760 29.92	750 29.53	725 28.54	700 27.56	675 26.57	650 25.59	625 24.61
0		14.89	14.60	14.41	13.92	13.44	12.96	12.47	11.99
1		14.47	14.19	14.00	13.53	13.06	12.59	12.12	11.65
2		14.08	13.81	13.63	13.17	12.71	12.25	11.80	11.34
3		13.71	13.44	13.26	12.82	12.37	11.93	11.48	11.03
4		13.35	13.09	12.92	12.48	12.05	11.61	11.18	10.75
5		13.00	12.75	12.58	12.16	11.73	11.31	10.89	10.47
6		12.68	12.43	12.26	11.85	11.44	11.03	10.61	10.20
7		12.36	12.12	11.96	11.56	11.15	10.75	10.35	9.95
8		12.07	11.83	11.67	11.28	10.89	10.49	10.10	9.71
9		11.78	11.55	11.40	11.01	10.63	10.24	9.86	9.47
10		11.50	11.27	11.12	10.74	10.37	9.99	9.62	9.24
11		11.22	11.00	10.85	10.49	10.12	9.75	9.39	9.02
12		10.98	10.76	10.62	10.26	9.90	9.54	9.18	8.82
13		10.73	10.52	10.38	10.03	9.68	9.33	8.97	8.62
14		10.50	10.29	10.15	9.81	9.46	9.12	8.78	8.43
15		10.27	10.07	9.94	9.60	9.26	8.92	8.59	8.25
16		10.05	9.85	9.72	9.39	9.06	8.73	8.40	8.07
17		9.84	9.65	9.52	9.20	8.87	8.55	8.23	7.90
18		9.64	9.45	9.32	9.01	8.69	8.37	8.05	7.74
19		9.45	9.26	9.14	8.82	8.51	8.20	7.89	7.58
20		9.25	9.07	8.95	8.64	8.34	8.03	7.73	7.42
21		9.08	8.90	8.78	8.48	8.18	7.88	7.58	7.28
22		8.90	8.72	8.60	8.31	8.01	7.72	7.42	7.13
23		8.73	8.56	8.44	8.15	7.86	7.58	7.29	7.00
24		8.57	8.40	8.29	8.00	7.72	7.43	7.15	6.86
25		8.41	8.24	8.13	7.85	7.57	7.29	7.01	6.73
26		8.26	8.09	7.98	7.70	7.43	7.15	6.88	6.60
27		8.11	7.95	7.84	7.57	7.30	7.03	6.76	6.49
28		7.97	7.81	7.70	7.44	7.17	6.90	6.64	6.37
29		7.83	7.67	7.56	7.30	7.04	6.78	6.51	6.25
30		7.70	7.54	7.44	7.18	6.92	6.66	6.40	6.14
31		7.56	7.41	7.31	7.05	6.80	6.54	6.29	6.03
32		7.43	7.28	7.18	6.93	6.68	6.43	6.17	5.92
33		7.31	7.16	7.06	6.81	6.57	6.32	6.07	5.82
34		7.20	7.05	6.95	6.71	6.46	6.22	5.97	5.73
35		7.07	6.93	6.83	6.59	6.35	6.11	5.87	5.63
36		6.96	6.82	6.72	6.49	6.25	6.01	5.77	5.53
37		6.85	6.71	6.62	6.38	6.15	5.91	5.67	5.44
38		6.75	6.61	6.52	6.28	6.05	5.82	5.59	5.35
39		6.65	6.51	6.42	6.19	5.96	5.73	5.50	5.27
40		6.55	6.41	6.32	6.09	5.86	5.64	5.41	5.18
41		6.44	6.31	6.22	6.00	5.77	5.55	5.32	5.10
42		6.35	6.22	6.13	5.91	5.69	5.46	5.24	5.02
43		6.26	6.13	6.04	5.82	5.60	5.38	5.16	4.94
44		6.17	6.04	5.95	5.73	5.52	5.30	5.08	4.86
45		6.08	5.95	5.86	5.65	5.43	5.22	5.00	4.78
46		5.99	5.86	5.77	5.56	5.35	5.13	4.92	4.70
47		5.91	5.78	5.70	5.48	5.27	5.06	4.85	4.63
48		5.83	5.70	5.62	5.41	5.19	4.98	4.77	4.56
49		5.75	5.62	5.54	5.33	5.12	4.91	4.70	4.49
50		5.66	5.54	5.46	5.25	5.04	4.83	4.63	4.42

Source Derived from 15 Edition "Standard Materials for the Examination of Water and Wastewater"

It should be noted that the barometric pressure as quoted by the Weather Bureau is not the true atmospheric pressure of the local, but it is corrected to an equivalent sea level reading.

For a reported pressure of 760 mm the true atmospheric pressure at a given altitude is shown in Table II.

Table II
RELATION OF ATMOSPHERIC PRESSURE TO ALTITUDE

Altitude	True Atmospheric Pressure	CALIB Setting for Altitudes Above 7000 Feet Set Meter to Read mg/l
Sea Level	760	
1000 Feet	733	
2000 Feet	707	
3000 Feet	681	
4000 Feet	656	
5000 Feet	632	
6000 Feet	609	
7000 Feet	586	
8000 Feet	564	10.02
9000 Feet	543	9.64
10,000 Feet	523	9.29
11,000 Feet	503	8.93

The temperature-solubility relationship of oxygen in sea water is not the same as that in fresh water.

The solubility of oxygen in sea water is given in Table III.

Table III
SOLUBILITY OF OXYGEN IN SEA WATER
(Chloride concentration 20,000 mg/1)

Temp. °C	Solubility mg/l	Temp. °C	Solubility mg/l
0	11.41	16	7.91
1	11.11	17	7.78
2	10.83	18	7.61
3	10.56	19	7.47
4	10.30	20	7.33
5	10.05	21	7.20
6	9.82	22	7.07
7	9.59	23	6.95
8	9.37	24	6.83
9	9.16	25	6.71
10	8.96	26	6.60
11	8.77	27	6.49
12	8.58	28	6.38
13	8.41	29	6.28
14	8.24	30	6.18
15	8.07		

Source: Derived from 15th Edition "Standard Materials for the Examination of [illegible]"

DISCUSSION OF MEASUREMENT ERRORS

When comparative measures are made on the same sample, under the same conditions, and with the same instrument, the reading should reproduce to ±0.1 mg/l or better. Many factors can contribute to measurement errors. The error figures given below are "worst case absolute error accumulation" where each contributing factor is at its extreme tolerance value and the sum of contributing factors is taken as the worst possible combination. There are three main types of errors:

TYPE 1. Errors due to instrument design, quality control and component limitations. They cannot be reduced without elaborate individual instrument calibration procedures.
1% meter tolerance 0.15 mg/l max.
Amp and circuit 0.05 mg/l max.
(Worst case Type 1 error: ±0.20 mg/l max.)

TYPE 2. Errors arising from temperature and oxygen sensor limitations, non-linear response, and membrane-to-membrane difference. The maximum permissible error is specified, and good maintenance will limit this type of error to those value.
Automatic temperature compensation for membrane temperature coefficient 0.03 mg/l max.
Dial Solubility control error
(1% component 0.10 mg/l max.)
Tracking of panel dial and printing error
-5 to +30°C — 0.05 mg/l max.
(30 to 45°C — 0.10 mg/l max.)

+0.2°C probe error — 0.14 mg/l max.
(Worst case Type 2 error: ±0.32 mg/l max.)

TYPE 3. Errors arising from assumptions made about the environment in which the measurements are made and as such are subject to control by the operator.
Altitude Effect —
1000 ft. change gives about a 3% error or 0.3 mg/l at 10 mg/l level.
Barametric Pressure —
Normal local variation is less than ±0.5" Hg., or 0.15 mg/l max.
Humidity —
If less than 100% RH in calibration chamber. Assume only 50% RH. The error varies with temperature.

TEMPERATURE	ERROR/mg/l
0°C	0.02
10°C	0.05
20°C	0.12
30°C	0.27
40°C	0.68

Neglecting the altitude error —
(Worst case Type 3 errors at 20°C, ±0.27 mg/l max.)

Under the worst conditions with all errors additive — The error at 20°C could amount to: ±0.79 mg/l (max.)

If Type 3 errors are omitted — the worst case error would be: ±0.52 mg/l (max.)

If calibration is achieved at or within 1°C of the sample temperature — the error can be further reduced to: ±0.38 mg/l (max.)

Bearing in mind that these accumulated errors represent manufacturing acceptability limits and that probability of all errors adding in the same direction is low, the probable error accumulation is about 1/2 the maximum: 0.26 mg/l if Type 3 errors are eliminated, and 0.19 mg/l if careful temperature matching technique is employed.

CIRCUIT DESCRIPTION, MAINTENANCE & CALIBRATION

The Model 51B contains two separate circuits:

1. A temperature bridge circuit.
2. An amplifier for oxygen measurement.

The amplifier features integrated circuitry for good temperature stability, low voltage power requirements and long battery life. Current from the oxygen probe develops a voltage across a resistor network which includes a thermistor (kept at O_2 probe temperature). This voltage is applied to the input of the circuit. A portion of the amplifier output is applied to the amplifier input in a standard negative feedback configuration.

The amplifier output circuitry is designed to perform specific manipulations on the input signal to achieve dial-in O_2 solubility factor and to provide calibration adjustment means.

The only normal maintenance is battery replacement. Four "C" size flashlight batteries are required. Battery life is at least 1000 hours of operation or 6 months shelf life.

Battery replacement is indicated if the "full scale" adjustment cannot be made or O_2 calibration cannot be achieved. (Warning: a faulty probe will also not permit O_2 calibration.)

Replace batteries every six months to reduce danger of corrosion due to leaky batteries. To replace batteries — remove six screws from bottom plate — battery holders are color coded. Positive (+ button) end of battery must go to red.

It is possible that the O_2 SOLUBILITY FACTOR dial can become loose and slip from its normal position. In an emergency the dial can be repositioned with the following procedure. It must be emphasized that this is an emergency procedure only, and that the instrument should be returned to the factory for proper recalibration at the earliest opportunity.

1. Calibrate in air to the local altitude in the normal fashion.
2. Switch to TEMP and read temperature of the probe.
3. Refer to Table I and determine solubility of oxygen in water at the observed temperature and current barometric pressure. Consult Table II or call the local Weather Bureau for an exact reading. The more accurate the reading the more accurate will be the calibration.
4. Switch to O_2 and set the O_2 SOLUBILITY FACTOR dial to the observed temperature with salinity of fresh water. The mg/l indication should agree with Table I. If it does not, rotate the SOLUBILITY FACTOR dial until the mg/l indication does agree with Table I. Loosen the dial reposition to the pointer indicates the observed temperature. This is a temporary calibration only. As soon as possible the instrument should be returned for factory recalibration. YSI maintains complete facilities for repair and recalibration of all YSI products.

INSTRUMENT BATTERIES

Battery replacement is indicated if full scale adjustment cannot be achieved or O_2 calibration cannot be achieved. (Warning: A faulty probe will also not permit O_2 calibration).

To replace batteries remove the four screws holding the rear cover of the instrument. The four batteries will be found on the battery terminal board inside. *See Figure 11.*

Battery holders are color coded. POSITIVE (+ button) end of battery must go to red.

Replace with Eveready No. 935 "C" size or equal.

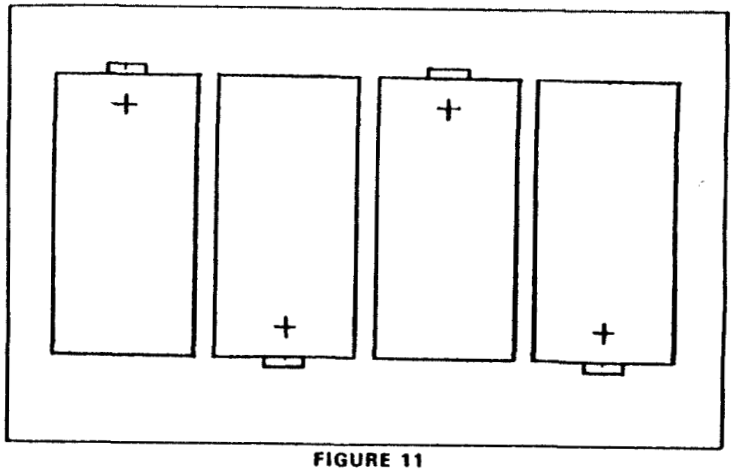


FIGURE 11

WARRANTY AND REPAIR

All YSI products carry a one-year warranty on workmanship and parts, exclusive of batteries. Damage through accident, misuse, or tampering will be repaired at a nominal charge, if possible, when the item is returned to the factory or to an authorized YSI dealer.

If you are experiencing difficulty with any YSI product, it may be returned for repair, even if the warranty has expired. YSI maintains complete facilities for prompt servicing of all YSI products.

Service Department
Yellow Springs Instrument Co., Inc.
P.O. Box 279
Yellow Springs, Ohio 45387, U.S.A.
Phone: (513) 767-7241
Telex: 20-5437

CARE AND FEEDING OF THE "MINI" & "DIGITAL"

I. GENERAL RECOMMENDATIONS

THE FOLLOWING RECOMMENDATIONS ARE PROVIDED AS A SUPPLEMENT TO THE CONDENSED OPERATING INSTRUCTIONS MOUNTED IN THE CARRYING CASE.

- *When transferring from one solution to another, thoroughly rinse electrode with water, shaking off any excess water. This simple procedure will prevent "carry-over" contamination between samples.*
- *After immersing electrode in sample or buffer, stir solution slightly to improve electrode response time.*
- *When storing electrode for extended period, put several drops of distilled water in plastic boot and place boot over end of electrode.*
- *Optimum performance is obtained when buffers and samples are at the same temperature.*
- *If calibrate or span adjustments are made per Steps 4, 5, and 6 of the Condensed Operating Instructions (Steps 5, 6 & 7 for analog meter), repeat these steps to check new settings.*

II. TEMPERATURE (SPAN) COMPENSATION

The "TEMP" knob serves the dual function of both temperature compensation and span adjustment.

Since pH electrode output is temperature dependent, the "TEMP" control corrects for changes in electrode output with temperature. Thus as solution temperature changes, the "TEMP" knob must be adjusted accordingly.

The "TEMP" control also provides a means adjusting the span of the meter to compensate for electrodes having less than the theoretical output voltage. The cali-

above. Check electrode using fresh buffer solutions. If condition persists replace probe.

D. **NO CHANGE IN READING FROM ONE BUFFER TO ANOTHER** – Replace electrode.

E. **UNSTABLE DIGITAL READINGS** – Due to the nature of digital circuitry, a change of one least significant digit (0.1 pH unit) may occur during normal operation. Since this one digit "toggle" occurs when the input signal is midway between two values, many users find it convenient to record such a reading with a "5" in the next decimal position. For example, a reading which toggles between 6.8 and 6.9 is recorded as 6.85.

NOTE: Repeated toggle action of more than ±0.1 pH unit is an indication that the batteries are nearing the end of their useful life and should be replaced with fresh ALKALINE batteries.

VI. BATTERY REPLACEMENT

A. Digital Mini-pH-Meter

When batteries require replacement, remove two screws in back of case and replace with 9 volt ALKALINE transistor radio batteries (Mallory MN1604 Duracell or equivalent).

NOTE: Use *ONLY ALKALINE BATTERIES* – substitution of other battery types may cause meter instability.

B. Analog Mini-pH-Meter

When batteries require replacement, remove two screws in back of case and replace with 9 volt transistor radio batteries (NEDA 1604).

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bration procedure listed in the Condensed Operating Instructions performs the span adjustment when the "TEMP" knob is set to give a reading of 4.0 in 4.01 pH buffer. Thus, when the calibration is complete, the "TEMP" knob may be set to a temperature other than the actual solution temperature.

In such cases, the observed "temperature setting differential" indicates the amount of span adjustment required for proper calibration. If it becomes necessary to adjust the "TEMP" knob because of changes in solution temperature, maintain the above "temperature differential" for the new temperature setting. Note: For optimum performance, all solutions should be at the same temperature.

III. USE WITH BUFFER SOLUTION OTHER THAN 6.86 AND 4.01 pH

Some applications may require the use of buffer solutions other than 6.86 and 4.01 pH. In these cases, the Condensed Operating Instructions must be amended as follows:

- *Step No. 4 (No. 5 for analog meter) – Immerse electrode in the buffer solution having a pH value nearest to 7 pH. Turn "CALIBRATE" knob so meter reads correct pH value.*
- *Step No. 6 (No. 7 for analog meter) – Immerse electrode in second buffer solution and turn "TEMP" knob (span adjust) so meter reads correct pH value of buffer solution.*

IV. MEASUREMENT OF DEIONIZED WATER

The measurement of deionized water or other poorly buffered solutions requires additional care to insure satisfactory readings. Solutions of this nature are prone to contamination by "carry-over" from the previous sample.

Thoroughly rinse electrode with water and blot dry between each successive sample or buffer.

Solutions having low specific conductivity (e.g. high purity water) may present the additional measurement problem of apparent drift or instability. Although these effects can be minimized by stirring the sample during measurement, there are some applications where a refillable combination electrode with a flowing reference is preferred.

V. TROUBLESHOOTING COMMON pH PROBLEMS

Most apparent instrument malfunctions are not associated with the electronic circuitry and can be traced to one or more of the following: weak batteries, contaminated buffers, improper measurement technique or inoperative electrode. If the pH meter fails to operate properly, the following checks should be made prior to returning the unit for repair:

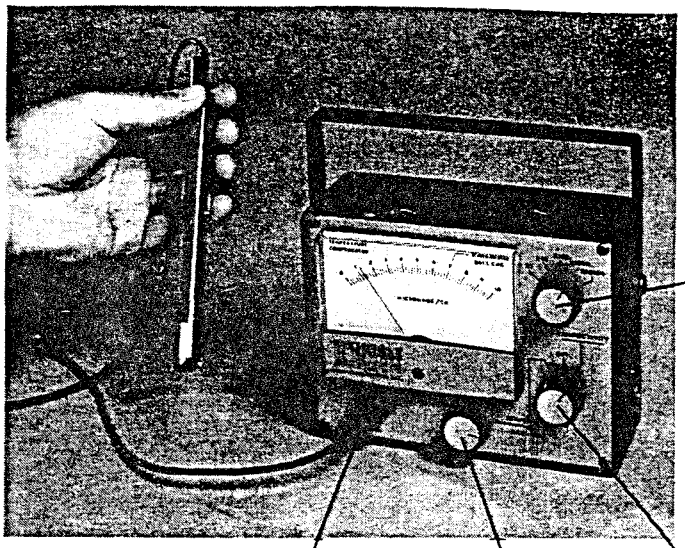
- *Replace batteries.*
- *Check meter using fresh buffer solutions.*
- *Check measurement procedure per Condensed Operating Instructions.*
- *Whenever possible, substitute a known good electrode.*

The following symptoms and proper corrective action will aid in locating the source of the problem.

A. **SLUGGISH RESPONSE** – Clean electrode tip with a mild detergent solution to remove any dirt or oily films on the membrane and rinse thoroughly. If condition persists, replace electrode.

B. **EXCESSIVE DRIFT** – Clean electrode per "A" above. If condition persists, replace electrode.

C. **INSUFFICIENT SPAN** – Clean electrode per "A"


RANGE
ON-OFF
FUNCTION
CELL CONNECTION
BATTERY CHECK/
STANDARDIZE

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- B. Calibration
  - 1. Automatic Calibration
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- C. Conductivity Measurement
- D. General Technique

V. Maintenance
- A. Replacement and Spare Parts List
- B. Troubleshooting
- C. Internal Recalibration

SHIPPING CHECK LIST

MODEL 10

1 each		Portable Conductivity Meter
1 each	# 1100	Cell
8 each	# 88	Alkaline Batteries(installed

MODEL 10A

1 each		Portable Conductivity Meter
1 each	# 1100	Cell
8 each	# 6799	NiCd Batteries(installed)
1 each	# 86	Charger

MODEL 10B

1 each		Portable Conductivity Meter
1 each	# 1100	Cell
8 each	# 6799	NiCd Batteries(installed)
1 each	# 6436	720 micromho standard solution (1 pint)
1 each	# 6437	6680 micromho standard solution (1 pint)
1 each	#13388	Carrying case
1 each	# 6793	Stand with base, clip and r
1 each	# 86	Charger

CHECK LIST

rtable Conductivity Meter
ll
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rtable Conductivity Meter
ell
Cd Batteries(installed)
20 micromho standard
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580 micromho standard
olution (1 pint)
arrying case
tand with base, clip and rod
harger

WARRANTY

The number on the attached packing list or invoice is your reference number for warranty service. Please refer to this number when inquiring about the instrument.

MARKSON SCIENCE warrants its Model 10 meter against defects in workmanship or materials for a period of one year from the date of sale. Warranty will be allowed whenever justified, but all warranty claims must be reviewed by the manufacturer.

If shortages are noted or you require additional parts or accessories, please contact MARKSON SCIENCE at (800) 854-2822.

Shipping damage, damage due to user mishandling and normal wear and tear are not covered under warranty.

Shipping damage claims should be filed with the carrier; they are not covered under warranty. In the event damage is noticed, retain all packing material for carrier inspection.

The return address for service is:

MARKSON SCIENCE INC.
533 Stevens Ave.
Solana Beach, CA 92075

See TROUBLESHOOTING section for instructions regarding explanation of problems.

SPECIFICATIONS

READABILITY

x 1	1-10 micromhos/cm
x 10	10-100 "
x 100	100-1000 "
x 1000	1000-10,000 "
x 10,000	10,000-100,000 "

Readings below 1 on the meter could be non-linear.

RELATIVE ACCURACY

± 1% of range

REPEATABILITY

± 0.5% of range

CONDUCTIVITY CELL

The 1100 conductivity cell can function as a dip type or flow through. It is constructed of PVC and epoxy with gold electrodes. It is temperature compensating over a range of 0 to 100° C.

The Model 10 meter and conductivity cell are calibrated as a unit. For replacement of cell, recalibration may be necessary. See page 11.

1-10 micromhos/cm
10-100 "
100-1000 "
1000-10,000 "
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meter and conductivity

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page 11.

IV. OPERATION

A. Set UP

1. Cell Holder and Stand Installation

   a. Remove the flat head screw from the post and attach the post to the stand base (for Model 10B only)

      Insert the conductivity cell through the "C" shaped clip in the end of the cell holder by slightly spreading the jaws of the clip. Clip the holder on the post to the desired level.

2. Cell Installation

   Connect the conductivity cell to the connector located at the lower left corner of the instrument. Note the socket and pin key. Do Not Force.

B. Calibration

1. Automatic Calibration

   a. Turn the ON-OFF knob to the left to the BATTERY CHECK/ STANDARDIZE position.

   b. Adjust the STANDARDIZE knob, to read 7. ~~Tighten the lock nut when you reach this position.~~

   See Section C for measurement procedure.

2. Standardizing Solutions Calibration

The automatic calibration can be used for field readings where standardizing solutions are not available. However, if you require more precise readings, the following procedure is recommended.

a. Pour about 1.75 inches of the standard solution closest to the conductivity range you will be measuring into a test tube or beaker. Four different standard solutions are available (75, 720, 6680, 58650 micromhos). See page 10.

b. Using the STANDARDIZE knob, adjust the meter reading to agree with the value of the value of the standard solution. Move the cell up and down vigorously to shake free any bubbles that might cling to the inside of the cell. When checking calibration, be certain to rinse the cell with a small amount of standard solution, then pour in fresh standard for final calibration. Lock down STANDARDIZE knob after calibration.

Solutions Calibration

calibration can be
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solutions are not
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eadings, the follow-
is recommended.

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Four different
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720, 6680, 58650
. See page 10.

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he cell with a small
standard solution,
in fresh standard for
bration. Lock down
E knob after calibra-

C. CONDUCTIVITY MEASUREMENT:

1. Turn RANGE switch to X 10,000.
2. Turn Function switch to Conductivity.
3. Insert cell in solution to a depth of 1.75 inches.
4. Select a Range that gives the highest possible meter reading.
5. Allow approximately one minute for the temperature compensation thermistor (in the tip of the conductivity cell) to reach solution temperature. Read conductivity directly in micromhos/cm^2 and multiply times the RANGE setting.

D. GENERAL TECHNIQUE

The care of the conductivity cell and proper technique are very important for accurate readings.

1. Before using, thoroughly clean the cell of dirt, grease and old sample by washing in a solution of warm water and a mild detergent. Rinse cell in DI water several times.

2. Be certain you have enough solution to reach both cell electrodes. If you are not getting a change in the reading when you change solutions, you may not be making contact. Raise the fluid level three inches up the cell. Jiggle the cell up and down in the solution to remove any air bubbles.

3. If you purchased the battery recharger, catalog number 86, use it whenever possible to relieve drain on the batteries. The meter will not function without batteries.

4. When measuring samples, rinse the cell three times with deionized water, preferably by squirting water through the cell, between samples to reduce the possibility of cross-contamination.

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educe the possibility
tamination.

5. After rinsing, flush the cell with the sample to be measured before taking a reading. This is especially important when going from a solution with high conductivity to one with lower conductivity.

6. Allow approximately one minute for temperature compensation thermistor to reach solution temperature before reading.

AFTER USAGE

The conductivity cell should be thoroughly rinsed In Acetone or Alcohol ~~and dryed~~, then stored in a cool, dry place.

BATTERY CHANGE

To change batteries unscrew the four screws in the corners of the front panel. Carefully separate the front panel and attached circuit board from the case. The batteries are attached to the back of the case.

V. MAINTENANCE

A. Replacement and Spare Parts List

#1100 Conductivity Cell

#6435 Conductivity standard
0.0005N KCl-75 micromhos

#6436 Conductivity standard
0.0005N KCl-720 micromhos

#6437 Conductivity standard
0.05N KCl-6,680

#6438 Conductivity standard
0.5N KCl-58,650

#6793 Stand with base, clip and rod

#13338 Carrying case

86 Recharger

88 Alkaline Batteries 8/pk

#6799 Rechargeable NiCd Batteries
8/pk

and Spare Parts List

ctivity Cell

ctivity standard
5N KCl-75 micromhos

ctivity standard
5N KCl-720 micromhos

ctivity standard
KCl-6,680

ctivity standard
KCl-58,650

with base, clip and rod

ing case

arger

Li Batteries 8/pk

argeable NiCd Batteries

B. Troubleshooting

Most problems which occur can be quickly solved by contacting MARKSON with a list of symptoms. Information needed includes sample size and composition, and a description of what is occurring.

MARKSON has personnel readily available to solve most of your problems over the telephone, but should the meter need to come home for repair, please call our toll free number (800) 854-2822 for return instructions. (See page 3 for return shipping address)

Internal Recalibration

The Model 10 meter and conductivity cell were coordinately calibrated at the factory. Therefore, if you have to replace the conductivity cell the Model 10 will probably need an internal recalibration.

This can be done by following the procedure below, or you may return the meter to MARKSON at the address listed on page 3 and we will make the needed adjustment for a mininal charge.

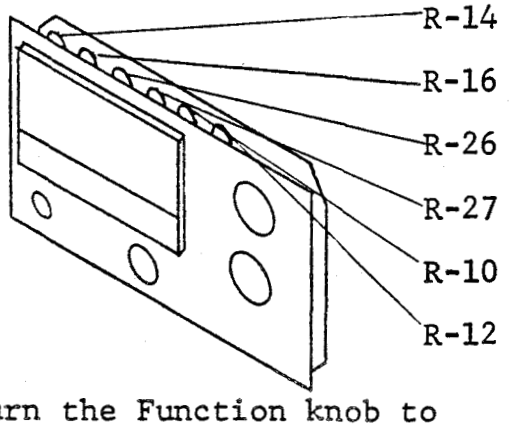
RECALIBRATION PROCEDURE

1. Unscrew the four screws in the corners of the front panel.
2. Carefully separate the back housing exposing the circuit board attached to the front panel.

3. Check the batteries in your meter at this point. If they are low this will effect the accuracy of your calibration.

4. Set the FUNCTION switch to STANDARDIZE. Turn the STANDARDIZE knob fully counterclockwise, then turn the knob clockwise about 10% of full travel. Set the lock nut in this position.

5. There are six pots across the top of the internal printed circuit board as diagramed below:



a. Turn the Function knob to CONDUCTIVITY.
b. Rinse the cell, in DI water, shake, and wipe the exterior dry.
c. Set the Range to X 100.
d. Place the cell into 720 micromho standard solution.
e. Adjust R26 until a meter reading of 720 occurs.

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:. If they are low
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:ION switch to STAND-
ı the STANDARDIZE knob
:clockwise, then turn
:kwise about 10% of
Set the lock nut in
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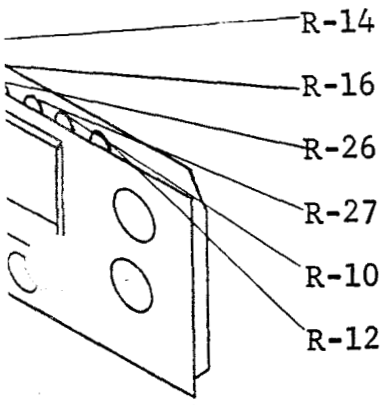
: pots across the top
ıal printed circuit
;ramed below:



Function knob to
/ITY.
: cell, in DI water,
ıd wipe the exterior

ıange to X 100.
: cell into 720
standard solution.
:6 until a meter reading
:curs.

6. Follow steps 5.a and 5.b above.
   c. Set the Range to X1000.
   d. Place cell into 6680 micromho standard.
   e. Adjust R~~26~~12 to read 6680.

7. Steps 5.a and 5.b
   c. Set Range to X10,000.
   d. Place cell into 58,650 micromho standard solution.
   e. Adjust R10 to read 58,650.

9. Repeat steps 5.a and 5.b
   c. Set Range to X1.
   d. Place cell into 7.2 micromho standard solution
   e. Adjust R16 pot to read 7.2.

10. a. Rinse cell with Acetone or Alcohol Shake ~~and thoroughly dry~~ the inside cylinder of the cell To Dry.
    b. Turn Function knob to STANDARDIZE.
    c. Set R27 to read 7.

11. Replace meter backing
    It is not necessary to use the exact values of standard solutions specified above as long as you have solutions that are undoubtably good in these various ranges.

    Remember, whenever in doubt, call us. We're glad to help.

8. Steps, 5a and 5b
   c. Set range to X10
   d. Place cell into 75 micromho standard solution
   e. Adjust R14 to read 7.5.

DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
ENVIRONMENT, SAFETY AND HEALTH DIVISION
ENVIRONMENTAL PROGRAMS BRANCH

COMPREHENSIVE ENVIRONMENTAL ASSESSMENT AND RESPONSE PROGRAM

PHASE 2:
ROCKY FLATS PLANT
INSTALLATION GENERIC MONITORING PLAN
(Comprehensive Source and Plume Characterization Plan)

TECHNICAL DATA MANAGEMENT PLAN

February 1987

DRAFT

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TECHNICAL DATA MANAGEMENT PLAN

1. INTRODUCTION

CEARP Phase 2 Confirmation consists of CEARP Phase 2a, Monitoring Plan, and CEARP Phase 2b, Site Characterization (Remedial Investigation). This Technical Data Management Plan is one component of the Monitoring Plan for Rocky Flats Plant. The Monitoring Plan typically consists of five parts: Synopsis, Sampling Plan, Health and Safety Plan, Quality Assurance/Quality Control Plan, and Technical Data Management Plan. Because of the Compliance Agreement made by the State of Colorado, Environmental Protection Agency, and Department of Energy (DOE), this Monitoring Plan also includes a Feasibility Study Plan. The Synopsis provides a discussion of the current situation and serves as an introduction to the other plans.

CEARP uses a three-tiered approach in preparing the monitoring plans: the CEARP Generic Monitoring Plan (CGMP), the Installation Generic Monitoring Plan (IGMP), and the Site-Specific Monitoring Plans (SSMPs).

This revised IGMP serves as the Comprehensive Source and Plume Characterization Plan required by the Compliance Agreement. Therefore, the acronym used to refer to this plan is IGMP/CSPCP.

The CGMP provides generic guidance and establishes procedures for conducting site characterization activities under CEARP Phase 2 site characterization (remedial investigation). The CGMP Technical Data Management Plan outlines how the DOE Albuquerque Operations Office will implement data management requirements under CEARP, and provides guidance to Rocky Flats Plant and to Los Alamos National Laboratory on data and documentation requirements under CEARP. The Technical Data Management Plan directs Los Alamos National Laboratory to establish a master data file to archive Rocky Flats Plant site- and installation-specific data and documentation required for DOE-Albuquerque Operations Office. Furthermore, it establishes reporting requirements under CEARP and DOE Order 5480.14 (CERCLA Implementation), with the provision that Los Alamos National Laboratory will perform final report preparation, or, if program implementation is delegated to Rockwell International at some time in the future, Los Alamos National Laboratory will review

all reports for conformance with previously established program guidelines. In the latter case, Los Alamos National Laboratory will document its evaluation for DOE-Albuquerque Operations Office use in report concurrence prior to its release to the public or regulatory agencies. Thus, the CGMP Technical Data Management Plan is the foundation for this Rocky Flats Plant IGMP/CSPCP Technical Data Management Plan.

2. OBJECTIVES

Specific objectives of this IGMP/CSPCP Technical Data Management Plan are to provide a structured and organized framework in which to identify and document contaminants in the Rocky Flats Plant environs. It ensures that necessary information for preparation of CEARP Phase 2b site characterization (remedial investigation) reports and CEARP Phase 3 technological assessment (feasibility study) reports are available, and that specific reporting requirements under CEARP are met. This encompasses the reporting requirements for RCRA continuing release sites and CERCLA sites.

3. IMPLEMENTATION

The CGMP Technical Data Management Plan identifies two major types of information needed for CEARP Phase 2b site characterizations (remedial investigations) at Rocky Flats Plant: documentation (e.g., reports, maps, drawings, and aerial photographs) and data (e.g., field measurements and sample analyses). This IGMP/CSPCP Technical Data Management Plan specifies how Rocky Flats Plant, Los Alamos National Laboratory, and their subcontractors will manage data and what documentation will be prepared while performing the CEARP Phase 2b site characterizations (remedial investigations) at Rocky Flats Plant.

Some information collected and managed under CEARP (e.g., data not requiring rapid retrieval or extensive analysis) may not be incorporated into a computerized data base. However, where applicable, an Information Management System will be implemented. General guidance for an information management system is presented in Appendix A of the CGMP Technical Data Management Plan. Specific components of an Information Management System are identified in this IGMP/CSPCP Technical Data Management Plan, Section 2, Information Management System Description. American Standard Code for Information Interchange (ASCII) formatted data files will be produced on magnetic media for archiving at Rocky Flats Plant and Los Alamos National Laboratory and for possible future transfer among computer systems.

The Information Management System will maintain a system access security level that meets requirements of DOE Order 1360.2 (Computer Security Program for Unclassified Computer Systems) and Albuquerque Operations Office Order 1360.2A. These orders establish procedures to be followed in establishing a computer security program for unclassified computer systems. A computer security plan will be submitted to DOE-Albuquerque Operations Office for review and approval as required by DOE-Albuquerque Operations Office Order 1360.2A.

4. DATA AND DOCUMENTATION REQUIREMENTS

General criteria for acceptance of data and documentation are presented in the CGMP Technical Data Management Plan, Section 2.2, and in the IGMP/CSPCP Quality Assurance/Quality Control Plan, Section 4. These criteria apply to data and documentation collected or utilized under CEARP at Rocky Flats Plant. These criteria establish guidelines for acceptable, marginally acceptable, and unacceptable information. Data maintained in the Information Management System data base will be labelled accordingly, based on adherence to procedures involving data collection and evaluation described in the IGMP/CSPCP Sampling and Quality Assurance/Quality Control Plans.

6. DATA REPORTING

Data reporting under CEARP for Rocky Flats Plant will follow the guidance set forth in DOE Order 5480.14 (CERCLA Implementation), as outlined in the CGMP Technical Data Management Plan. It will be responsive to EPA guidance for reporting on remedial investigations and feasibility studies under CERCLA, as well as remedial investigations and corrective measures under RCRA for continuing release sites. Reporting for site characterizations (remedial investigations) at Rocky Flats Plant will be provided in the CEARP Phase 2b site characterization (remedial investigation) reports, as discussed in the IGMP/CSPCP Synopsis.

General guidance on CEARP Phase 2 reporting requirements is provided in the CGMP Technical Data Management Plan, Section 5.1. Additionally, effective analysis and reporting methodologies, as components of an Information Management System, will be implemented as described in Section 8.3 of this plan.

7. DATA ARCHIVE

As described in the CGMP Technical Data Management Plan, a CEARP master data archive for CEARP-related documentation will be maintained for DOE-Albuquerque Operations Office at Los Alamos National Laboratory. This data archive will contain only that information necessary to document CEARP activities and to allow subcontractors to perform additional CEARP-related tasks at any given site without having to re-collect data. In addition, this archive will allow easy access to relevant information regarding Rocky Flats Plant if it becomes necessary to reevaluate sites. Data archival for CEARP will be consistent with DOE Order 1324.2A (Records Disposition). A parallel data archive will be maintained at Rocky Flats Plant.

8. INFORMATION MANAGEMENT SYSTEM DESCRIPTION

This IGMP/CSPCP Technical Data Management Plan outlines procedures to be used in archiving, manipulating, analyzing, and evaluating physical, chemical, and biological data collected during site characterizations (remedial investigations) at Rocky Flats Plant. An Information Management System provides an effective mechanism for data management.

8.1. INFORMATION MANAGEMENT SYSTEM

Specific objectives of an Information Management System are to

- enable rapid, cost-effective determination of the extent of contamination at affected sites and to support technology assessments (feasibility studies), standards/criteria development, remedial action planning, and design of subsequent field investigations;
- enable effective electronic transfer of data and information;
- minimize personnel time required to manage, analyze, interpret, and report information;
- apply automated techniques to archive, manipulate, and analyze environmental data from a centralized, structured data base; and
- provide an integrated, systematic approach to data management and analysis.

8.1.1. Information Flow Processes

An Information Management System emulates the information flow processes through application-oriented, problem solving techniques that deliver technical and managerial summaries from massive amounts of data. Figure A-1 (Appendix A) represents a conceptualization of an information flow process based on examination of workflow procedures and decision making requirements. Basic Information Management System components are identified below:

- data collection requirements
- data encoding
- data review
- data base management system
- data entry
- data verification

- data base
- data editing
- data modification and deletion
- data analysis/presentation preparation
- data analysis and modeling processors
- data evaluation/design criteria
- decision/design.

A description of information flow processes and an elaboration of Information Management System components are found in Appendix A.

8.1.2. Information Management System Structure

The Information Management System will consist of two major subsystems. One subsystem controls the data base management, and the other controls data reporting, analysis, and presentation. Each subsystem will consists of several components that perform specific tasks.

The data base management subsystem provides

- a well-defined, efficient, flexible data base structure,
- a powerful, efficient, versatile data base manager,
- maintenance modules for entry, modification, and deletion of data, and
- reporting modules for retrieval of basic data.

The data reporting, analysis, and presentation subsystem provide

- data manipulation, analysis, and reporting modules for retrieval and reporting of information;
- graphics/numerics modules for numerical surface generation, graphical display, and spatial data analysis (the graphics system should be capable of generating various charts [e.g., line, bar, and pie] and maps); and
- a statistical analysis system and program/model library.

8.1.3. System Access Security

Computerized data base management systems will be secured in accordance with DOE Order 1360.2 and will follow procedures for implementing computer

security programs in accordance with DOE-Albuquerque Operations Order 1360.2A. These orders establish security programs for unclassified computer systems; in no case will these systems archive or process classified information. Primary aspects involving security are as follows:

- controlling access to data for retrieval and update,
- protecting data from accidental loss, improper use, alteration, manipulation, or unauthorized disclosure.

Basic methods for tracking and maintaining security are as follows:

- identify the person who last entered or modified data,
- log the date on which the entry or update was performed,
- track whether data has been validated and locked from further changes or uses, and
- track whether data is available for viewing and which access is permitted by which individuals.

8.2. DATA COLLECTION AND ENTRY

This section provides guidelines for data collection and entry into the Information Management System. Data collection forms and required formats for magnetic recording of data are described.

8.2.1. Data Collection Forms and Formats

Standard data collection forms provide a means to record data in a consistent format that reduces individual interpretations and preferences. By illustrating methods to be used in reporting data, identifying appropriate units of measure, and listing variable test procedures, standard data collection forms in themselves provide a measure of quality control and quality assurance in the data collection effort. This approach overcomes difficulties that may arise from changes in field personnel or from use of multiple laboratories for sample analyses, by structuring data collection results in an objective, rather than subjective manner.

Standardization of data collection forms may be viewed as a prime factor in the overall effectiveness and usefulness of an Information Management System. Each

data collection form precisely defines what data are necessary to accurately characterize a particular property or relationship. This reduces the likelihood of initiating field sampling or laboratory analyses, only to discover that key pieces of information have not been collected and that further sampling is required. Sample data collection forms are shown in Appendix B.

8.2.2. Automated Data Entry and Transfer

Data collection may be enhanced through the use of automated data entry and transfer devices. Although not a consideration for minor data collection efforts, these systems become cost-effective when large amounts of data are processed. They also eliminate one potential mechanism for error: manual data transcription.

The design of an automated data entry and transfer system will parallel the Information Management System in both function and structure. It will incorporate mechanisms for data verification, deletion, and modification, and will maintain the data type structures that are central to the Information Management System.

8.2.3. Data Base Design and Structure

The Information Management System stores data in a structured centralized data base that consists of three data regions. The first region contains information about the installation, the second region contains information common to all sites, and the third region contains information specific to individual sites. The Information Management System will provide the following:

- a centralized data base for distributed access and processing that is independent of processing software,
- a data management system that minimizes storage space and provides efficient operating capabilities, and
- file structure definition that enhances the ability to access, retrieve, and update data.

8.3. DATA ANALYSIS

The Information Management System will allow for preliminary examination of raw data to assess its integrity, completeness, and accuracy, and to determine its

suitability for further processing and/or analysis. This will be accomplished by the data base management system software that sorts, selects, and reduces numerous records of information into concise summaries for data evaluation.

The capabilities of data base management systems are further enhanced through the use of system processors and utilities, program models, and reporting modules designed specifically for the presentation of the data in specific formats. Data contained in the Information Management System can be accessed to develop input files for models that are used to perform simulations and analyses.

Information may also be analyzed through data enhancement by graphical processors. By analyzing data in graphical formats, it is possible to identify trends and irregularities that are otherwise obscure. Graphical processors serve to synthesize vast amounts of data, and allow for rapid and simplified display of information.

8.3.1. Data Preparation

The Information Management System will contain algorithms that select and format data subjects from the technical data base to provide input to analytical subsystems. The general analytical subsystems are

- graphics/numerics subsystem,
- general graphics subsystem,
- statistical analysis subsystem, and
- programs and models subsystem.

Functionally, data are copied from the technical data base and loaded into subsystem input files. Data format in the input files is flexible, and is produced in accordance with the specific processing module requirements of the subsystem.

8.3.2. Data Analysis and Reporting

The Information Management System provides an applications-orientated approach to data analysis and reporting. Key components that provide these capabilities include

- versatile centralized data base and distributed processing,
- maximum use of general purpose standard software packages that operate independently of data base management systems,

- modular processing software for efficient maintenance,
- report writer capability for data reporting,
- base map graphical capability (digitized maps) for manipulation and display of spatial reference,
- general purpose statistical software packages for descriptive statistics and hypothesis testing.
- general purpose graphing capability for display of scientific, technical, and management data,
- general purpose numerical surface/contouring capability for data analysis and reporting,
- model library containing appropriate groundwater, air, and other technical programs for data analysis and reporting, and
- data preparation modules for interfacing external programs and models with the data base.

8.3.3. Statistical Data Analysis

The Information Management System includes a statistical analysis subsystem to perform standard statistical operations, (e.g., minimum, maximum, mean, standard deviation, regression, correlation analysis of variance and co-variance, and hypothesis testing). This subsystem will operate independently of the data base management system, enabling it to process preliminary data that may not be entered into the data base.

8.4. PROGRAM AND MODEL LIBRARY

Programs and models acquired or developed will be collected into a common library. All models will be tested to run accurately against standard test data as provided in original documentation. The test data and an example run pattern will be kept in the library. The model library will be composed of, but not limited to, the following areas:

- hydrology and hydraulics
- groundwater flow
- aquifer simulation
- meteorology
- solute transport and dispersion

- soil and rock mechanics
- chemical equilibrium

8.4.1. Data Validation Software

Specific programs and utilities that analyze and validate the extent, quantity, and quality of the data collected should be provided. Such programs include data inventory reporting and laboratory analysis validation.

8.4.2. Program/Model Documentation

All reference material pertaining to programs or models will be available for inspection and study. This material may include user guides, system design and operation manuals, test input data and output results, and other information as provided by the author or agency from which the model was acquired.

Programs or models which are developed specifically for the project will be tested and documented accordingly.

APPENDIX A

INFORMATION FLOW PROCESS

The overall flow of information (Figure A-1), as described below, is the basis for design of a data base management system. Individual components are integrated into operational units that form the Information Management System.

Data Collection Requirements. Date collection requirements depend on intended data use. For site characterizations (remedial investigations), site assessments provide the initial requirements by quantifying the extent of information in the historical data base. Subsequent confirmation and quantification of site contaminants refine these requirements.

This process establishes a feedback loop between data evaluation and data collection requirements, as shown in Figure A-1.

Data Encoding. Data encoding has three steps to control and organize data (Figure A-1). This grouping consolidates data recording and handling from field collection to transfer into the data base. Data encoding considerations include obtaining data from the field in a complete and accurate manner and minimizing human transcription errors. Preservation of integrity constitutes the primary objective of data encoding.

Data quality is subject to and influenced by several primary factors that are considered in the data collection process.

- Units of measure for parameters are consistent for that parameter.
- Low concentration values, values less than a specified detection limit, are qualitatively denoted.
- Significant figures are reported with a consistent number of digits, subject to the same round-off rules, and measured with equal precision. Typically, parameter values are reported with at least three significant figures in order to minimize errors associated with the least significant digits.

- Outlier values of parameters are carefully evaluated. Outliers are caused by chemical spills or leaching, inconsistent sampling or analytical methods, errors in data transcription, order of magnitude errors (decimal point position), and correct but extreme measured values.

Standard data collection forms unify the content of information regardless of its origin. This methodology consolidates data collection possibilities into groups of information pertinent to identified problem-solving needs. This focused approach protects against collection of invalid or redundant data and eliminates critical data gaps. Standard data collection forms correspond directly to the technical data base.

Equally important to data collection are standard operating procedures that outline the steps to be taken in data acquisition and review. These procedures address the integrity, validity, and security of information based on the objectives outlined above. Operating procedures also provide the vehicle for establishing authority, responsibility, and accountability for the acquisition and classification of data.

Data Review. The focal point of data collection and any data base management system is manual data review for completeness and accuracy. The above discussion on data encoding concentrates on data organization and consistency through standard data collection forms. While these mechanisms strive to ensure regularity in collected data, they do not guarantee that correct data has been obtained in accordance with original data collection requirements.

Data review provides a checkpoint for enforcing data collection requirements by assessing whether the program implemented has been fulfilled as planned. This review typically involves evaluating whether there is a full set of data and whether the collected data is reasonable. The enforcement process is accomplished by returning data to the field or laboratory for revision or completion as necessary.

Data Base Management System. The data base management system, either manual or automated, conducts data into the data base and routes data to a variety of analytical and/or report processors. The automated data base management system approach affords a significant advantage over its manual counterpart in its ability to perform repetitive analyses on the same set of data under varying problem-solving conditions.

The following stages in the information flow process are considered to be part of the data base management system.

- data entry
- data verification
- data base
- data editing
- data modification and deletion, and
- data analysis/presentation preparation.

Data Entry. Data entry methodology is intended to be independent of data base organization and structure. The primary focus is on efficient entry of data into the data base by linking data encoding with standard data collection forms and operating procedures.

Data Verification. Data verification identifies errors, determines data gaps, and ensures that the information hierarchy requirements are satisfied. Verification can range from simple value checking to examining relationships among data types. Verification ensures data base integrity by rejecting unacceptable data.

Data Base. In its simplest form, a data base is an organized repository for information which provides access by analytical techniques. The data base itself is central to the information flow process. Information is consolidated into well-defined files, which are logically connected by identification fields.

Data Editing. Data editing is used after data entry to rectify anomalies that jeopardize the integrity of the data. Maintaining the contents of the data base keeps the data repository current and viable. Although standard forms and operating procedures are used to collect data, data entry errors may still be made. Data editing provides a means of correcting, verifying, and then re-entering data into the data base.

Data Modification and Deletion. As described in the section on data editing, the data base must be maintained. Data modification and deletion function in a similar manner to data entry, in that the same degree of regard for data quality and integrity is adhered to. Data modification and deletion requests are routed through data verification prior to any updating of the data base.

Data Analysis/Presentation Preparation. Data analysis and presentation preparation are the means by which data are transformed into effective information. In this process data fields are collected from various data base files and a new file containing data common to a specific analysis requirement is generated. The new file includes calculated values and coded data translated as necessary. The significance of this component of the data base management system is the generation of many files that are the precursor to final analysis and presentation of the data.

Data Analysis and Modeling Processors. Data analysis and modeling processors provide the transition from data acquisition to data analysis in the information flow process. These processors include graphical and numerical systems, analytical systems, and modeling systems.

Data Evaluation/Design Criteria. Following data acquisition and data analysis, the information flow process is intercepted by the analyzer/designer. This stage culminates in the final decision made from data, data analysis, and data evaluation.

Two significant feedback loops branch from this stage of the information flow process. The first loop returns to the data analysis/presentation preparation stage. Based on review and evaluation of data, additional data analysis may be required.

The second loop returns to the data collection requirements stage. Following data evaluation or the application of design criteria, additional data collection needs may be discovered.

Decision/Design. The ultimate end to the information flow process is the decisions and/or designs made from data evaluation and interpretation. The concern of this final stage is to provide the best solution possible to the decision-maker.

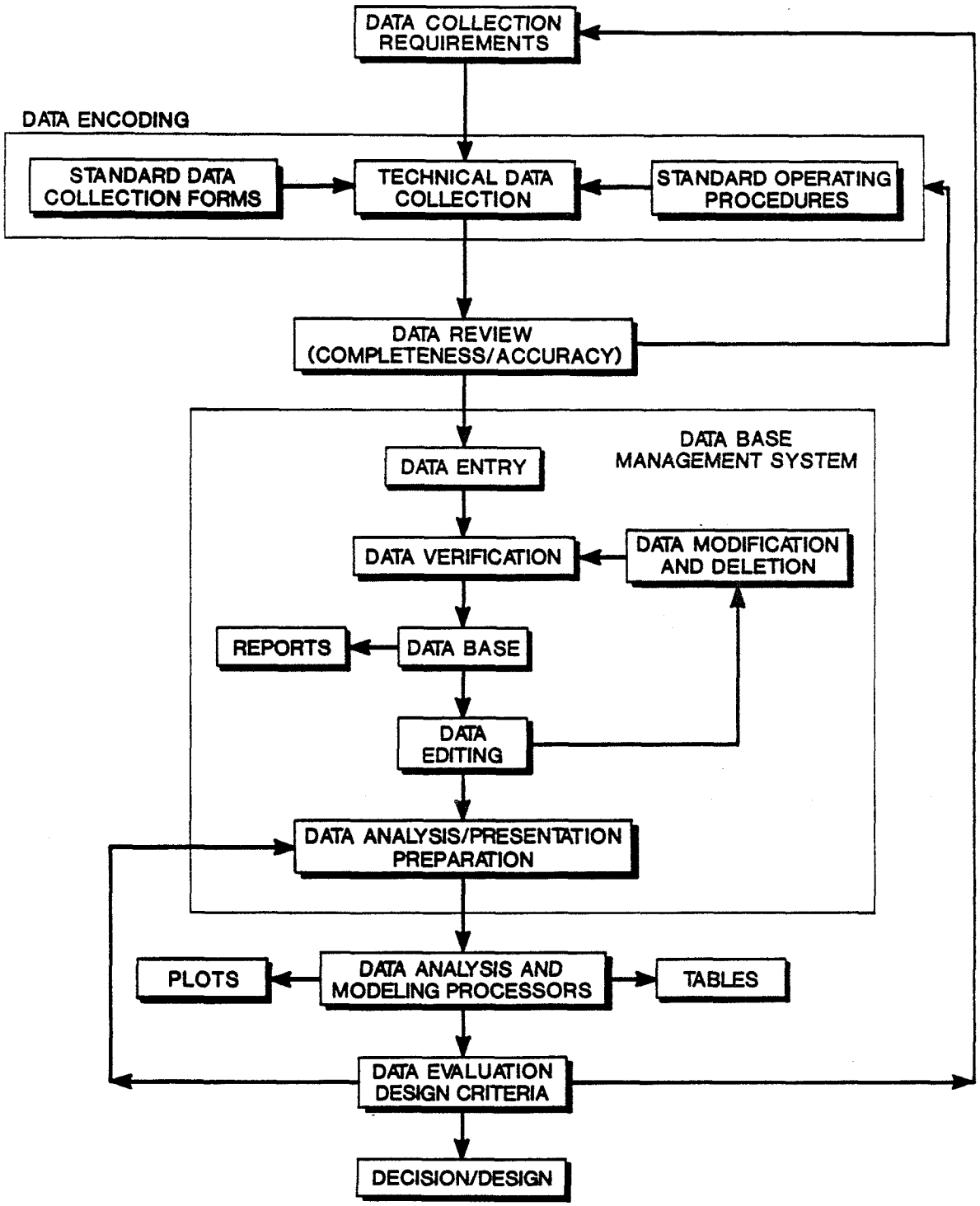


Figure A-1. IMS Information Flow Process

DATA COLLECTION FORMS

1	- Location Information	2
2	- Borehole Log(Soil)	3
3	- Borehole Log (Rock)	5
4	- Test Pit Log	7
5	- Well Completion Information	9
6	- Lithological Summary	10
7	- Standard Penetration Test	11
8	- Physical Properties Test	12
9	- Mechanical Sieve Test	13
10	- Hydrometer Analysis	14
11	- In-Situ Moisture Density Determination	15
12	- Erosion Properties Test	16
13	- Rock Properties Test	17
14	- Permeability Test	18
15	- Capillary Moisture Test	19
16	- Moisture-Density Relationship	20
17	- Consolidation Test	21
18	- Direct Shear Test	22
19	- Unconfined Compression Test	23
20	- Unconsolidated-Undrained Triaxial 'Q' Test	24
21	- Consolidated-Undrained Triaxial 'R' Test with Pore Pressure Measurement	25
22	- Soil Sample Inventory	26
23	- Soil Sample Identification Label	27
24	- Water Sample Identification Label	27
25	- Ground Water Level Data	28
26	- Slug Test Data	29
27	- Pump/Recovery Test Data	30
28	- Surface Water Quality Sampling Record	32
29	- Ground Water Quality Sampling Record	33
30	- Water Quality Analytical Results	35
31	- Water Sample Inventory	37
32	- Radiological Data (Reserved)	38
33	- Soil Chemistry Analytical Results	39
34	- Environmental Monitoring Data	41

LOCATION INFORMATION

INSTALLATION ID _____ LOCATION ID _____

LOCATION TYPE _____ LOCATION PROXIMITY _____

COORDINATES (FT): NORTH _____ EAST _____

SURFACE ELEVATION (FTMSL) _____

ESTABLISHED BY _____ DATE ESTABLISHED _____

LOCATION DESCRIPTION _____

PURPOSE FOR ESTABLISHING LOCATION _____

DATA COLLECTION REQUIREMENTS/METHODS _____

LOCATION DIAGRAM

N

LOCATION TYPES		LOCATION PROXIMITY
BH - BORHOLE	WL - WELL	I - WITHIN INSTALLATION
TP - TEST PIT	SP - SPRING	O - OUTSIDE INSTALLATION
SL - SURFACE LOCATION	RV - RIVER/STREAM	
OC - OUT CROP	LK - LAKE/POND	
	CH - CHANNEL/DITCH	

BOREHOLE LOG (SOIL)

PAGE 1 OF ___

INSTALLATION ID _____ LOCATION ID _____

LOCATION TYPE BH LOCATION PROXIMITY _____

COORDINATES (FT): NORTH _____ EAST _____

SURFACE ELEVATION (FTMSL) _____

DRILLER CODE _____ CONSTRUCTION METHOD _____

DATE STARTED _____ DATE COMPLETED _____

DEPTH (FT) _____ BOREHOLE DIAM. (IN) _____

GROUNDWATER LEVELS		
DATE	TIME	DEPTH (FT)

LOCATION DESCRIPTION

_____

_____

_____

_____

_____

LITHOLOGIC LOG

LOGGER CODE _____

DEPTH (FT)	SAMPLE INTERVAL	SAMPLE RECOVERY	SAMPLE RETAINED	SAMPLE METHOD	SAMPLE ID	BLOW COUNT (PER 6 in.)	N VALUE	USCS	VISUAL DESCRIPTION

LOCATION PROXIMITY

I - WITHIN INSTALLATION O - OUTSIDE INSTALLATION

CONSTRUCTION METHODS

A - AIR ROTARY
B - BORED OR AUGERED
C - CABLE-TOOL
D - DUG
H - HYDRAULIC-ROTARY
J - JETTED
P - AIR-PERCUSSION
R - REVERSE ROTARY
T - TRENCHING
V - DRIVEN
W - DRIVE AND WASH
Z - OTHER (SPECIFY)

SAMPLE METHODS

A - AUGER CUTTINGS
S - 2" O.D. 1.38" I.D. DRIVE SAMPLE
U - 3" O.D. 2.42" I.D. TUBE SAMPLE
T - 3" O.D THIN-WALLED SHELBY TUBE

BOREHOLE LOG (SOIL)

PAGE ___ OF ___

INSTALLATION ID _____

LOCATION ID _____ DATE STARTED _____

LITHOLOGIC LOG

DEPTH (FT)	SAMPLE INTERVAL	SAMPLE RECOVERY	SAMPLE RETAINED	SAMPLE METHOD	SAMPLE ID	BLOW COUNT (PER 6 in.)	N VALUE	USCS	VISUAL DESCRIPTION

BOREHOLE LOG (ROCK)

PAGE 1 OF ____

INSTALLATION ID _____ LOCATION ID _____

LOCATION TYPE BH LOCATION PROXIMITY _____

COORDINATES (FT): NORTH _____ EAST _____

SURFACE ELEVATION (FTMSL) _____

DRILLER CODE _____ CONSTRUCTION METHOD _____

DATE STARTED _____ DATE COMPLETED _____

DEPTH (FT) _____ BOREHOLE DIAM. (IN) _____

GROUNDWATER LEVELS		
DATE	TIME	DEPTH (FT)

LOCATION DESCRIPTION

_____

_____

_____

_____

_____

LITHOLOGIC LOG

LOGGER CODE _____

DEPTH (FT)	PACKER TEST INTERVAL	SAMPLE METHOD	SAMPLE ID	% CORE RECOVERY	% ROCK QUALITY DESIGNATION (RQD)	% DRILLING FLUID RECOVERY	SPACING	ORIENTATION	CONDITION	WEATHERING	HARDNESS	LITHOLOGIC	VISUAL DESCRIPTION

CONSTRUCTION METHODS

A - AIR ROTARY
B - BORED OR AUGERED
C - CABLE-TOOL
D - DUG
H - HYDRAULIC-ROTARY
J - JETTED
P - AIR-PERCUSSION
R - REVERSE ROTARY
T - TRENCHING
V - DRIVEN
W - DRIVE AND WASH
Z - OTHER (SPECIFY)

SAMPLE METHODS

H - 8 1/2 HOLLOW STEM AUGER
C - 4 1/2 CONTINUOUS FLIGHT AUGER
GB - GEAR BIT
NX - NX ROCK CORING
NQ - NQ WIRELINE ROCK CORING

BOREHOLE LOG (ROCK)

PAGE ____ OF ____

INSTALLATION ID _____

LOCATION ID _____ DATE STARTED _____

LITHOLOGIC LOG

DEPTH (FT)	PACKERTEST INTERVAL	SAMPLE METHOD	SAMPLE ID	% CORE RECOVERY	% ROCK QUALITY DESIGNATION (RQD)	% DRILLING FLUID RECOVERY	SPACING	ORIENTATION	CONDITION	WEATHERING	HARDNESS	LITHOLOGIC	VISUAL DESCRIPTION

SPACING

BEDDED, FOLIATION, ETC.

VT - VERY THICKLY
T - THICKLY
M - MEDIUM
TN - THINLY
VTN - VERY THINLY

JOINTS/FAULTS:

VW - VERY WIDELY
W - WIDELY
M - MEDIUM
C - CLOSELY
VC - VERY CLOSELY

CONDITION

ND - NODULAR
MT - MOTTLED
VV - VARVED
BN - BANDED
ST - STINGERS
SM - SMOOTH
CL - CLEAN
RH - ROUGH
SL - SLIGHT

WEATHERING

F - FRESH
RS - RESIDUAL SOIL
SL - SLIGHTLY WEATHERED
MW - MODERATLY WEATHERED
HW - HIGHLY WEATHERED
CW - COMPLETELY WEATHERED

HARDNESS

EH - EXTREMELY HARD
VH - VERY HARD
H - HARD
S - SOFT
VS - VERY SOFT

TEST PIT LOG

PAGE 1 OF ____

INSTALLATION ID _____ LOCATION ID _____

LOCATION TYPE TP LOCATION PROXIMITY _____

COORDINATES (FT): NORTH _____ EAST _____

SURFACE ELEVATION (FTMSL) _____

EXCAVATOR CODE _____ CONSTRUCTION METHOD _____

DATE STARTED _____ DATE COMPLETED _____

DEPTH (FT) _____

GROUNDWATER LEVELS		
DATE	TIME	DEPTH (FT)

LOCATION DESCRIPTION

_____

_____

_____

_____

_____

LITHOLOGIC LOG

LOGGER CODE _____

DEPTH (FT)	SAMPLE INTERVAL	SAMPLE METHOD	SAMPLE ID	USCS	VISUAL DESCRIPTION

CONSTRUCTION METHODS

A - AIR ROTARY
B - BORED OR AUGERED
C - CABLE-TOOL
D - DUG
H - HYDRAULIC-ROTARY
J - JETTED
P - AIR-PERCUSSION
R - REVERSE ROTARY
T - TRENCHING
V - DRIVEN
W - DRIVE AND WASH
Z - OTHER (SPECIFY)

SAMPLE METHODS

B - UNDISTURBED BLOCK
D - DISTURBED BULK

LOCATION PROXIMITY

I - WITHIN INSTALLATION
O - OUTSIDE INSTALLATION

TEST PIT LOG

PAGE___OF___

INSTALLATION ID _____

LOCATION ID _____ DATE STARTED _____

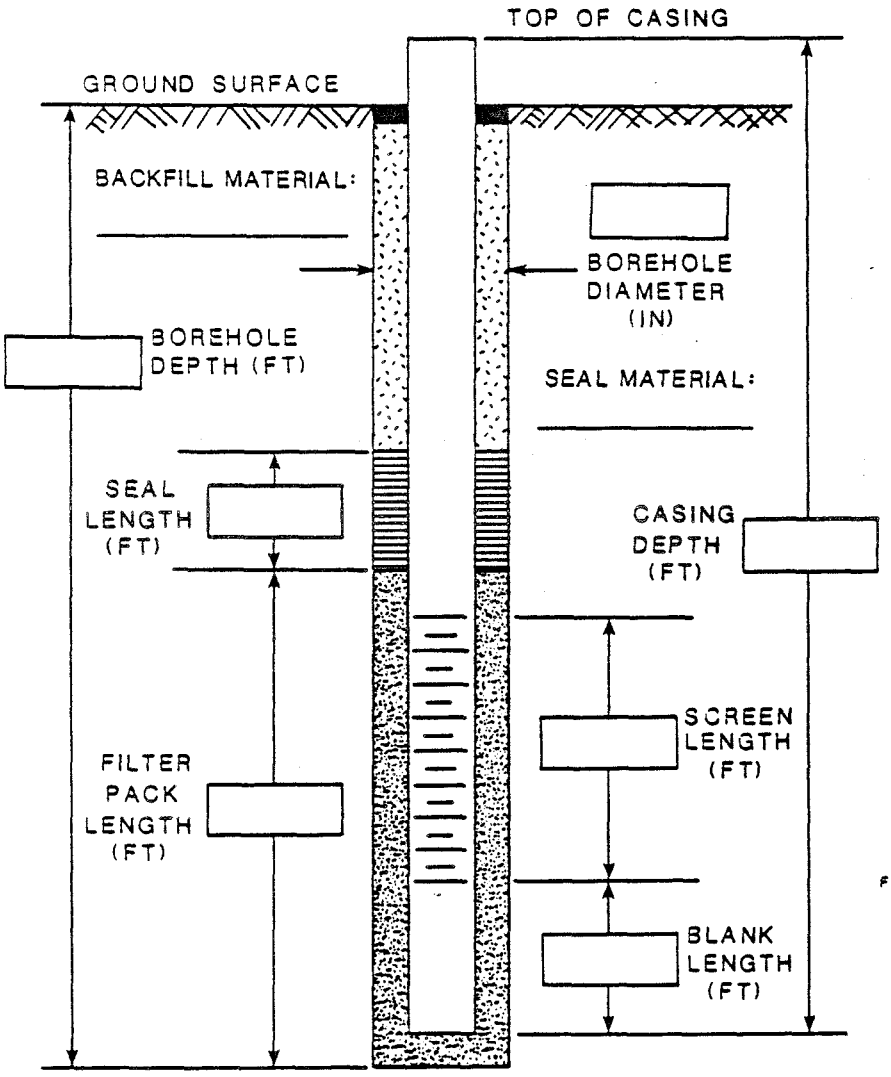
LITHOLOGIC LOG

DEPTH (FT)	SAMPLE INTERVAL	SAMPLE METHOD	SAMPLE ID	USCS	VISUAL DESCRIPTION

WELL COMPLETION INFORMATION

INSTALLATION ID _____ LOCATION TYPE WL
LOCATION ID _____ INSTALLATION DATE _____
WELL OWNER _____ INSTALLER _____
WELL TYPE CLASS. _____ WELL COMPLETION METHOD _____
FORMATION OF COMPLETION _____ ZONE OF COMPLETION _____

SEAL END DEPTH (FT) _____ FILTER PACK LENGTH (FT) _____
CASING ELEVATION (FTMSL) _____ SCREEN BEGIN. DEPTH (FT) _____
CASING DEPTH (FT) _____ SCREEN LENGTH (FT) _____
CASING DIAMETER (IN) _____ SCREEN OPEN AREA (IN/FT) _____
CASING MATERIAL _____
COMMENTS _____



WELL TYPE CLASSIFICATIONS

M - MONITORING WELL
P - PRODUCTION WELL
T - TEST WELL

CASING MATERIAL

B - BRICK
C - CONCRETE
D - COPPER
F - FIBERGLASS
G - GALVANIZED IRON
I - WROUGHT IRON
J - STAINLESS STEEL
M - OTHER MATEL
N - TEFLON
P - PVC
R - ROCK OR STONE
S - STEEL
T - TILE
U - COATED STEEL
W - WOOD
Z - OTHER (SPECIFY)

GEOHYDROLOGIC FLOW CLASS.

U - UP GRADIENT
D - DOWN GRADIENT
C - CROSS GRADIENT
O - ON SITE
B - BACKGROUND
N - NOT KNOWN

ZONE OF COMPLETION:

A - AQUIFER
C - CONFINING LAYER

WELL COMPLETION METHODS.

C - POROUS CONCRETE
F & G - GRAVEL PACK
H - HORIZONTAL GALLEY
O - OPEN END
P - PERFORATED OR SCOTTED
S - SCREEN
T - SAND POINT
W - WALLED OR SHORED
X - OPEN
Z - OTHER (SPECIFY)

FILTER PACK MATERIAL: _____

LITHOLOGICAL SUMMARY

PAGE__OF__

INSTALLATION ID _____ LOGGER CODE _____

LOCATION ID _____ LOG DATE _____

LOG DEPTH (FT)	USCS OR ROCK CLASS.	STRAT. ORDER	VISUAL DESCRIPTION

STANDARD PENETRATION TEST

PAGE ___ OF ___

INSTALLATION ID _____ LOGGER CODE _____

LOCATION ID _____ LOG DATE _____

SAMPLE ID	DEPTH INTERVAL (FT)	BLOW COUNT	PENETRATION DEPTH (IN)

PHYSICAL PROPERTIES TEST

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE CHECKED _____

COMMENTS _____

SAMPLE ID	TEST NO.	DEPTH INTERVAL (FT)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	SPECIFIC GRAVITY

MECHANICAL SIEVE TEST

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE CHECKED _____

COMMENTS _____

SAMPLE ID	TEST NO.	DEPTH INTERVAL (FT)	% PASSING STANDARD SIEVE NUMBER *										
			3"	1 1/2"	3/4"	3/8"	#4	#8	#16	#30	#50	#100	#200

* ENTER ONLY VALUES LESS THAN 100%

HYDROMETER ANALYSIS

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE CHECKED _____

COMMENTS _____

SAMPLE ID	TEST NO.	DEPTH INTERVAL (FT)	% FINER THAN (mm)*							
			.074mm	.05mm	.037mm	.019mm	.009mm	.005mm	.002mm	.001mm

* ENTER ONLY VALUES LESS THAN 100%

IN - SITU MOISTURE - DENSITY DETERMINATION

INSTALLATION ID _____
LOG DATE _____

LAB CODE _____ DATE RECEIVED _____
LAB SAMPLE CONTROL ID _____
ANALYSIS CHECKED BY _____ DATE CHECKED _____
COMMENTS _____

LOCATION ID	SAMPLE ID	TEST NO.	DEPTH INTERVAL (FT)	MOISTURE CONTENT (%)	DRY DENSITY (PCF)

EROSION PROPERTIES TEST

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

_____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE _____

COMMENTS _____

_____

_____

SAMPLE ID	TEST NO.	DEPTH INTERVAL (FT)	CRUMB TEST	DOUBLE HYDROMETER (% DISPERSION)	PINHOLE TEST

CRUMB TEST:

1 - NO REACTION
2 - SLIGHT REACTION
3 - MODERATE REACTION
4 - STRONG REACTION

PINHOLE TEST

DISPERSIVE:
1 - DARK FLOW
2 - CLOUDY FLOW

INTERMEDIATE:
3 - SLIGHTY CLOUDY FLOW
4 - CLOUDY FLOW

NONDISPERSIVE:
5 - CLOUDY FLOW
6 - CLEAR FLOW

NOTE: TABULATE DOUBLE HYDROMETER TEST RESULTS ON THE HYDROMETER ANALYSIS FORM

ROCK PROPERTIES TEST

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

_____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE _____

COMMENTS _____

_____

_____

SAMPLE ID	TEST NO.	DEPTH INTERVAL (FT)	LA ABRASION (%)		SPECIFIC GRAVITY		ABSORPTION %	SLAKE DURABILITY (%)	SULFATE AGGREGATE SOUNDNESS (% LOSS)
			TOTAL LOSS	100/500 CYCLE LOSS	APPARENT	BULK			

PERMEABILITY TEST

INSTALLATION ID _____

LOG DATE _____

_____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE _____

COMMENTS _____

_____

_____

LOCATION ID	SAMPLE ID	TEST NO.	DEPTH INTERVAL (FT)	TEST METHOD	COMPACTION (%)	MOISTURE CONTENT (%)		DRY DENSITY (PCF)		SATURATION (%)		TOTAL PRESSURE HEAD (FT)	PERMEABILITY (CM/SEC)
						INIT.	FINAL	INIT.	FINAL	INIT.	FINAL		

TEST METHODS : CH-CONSTANT HEAD FH-FALLING HEAD TX-TRIAXIAL BACK PRESSURE FALLING HEAD

CAPILLARY MOISTURE TEST

INSTALLATION ID _____ LOG DATE _____
LOCATION ID _____ SAMPLE ID _____

LAB CODE _____ DATE RECEIVED _____
LAB SAMPLE CONTROL ID _____
ANALYSIS CHECKED BY _____ DATE CHECKED _____
COMMENTS _____

TEST NO.	DEPTH INTERVAL (FT)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	COMPACTION (%)

TEST RESULTS

TEST NO. _____		TEST NO. _____		TEST NO. _____	
TENSION (BARS)	MOISTURE CONTENT (%)	TENSION (BARS)	MOISTURE CONTENT (%)	TENSION (BARS)	MOISTURE CONTENT (%)

MOISTURE - DENSITY RELATIONSHIP

INSTALLATION ID _____ LOG DATE _____
LOCATION ID _____ SAMPLE ID _____

LAB CODE _____ DATE RECEIVED _____
LAB SAMPLE CONTROL ID _____
ANALYSIS CHECKED BY _____ DATE CHECKED _____
COMMENTS _____

TEST NO.	DEPTH INTERVAL (FT)	TEST METHOD	MAXIMUM DRY DENSITY (PCF)	OPTIMUM MOISTURE CONTENT (%)

TEST RESULTS

TEST NO. _____		TEST NO. _____		TEST NO. _____	
DRY DENSITY (PCF)	MOISTURE CONTENT (%)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)

TEST METHODS : SP-STANDARD PROCTOR (ASTM-D698) MP-MODIFIED PROCTOR (ASTM-D1557)

CONSOLIDATION TEST

INSTALLATION ID ____________

LOCATION ID ________ LOG DATE ____________

SAMPLE ID ________ TEST NO. ____________

LAB CODE ____________ DATE RECEIVED ________

LAB SAMPLE CONTROL ID ______________________

ANALYSIS CHECKED BY ________ DATE ____________

COMMENTS ______________________________

DEPTH INTERVAL (FT)	BEGINNING SUBMERGED STRESS (PSF)	COMPACTION (%)

CONDITION	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	DEGREE OF SATURATION (%)	VOID RATIO
INITIAL				
FINAL				

TEST RESULTS		
AXIAL STRESS (PSF)	VOID RATIO	COEFFICIENT OF CONSOLIDATION (cm^2/sec.)

NOTE: ATTACH INDIVIDUAL TIME-RATE INCREMENTS ON SEPARATE LABORATORY FORMS.

DIRECT SHEAR TEST

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

SAMPLE ID _____ TEST NO. _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE _____

COMMENTS _____

DEPTH INTERVAL (FT)	STRAIN RATE (IN/IN)	COMPACTION (%)	APPLIED NORMAL STRESS (PSF)

CONDITION	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	DEGREE OF SATURATION (%)	VOID RATIO
INITIAL				
FINAL				

NOTE: ATTACH CONSOLIDATION DATA ON LABORATORY FORMS

TEST RESULTS					
HORIZ. DISPL. (IN)	VERT. DISPL. (IN)	SHEAR STRESS (PSF)	HORIZ. DISPL. (IN)	VERT. DISPL. (IN)	SHEAR STRESS (PSF)

UNCONFINED COMPRESSION TEST

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

SAMPLE ID _____ TEST NO. _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE _____

COMMENTS _____

DEPTH INTERVAL (FT)	STRAIN RATE (IN/IN)	COMPACTION (%)

CONDITION	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	DEGREE OF SATURATION (%)	VOID RATIO
INITIAL				
FINAL				

TEST RESULTS			
AXIAL STRESS (PSF)	AXIAL STRAIN (%)	AXIAL STRESS (PSF)	AXIAL STRAIN (%)

UNCONSOLIDATED - UNDRAINED TRIAXIAL "Q" TEST

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

SAMPLE ID _____ TEST NO. _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE _____

COMMENTS _____

DEPTH INTERVAL (FT)	COMPACTION (%)	CELL CONFINING PRESSURE (PSF)

CONDITION	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	DEGREE OF SATURATION (%)	VOID RATIO
INITIAL				
FINAL				

TEST RESULTS					
AXIAL STRESS (PCF)	AXIAL STRAIN (%)	AXIAL STRESS (PCF)	AXIAL STRAIN (%)	AXIAL STRESS (PCF)	AXIAL STRAIN (%)

CONSOLIDATED - UNDRAINED TRIAXIAL "R" TEST WITH PORE PRESSURE MEASUREMENT

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

SAMPLE ID _____ TEST NO. _____

DEPTH INTERVAL (FT) _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE _____

COMMENTS _____

COMPACTION (%)	CELL CONFINING PRESSURE (PSF)	B PARAMETER

CONDITION	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	DEGREE OF SATURATION (%)	VOID RATIO
INITIAL				
FINAL				

NOTE: ATTACH CONSOLIDATION DATA ON LABORATORY FORMS.
USE ONE FORM PER PHASE FOR MULTI PHASE TRIAXIAL TESTS.

TEST RESULTS					
AXIAL STRAIN (%)	MAJOR PRINCIPAL STRESS (PSF)	PORE PRESSURE (PSF)	AXIAL STRAIN (%)	MAJOR PRINCIPAL STRESS (PSF)	PORE PRESSURE (PSF)

SOIL SAMPLE INVENTORY

PAGE ___ OF ___

INSTALLATION ID _____ LOGGER CODE _____

LOG DATE _____ LAB CODE _____

LOCATION ID	SAMPLE ID	DEPTH INTERVAL (FT)	SAMPLE METHOD	SAMPLE TYPE	INSTRUCTIONS/COMMENTS

SAMPLE METHODS

A - AUGER CUTTINGS
S - 2" O.D. 1.38" I.D. DRIVE SAMPLE
U - 3" O.D 2.42" I.D. TUBE SAMPLE
T - 3" O.D THIN - WALLED SHELBY TUBE

H - 8 1/2 HOLLOW STEM AUGER
C - 4 1/2 CONTINUOUS FLIGHT AUGER
GB - GEAR BIT
NX - NX ROCK CORING

NQ - NQ WIRELINE ROCK CORING
B - UNDISTURBED BLOCK SAMPLE
D - DISTURBED BULK SAMPLE

SAMPLE TYPES

A - BACKGROUND MATERIAL
B - ON SITE MATERIAL
C - SEDIMENTS

SOIL SAMPLE IDENTIFICATION LABEL

INSTALLATION ID _____ SAMPLE TYPE _____
LOCATION ID _____ SAMPLE ID _____
LOG DATE _____ LAB CODE _____
SAMPLE DEPTH INTERVAL FROM DATUM:
BEGINNING DEPTH (FT) _____
ENDING DEPTH (FT) _____
LOGGER CODE _____
INSTRUCTIONS/COMMENTS _____

WATER SAMPLE IDENTIFICATION LABEL

INSTALLATION ID _____ LOT CONTROL NO. _____
LOCATION ID _____ SAMPLE TYPE _____
SAMPLE ID _____ LOG DATE _____
SAMPLE DEPTH (FT) _____ LOG DATE _____
LOGGER CODE _____
PRESERVATION METHOD _____
INSTRUCTIONS/COMMENTS _____

GROUND WATER LEVEL DATA

INSTALLATION ID _____ LOG DATE _____

LOGGER CODE _____

COMMENTS _____

LOCATION ID	LOG TIME* (HH:MM)	DEPTH TO WATER (FT)	LOCATION ID	LOG TIME* (HH:MM)	DEPTH TO WATER (FT)

* USE 24 HOUR CLOCK

SLUG TEST DATA

INSTALLATION ID ____________________

LOCATION ID ______________ LOG DATE ______________

LOGGER CODE ____________________ SLUG VOLUME (FT^3) ______________

TEST METHOD ______ SLUG INJECTION OR ______ SLUG WITHDRAWAL

COMMENTS ____

____

____

ELAPSED TIME (MIN.)	DEPTH TO WATER (FT)	ELAPSED TIME (MIN.)	DEPTH TO WATER (FT)

PUMP/RECOVERY TEST DATA

PAGE 1 OF ____

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

LOGGER CODE _____ DISTANCE FROM PUMPED WELL (FT) _____

TEST START:
DATE _____
TIME _____
STATIC WATER LEVEL (FT) _____

TEST END:
DATE _____
TIME _____
STATIC WATER LEVEL (FT) _____

AVERAGE PUMPING RATE (GAL/MIN) _____

MEASUREMENT METHODS _____

COMMENTS _____

PUMP TEST			RECOVERY TEST	
ELAPSED TIME (MIN.)	DEPTH TO WATER (FT)	PUMPING RATE (GAL/MIN)	ELAPSED TIME (MIN.)	DEPTH TO WATER (FT)
0.00			0.00	

PUMP/RECOVERY TEST DATA

PAGE____ OF____

INSTALLATION ID _____

LOCATION ID_____ LOG DATE _____

PUMP TEST			RECOVERY TEST	
ELAPSED TIME (MIN.)	DEPTH TO WATER (FT)	PUMPING RATE (GAL/MIN)	ELAPSED TIME (MIN.)	DEPTH TO WATER (FT)

SURFACE WATER QUALITY SAMPLING RECORD

INSTALLATION ID _____ LOG DATE _____
LOCATION ID _____ LOT CONTROL NO. _____
SAMPLE TYPE _____ SAMPLE ID _____

SAMPLING PERIOD: START _____ COMPLETE _____
SAMPLING METHOD _____ LOGGER CODE _____
LAB CODE _____ DATE SENT _____
PRESERVATION METHOD _____
COMMENTS _____

PARAMETER MEASUREMENTS:

POTENTIAL OF HYDROGEN	pH	S.U.	_____
SPECIFIC CONDUCTANCE	Ec	µmhos/cm	_____
REDOX POTENTIAL	Eh	mvolts	_____
TEMPERATURE	TMP	°C	_____
ALKALINITY ($CaCO_3$)	ALK	mg/l	_____

INSTALLATION ID _____ LOG DATE _____
LOCATION ID _____ LOT CONTROL NO. _____
SAMPLE TYPE _____ SAMPLE ID _____

SAMPLING PERIOD: START _____ COMPLETE _____
SAMPLING METHOD _____ LOGGER CODE _____
LAB CODE _____ DATE SENT _____
PRESERVATION METHOD _____
COMMENTS _____

PARAMETER MEASUREMENTS:

POTENTIAL OF HYDROGEN	pH	S.U.	_____
SPECIFIC CONDUCTANCE	Ec	µmhos/cm	_____
REDOX POTENTIAL	Eh	mvolts	_____
TEMPERATURE	TMP	°C	_____
ALKALINITY ($CaCO_3$)	ALK	mg/l	_____

SAMPLE TYPES:

A - DUPLICATE
B - REPLICATE
C - SPIKE
D - KNOWN
E - FIELDBLANK
F - TRIPBLANK
G - LAB BLANK

SAMPLE METHODS:

G - GRAB
B - BAILER
PP - PERISTALIC PUMP
SL - SUCTION LIFT PUMP
SP - SUBMERSIBLE PUMP
AL - AIR-LIFT SAMPLER
BP - BLADDER PUMP

GROUND WATER QUALITY SAMPLING RECORD

INSTALLATION ID _____
LOCATION ID _____ LOG DATE _____
SAMPLE TYPE _____ LOT CONTROL NO. _____
SAMPLE ID _____ SAMPLING DEPTH (FT) _____

INITIAL GROUNDWATER DEPTH (FT) _____
SAMPLING PERIOD: START _____ COMPLETE _____
SAMPLING METHOD _____ LOGGER CODE _____
LAB CODE _____ DATE SENT _____
PRESERVATION METHOD _____
COMMENTS _____

FINAL PARAMETER MEASUREMENTS:

POTENTIAL OF HYDROGEN	pH	S.U.	_____
SPECIFIC CONDUCTANCE	Ec	µmhos/cm	_____
REDOX POTENTIAL	Eh	mvolts	_____
TEMPERATURE	TMP	°C	_____
ALKALINITY ($CaCO_3$)	ALK	mg/l	_____

TIME	TOTAL VOLUME WITHDRAWN		pH	Ec (µmhos/cm)	TEMP. (°C)	COMMENTS
	(GALS)	(Bore Volumes)				
	0.0	0.0	-	-	-	START PUMPING

SAMPLE TYPES

A - DUPLICATE
B - REPLICATE
C - SPIKE
D - KNOWN
E - FIELDBLANK
F - TRIPBLANK
G - LAB BLANK

SAMPLING METHODS:

G - GRAB
B - BAILER
PP - PERISTALIC PUMP
SL - SUCTION LIFT PUMP
SP - SUBMERSIBLE PUMP
AL - AIR-LIFT SAMPLER
BP - BLADDER PUMP

GROUND WATER QUALITY SAMPLING RECORD

INSTALLATION ID _____

LOCATION ID _____ SAMPLE DATE _____

SAMPLE TYPE _____ LOT CONTROL NO. _____

SAMPLE ID _____ SAMPLING DEPTH (FT) _____

TIME	TOTAL VOLUME WITHDRAWN		pH	Ec (µmhos/cm)	TEMP. (° C)	COMMENTS
	(GALS)	(Bore Volumes)				

WATER QUALITY ANALYTICAL RESULTS

PAGE 1 OF ____

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

SAMPLE TYPE _____ LOT CONTROL NO. _____

SAMPLE ID _____ SAMPLE DEPTH (FT) _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE CHECKED _____

COMMENTS _____

PARAMETER ID	PARAMETER VALUE +/- UNCERTAINTY	DETECTION LIMITS	UNITS OF MEASURE	COMMENTS

SAMPLE TYPES

A - DUPLICATE
B - REPLICATE
C - SPIKE
D - KNOWN
E - FIELDBLANK
F - TRIPBLANK
G - LAB BLANK

WATER QUALITY ANALYTICAL RESULTS

PAGE ___ OF ___

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

SAMPLE TYPE _____ LOT CONTROL NO. _____

SAMPLE ID _____

PARAMETER ID	PARAMETER VALUE +/- UNCERTAINTY	DETECTION LIMITS	UNITS OF MEASURE	COMMENTS

WATER SAMPLE INVENTORY

PAGE___OF___

INSTALLATION ID _____ LOGGER CODE _____

LOG DATE _____ LAB CODE _____

LOT CONTROL NO _____

LOCATION ID	SAMPLE TYPE	SAMPLE ID	SAMPLING DEPTH (FT)	INSTRUCTIONS/COMMENTS

SAMPLE TYPES

A - DUPLICATE
B - REPLICATE
C - SPIKE
D - KNOWN
E - FIELDBLANK
F - TRIPBLANK
G - LAB BLANK

SOIL CHEMISTRY ANALYTICAL RESULTS

PAGE 1 OF ____

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

SAMPLE TYPE _____ SAMPLE ID _____

SAMPLE DEPTH INTERVAL (FT) _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE CHECKED _____

COMMENTS _____

PARAMETER ID	PARAMETER VALUE +/- UNCERTAINTY	DETECTION LIMITS	UNITS OF MEASURE	COMMENTS

SAMPLE TYPES

A - BACKGROUND MATERIAL
B - ON-SITE MATERIAL
C - SEDIMENTS

SOIL CHEMISTRY ANALYTICAL RESULTS

PAGE ___ OF ___

INSTALLATION ID _____

LOCATION ID _____ LOG DATE _____

SAMPLE TYPE _____ SAMPLE ID _____

SAMPLE DEPTH INTERVAL (FT) _____

PARAMETER ID	PARAMETER VALUE -/- UNCERTAINTY	DETECTION LIMITS	UNITS OF MEASURE	COMMENTS

ENVIRONMENTAL MONITORING DATA

PAGE 1 OF ____

INSTALLATION ID _____

TEST TYPE _____ LOCATION ID _____

LOG DATE _____ LOG TIME _____

SAMPLE TYPE _____ SAMPLE ID _____

SAMPLING DEPTH/HEIGHT (FT) _____

LOGGER CODE _____

LAB CODE _____ DATE RECEIVED _____

LAB SAMPLE CONTROL ID _____

ANALYSIS CHECKED BY _____ DATE CHECKED _____

COMMENTS _____

PARAMETER ID	PARAMETER VALUE +/- UNCERTAINTY	DETECTION LIMITS	UNITS OF MEASURE	COMMENTS

TEST TYPES:

AIR - ATMOSPHERIC
CLI - CLIMATOLOGY
MET - METEOROLOGY
FIS - FISH
WIL - WILDLIFE
VEG - VEGETATION

SAMPLE TYPES:

TIS - TISSUE
BOD - BODY PART
ROT - ROOT PART
STE - STEM PART
AIR - AIR
DAY - DAILY
LEA - LEAF PART
MON - MONTHLY
YEA - YEARLY

DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
ENVIRONMENT, SAFETY AND HEALTH DIVISION
ENVIRONMENTAL PROGRAMS BRANCH

COMPREHENSIVE ENVIRONMENTAL ASSESSMENT AND RESPONSE PROGRAM

PHASE 2:
ROCKY FLATS PLANT
INSTALLATION GENERIC MONITORING PLAN
(Comprehensive Source and Plume Characterization Plan)

HEALTH AND SAFETY PLAN

February 1987

DRAFT

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1. INTRODUCTION

CEARP Phase 2 Confirmation consists of CEARP Phase 2a, Monitoring Plan, and CEARP Phase 2b, Site Characterization (Remedial Investigation). This Health and Safety Plan is one component of the Monitoring Plan for Rocky Flats Plant. The Monitoring Plan consists of five parts: Synopsis, Sampling Plan, Technical Data Management Plan, Health and Safety Plan, and Quality Assurance/Quality Control Plan. Because of the Compliance Agreement made by the State of Colorado, Environmental Protection Agency, and Department of Energy (DOE), this Monitoring Plan also includes a Feasibility Study Plan. The Synopsis provides a discussion of the current situation and serves as an introduction to the other plans.

CEARP uses a three-tiered approach in the preparation of monitoring plans: the CEARP Generic Monitoring Plan (CGMP), the Installation Generic Monitoring Plan (IGMP), and the Site-Specific Monitoring Plans (SSMPs). This IGMP is the Comprehensive Source and Plume Characterization Plan required by the compliance agreement. Therefore, the acronym used to refer to this plan is IGMP/CSPCP.

This IGMP/CSPCP Health and Safety Plan incorporates the specific safety practices and procedural review requirements for Rocky Flats Plant.

The CGMP Health and Safety Plan provides generic guidance and establishes procedures for conducting site characterization (remedial investigation) activities under CEARP Phase 2. It outlines how the DOE-Albuquerque Operations Office will implement health and safety requirements under CEARP. Specifically, it provides generic guidelines and procedures that will be employed by Rocky Flats Plant and Los Alamos National Laboratory during CEARP Phase 2b site characterization (remedial investigation) activities to protect the health and safety of personnel involved in CEARP. Thus, the CGMP Health and Safety Plan becomes the foundation for the Rocky Flats Plant IGMP/CSPCP Health and Safety Plan and is incorporated, as appropriate, by reference.

2. POLICY AND STANDARDS

It is DOE's policy that its operations shall be conducted in a manner that will (1) limit risks to the health and safety of the public and employees, and (2) adequately protect property and the environment. As outlined in the CGMP Health and Safety Plan, DOE has responsibility for health, safety, and environmental protection programs at DOE-owned contractor-operated facilities. Consistent with this responsibility, this Health and Safety Plan includes the current health and safety policy and standards in effect at Rocky Flats Plant. It also includes provisions to implement external subcontractor policy and standards when the latter are determined to be more restrictive.

2.1. POLICY

The main tenet of this IGMP/CSPCP Health and Safety Plan is to keep human exposure to toxic materials and radiation at levels as low as reasonably achievable (ALARA). The ALARA review will demonstrate that all reasonable efforts have been made to minimize worker and public exposures to toxic and/or radioactive materials.

Specific ALARA procedures will include engineering controls, administrative controls, and the use of personal protective equipment. The length of time employees spend in areas with elevated levels of radioactive or toxic materials will be minimized. If conditions produce airborne contaminants, dust suppressant measures will be taken. General requirements for limiting exposures, and protective clothing and equipment necessary to protect personnel from contaminants are identified in the CGMP Health and Safety Plan and are specifically addressed in this IGMP/CSPCP Health and Safety Plan, Section 4.2.

2.2. STANDARDS AND REGULATIONS

The environmental, safety, and health protection requirements applicable to Rocky Flats Plant operations are set forth in DOE and DOE-Albuquerque Operations Office Orders. These orders require compliance with applicable Federal, State of Colorado, or local standards. This Rocky Flats Plant IGMP/CSPCP Health and Safety

Plan is based on these DOE Orders, Federal regulations, and other professional standards specified in Section 2 of the CGMP Health and Safety Plan.

2.3. PERMITS

Permits issued by Rocky Flats will be obtained as required for all land use activities (e.g., drilling, boring, samples, and entry), following the current health and safety policy and standards in effect at Rocky Flats Plant.

3. HEALTH AND SAFETY RESPONSIBILITIES

The line organizations conducting CEARP Phase 2b Site Characterizations (Remedial Investigations) are responsible for providing adequate precautions and protection to ensure the health and safety of employees and the public. The simplified organizational chart for health and safety at Rocky Flats Plant is presented in Figure 3.1.

3.1. GENERAL RESPONSIBILITIES

For site characterization (remedial investigation) activities conducted at Rocky Flats Plant, the Rockwell International CEARP Manager establishes requirements following guidelines specified in this IGMP/CSPCP Health and Safety Plan that are consistent with current health and safety requirements. The Subcontractor Site Manager is responsible for ensuring the health and safety of field team personnel during CEARP Phase 2b site characterization (remedial investigation) activities. The Subcontractor Site Health and Safety Coordinator provides guidance to the Subcontractor Site Manager regarding potential health hazards during characterization activities. The Subcontractor Site Health and Safety Coordinator has the authority to terminate field activities at specific sites if unsafe conditions develop.

3.2. INSTALLATION REQUIREMENTS

Primary health and safety responsibility at Rocky Flats Plant rests with Rockwell International Health, Safety and Environment Department Director. Representatives of the Rockwell International Health, Safety, and Environment Department, under direction of the Rockwell International CEARP Manager, will review and concur with the SSMP Health and Safety Plans prior to commencement of site characterizations (remedial investigations). The Rockwell International Health, Safety, and Environment Department will also provide guidance to the Subcontractor Project Manager for establishing health and safety requirements.

3.3. SPECIFIC RESPONSIBILITIES

Specific responsibilities assigned to the functional health and safety organization for the Rocky Flats Plant CEARP Phase 2b site characterizations (remedial investigations) are provided in the following sections.

3.3.1. Los Alamos National Laboratory

Because the site characterizations (remedial investigations) will be conducted by Rockwell International, Los Alamos National Laboratory does not have responsibility for implementing Health and Safety Plans.

3.3.2. Rockwell International CEARP Manager

The Rockwell International CEARP Manger shall

- ensure that the Rocky Flats Plant SSMP Health and Safety Plans are prepared, reviewed, and concurred with by the appropriate individuals within DOE-Albuquerque Operations Office and Rocky Flats Plant;
- concur in the selection of the Subcontractor Site Manager and Subcontractor Site Health and Safety Coordinator;
- ensure that personnel involved with CEARP Phase 2b site characterizations (remedial investigations) comply with the IGMP/CSPCP Health and Safety Plans;
- require periodic health and safety audits (at least once during each stage of sampling), review Health and Safety Audit Reports, and require responses to Health and Safety Audit Report findings and recommendations;
- act on employee concerns in accordance with the procedures outlined in DOE Orders and take appropriate action to correct violations;
- review and evaluate requests for variance from the Health and Safety plans; and
- ensure that the proper reports required by DOE and DOE-Albuquerque Operations Office orders are submitted, including accident investigation reports, as necessary.

3.3.3. Subcontractor Project Manager

The Subcontractor Project Manager shall

- assign a Subcontractor Site Manager (Section 3.3.4) who will be responsible for ensuring the health and safety of field team personnel during CEARP Phase 2b Site Characterization (Remedial Investigation) activities;

- assign a Subcontractor Site Health and Safety Coordinator (Section 3.3.5) to ensure implementation of the Rocky Flats Plant IGMP/CSPCP Health and Safety Plan and each SSMP Health and Safety Plan; and

- read, concur, and comply with the Rocky Flats Plant IGMP/CSPCP Health and Safety Plan.

3.3.4. Subcontractor Site Manager

The Subcontractor Site Manager shall

- submit requests for variance from the requirements of this plan to the Subcontractor Project Manager and Rockwell International CEARP Manager, when appropriate;

- assure that requirements specified in DOE and DOE-Albuquerque Operations Office Orders 5484.1 are recorded and reported for all employees;

- ensure that personnel involved with CEARP Phase 2b site characterizations (remedial investigations) comply with the IGMP/CSPCP Health and Safety Plans;

- monitor the performance of employees involved in site characterization (remedial investigation) activities to ensure compliance with health and safety requirements;

- be familiar with emergency response procedures and notification requirements, and implement them accordingly; and

- terminate work activities if unsafe conditions develop or when directed to do so by the Subcontractor Site Health and Safety Coordinator.

3.3.5. Subcontractor Site Health and Safety Coordinator

A Subcontractor Site Health and Safety Coordinator will be designated by the Subcontractor Project Manager for each stage of the Phase 2b site characterization

(remedial investigation) activities. The Rockwell International CEARP Manager shall concur in the selection of the Subcontractor Site Health and Safety Coordinator. The Subcontractor Site Health and Safety Coordinator is responsible for conducting a review of the proposed activities prior to commencement of operations, evaluating potential hazards, and recording the appropriate information on a Work Location, Personnel Protection, and Safety Evaluation Form (Appendix A). Activities that require special monitoring or certain personal protective equipment will be specified in the SSMP Health and Safety Plans. In addition to the duties outlined in Section 3.4 of the CGMP Health and Safety Plan, specific responsibilities of the Subcontractor Site Health and Safety Coordinator include the following:

- being present or having an acceptable alternate present when subcontractor work activities are being performed in areas requiring decontamination of personnel or equipment;

- advising the Rockwell International CEARP Manager, and the Subcontractor Site Manager of potential health and safety hazards during site characterization (remedial investigation) activities;

- conduct special monitoring, if necessary;

- evaluate potential modifications to work plans and personal protective equipment requirements to ensure employee safety;

- ensure that site characterization (remedial investigation) team members have been trained in the appropriate safety procedures for the activities they will conduct, have current medical certification that they are physically fit to perform required tasks; and have participated in all required dosimetry or bioassay training programs;

- contact the appropriate local emergency organizations (police, fire, ambulance, and hospital) to coordinate emergency response activities;

- require that the Subcontractor Field Team Leader terminate work activities if unsafe conditions develop, or an imminent hazard is perceived;

- prepare variances from the health and safety requirements if needed; and

- carry out health and safety audits and prepare health and safety audit reports as required by this IGMP/CSPCP Health and Safety Plan.

3.4. AUDITS

Health and safety audits will be conducted by the Subcontractor to ensure adequate implementation of the requirements of this IGMP/CSPCP Health and Safety Plan. Audits will be conducted by the Subcontractor Site Health and Safety Coordinator and documented in Health and Safety Audit Reports to be issued by the Subcontractor Project Manager. The Los Alamos National Laboratory CEARP Team Leader and the Rockwell International CEARP Manager will receive copies of these reports. Individuals responsible for health and safety deficiencies noted in the audit findings will provide written responses describing corrective actions that have been implemented to resolve the findings.

The Rockwell International Health, Safety, and Environment Department may also conduct health and safety audits, separately or concurrently, with subcontractor audits.

3.5. VARIANCES FROM HEALTH AND SAFETY REQUIREMENTS

Where special conditions exist, a written request for a variance from a specific health and safety requirement may be submitted by the Subcontractor Site Health and Safety Coordinator to the Subcontractor Project Manager. If the Subcontractor Project Manager agrees with the request, the request will be reviewed by the Rockwell International CEARP Manager and representatives of the Rockwell International Health, Safety, and Environment Department. The conditions of the request will be evaluated and, if appropriate, a variance specifying the conditions under which the requirement may be modified will be granted in writing. A copy of the variance will be retained in the field during work activities in which it is invoked.

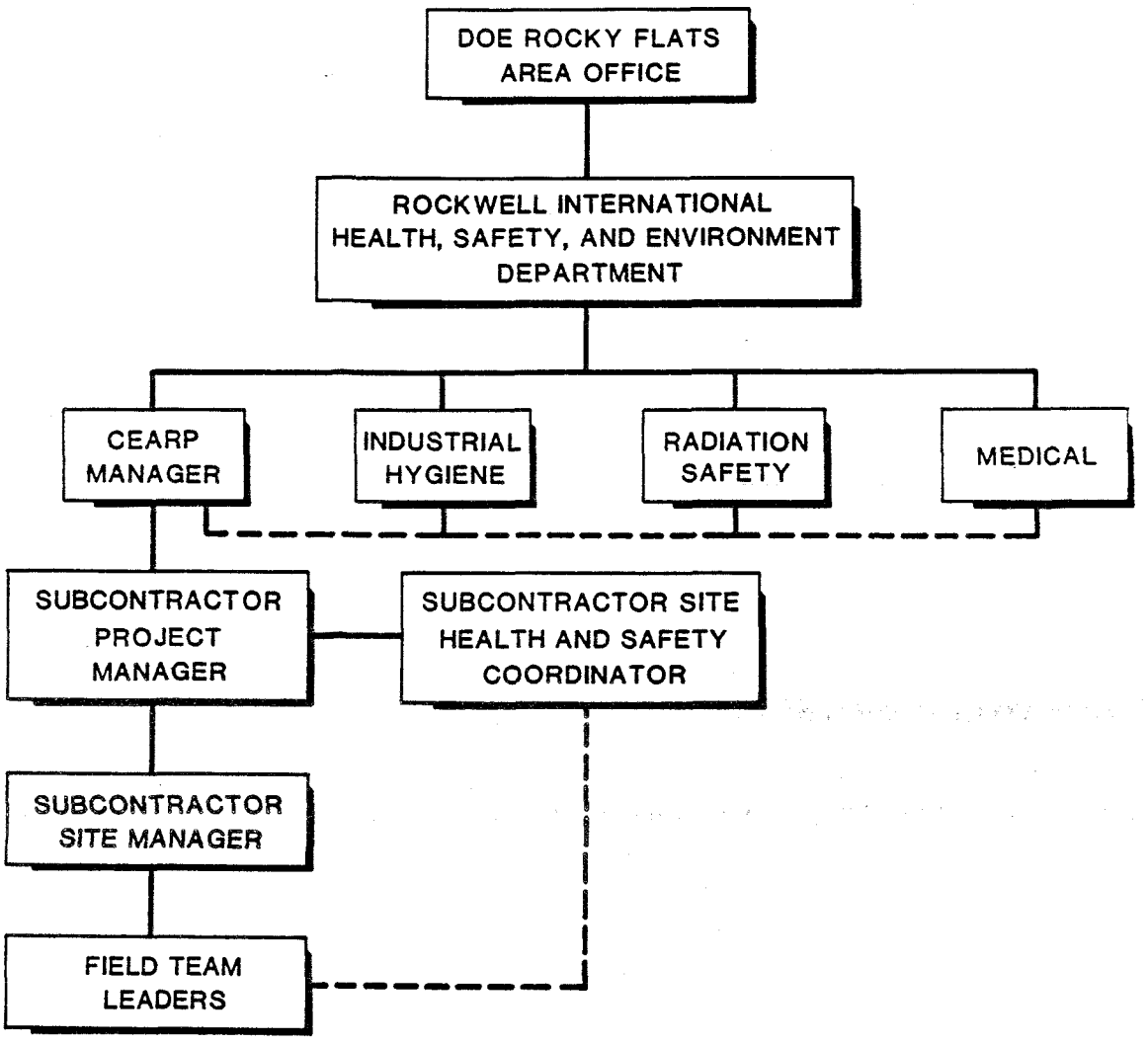

Figure 3.1. Simplified Health and Safety Organizational Chart for Rocky Flats Plant.

4. HAZARD ASSESSMENT AND PERSONNEL PROTECTION REQUIREMENTS

The following section provides a description of anticipated potential hazards anticipated at Rocky Flats Plant. The hazards description includes physical, chemical, radiological and biological hazards, followed by general requirements for limiting exposures, monitoring contaminant concentrations, and measuring employee exposure.

4.1. IDENTIFICATION OF POTENTIAL HAZARDS

4.1.1. Physical Hazards

The following physical hazards are anticipated at Rocky Flats Plant.

Heat Stress

The body's physiological processes fail to maintain a normal body temperature because of excessive heat. A number of physical reactions can occur, ranging from mild to fatal.

Heat-Related Problems

- Heat Rash, caused by continuous exposure to heat and humid air aggravated by chafing clothes. Decreases ability to tolerate heat and becomes a nuisance.

- Heat Cramps, caused by profuse perspiration with inadequate fluid intake and chemical replacements (especially salts). Signs: muscle spasm and pain in the extremities and abdomen.

- Heat exhaustion, caused by increased stress on various organs to meet increased demands to cool the body. Signs: shallow breathing; pale, cool, moist skin; profuse sweating; dizziness and lassitude.

- Heat stroke, the most severe form of heat stress. Body must be cooled immediately to prevent severe injury and/or death. Signs: red, hot, dry skin; no perspiration; nausea; dizziness and confusion; strong rapid pulse; coma.

Work/Rest Schedule

When working in level B or C protective clothing, the following guideline for calculating the work/rest schedule shall be used.

Calculate the adjusted temperature,

T(adjusted) = T(actual) + (13 x sunshine fraction)

100% sunshine =	no cloud cover	= 1.0
50% sunshine =	50% cloud cover	= 0.5
0% sunshine =	full cloud cover	= 0.0

Adjusted Temperature	Active Work Time (min./hr)
75 or less	50
80	40
85	30
90	20
95	10
100	0

Cold Exposure

Persons working outdoors in temperatures at or below freezing can become frostbitten. Exposure to extreme cold for short time periods can cause severe injury to the body surface or can result in profound generalized cooling, causing death. Body areas which have high surface-area-to-volume ratios (e.g., fingers, toes, and ears) are the most susceptible.

Cold Exposure-Related Problems

- Frost nip or incipient frostbite, characterized by sudden blanching or whitening of skin.
- Superficial frost bite, which causes skin to become waxy or white and superficially firm, but resilient beneath.
- Deep frostbite, characterized by cold, pale, solid skin tissues.
- Systemic hypothermia, caused by exposure to freezing or rapidly dropping temperature. Symptoms are usually exhibited in five stages: 1) shivering, 2) apathy, listlessness, sleepiness and (sometimes) rapid cooling of the body to less than 95°F, 3) unconsciousness, glassy stare, slow pulse and slow respiratory rate, 4) freezing of the extremities, and finally, 5) death.

Caution will be used to prevent cold exposure by wearing properly insulated garments beneath protective clothing and by taking frequent warm-up breaks.

Noise

When noise exceeds acceptable levels (limits specified in Department of Air Force Regulation 161-35 TLV's) administrative or engineering controls designed to reduce exposures will be utilized. If these controls are not sufficient, approved ear protection will be provided and its use mandated. Noise levels will be monitored when it becomes necessary to speak loudly under normal working conditions.

Standard Precautions for Equipment and Structures

Site characterizations (remedial investigations) at Rocky Flats Plant may require the use of shovels, drill rigs, portable augers, and backhoes. Prior to any surface disturbance the required permit will be obtained from Rocky Flats Plant. Heavy equipment will be operated according to OSHA recommendations and requirements.

- Only qualified and licensed personnel shall be allowed to operate this equipment.

- Heavy equipment shall be operated and maintained in conformance with established standards and inspected prior to use, as directed by Federal, State or OSHA regulations.

- Overhead electrical power lines shall be considered energized unless Rocky Flats Plant Utilities Manager has verified de-energization.

- While in use, drilling rigs shall maintain the following minimum distances from overhead power lines: 10 ft for 50 kv, 20 ft for 345 kv, and 34 ft for 750 kv.

  In transit, with the boom or derrick lowered, the closest approach to a powerline shall be 4 ft for 50 kv, 10 ft for 50-345 kv, and 16 ft for 345-750 kv.

Flammable and/or Combustible Materials

Several sites requiring characterization could contain flammable or combustible materials. The SSMP Health and Safety Plans will contain detailed information on the likelihood of encountering combustible materials and specific health and safety requirements for these areas.

4.1.2. Known Chemical Hazards

Known chemical hazards at Rocky Flats Plant include possible inhalation, ingestion, or dermal absorption of organic compounds, solvents, or other toxic materials. Specific properties of known chemical contaminants are provided in Appendix A. If it is determined that additional chemicals are present at Rocky Flats Plant, Appendix A will be amended. Levels or concentrations of these hazardous materials can be estimated from groundwater sampling results.

4.1.3. Known Radiological Hazards

Radionuclides are expected to be present at Rocky Flats Plant. The specific properties of the known radionuclides, including type of emission, half-life, maximum allowable concentrations, and body burdens are provided in Appendix A. The specific properties of the known radionuclides including type of emission, half-life, maximum allowable concentrations, and body burdens are provided in Appendix A.

There are three principal pathways by which individuals could be exposed to radioactivity during site characterizations (remedial investigations). These are (1) inhalation or ingestion, (2) dermal absorption, and (3) exposure to direct radiation from contaminated materials (see 4.2. for personnel protection requirements).

4.1.4. Biological Hazards

Certain biological hazards are anticipated at Rocky Flats Plant:

- insects, including ticks and mosquitoes;
- snakes of poisonous and nonpoisonous species; and
- rodents, including mice and rats.

If a worker is bitten by a rodent or snake, the Subcontractor Site Health and Safety Coordinator will be immediately notified. The Rocky Flats Plant installation medical center shall be contacted and appropriate medical care given.

4.2. PERSONNEL PROTECTION REQUIREMENTS

4.2.1. Protection Levels and Protective Clothing

As stated in the CGMP Health and Safety Plan, the U.S. Environmental Protection Agency (EPA) has established four levels of protection for personnel entering potentially hazardous sites. The work at Rocky Flats Plant is anticipated to be conducted in levels B, C, and D protection based upon known hazards. The SSMP Health and Safety Plan will define zones of contamination and identify which levels of protection will be required for each zone. All personnel entering a zone will be required to wear the attire designated for that zone.

4.2.2. Protective Equipment

As stated in the CGMP Health and Safety Plan, a variety of safety equipment will be used to protect personnel from safety hazards and minimize exposures to hazardous chemicals and radionuclides during Rocky Flats Plant site characterizations (remedial investigations). Portable monitors and meters will be used to determine exposures and measure air concentrations of radiological and chemical contaminants. The safety equipment used will include photoionization and organic vapor analyzers, air samplers, radiation survey meters, explosive gas concentration meters, detector tubes, and thermoluminescent dosimeters. This safety equipment is fully described in the CGMP Health and Safety Plan. The SSMP Health and Safety Plans will outline specific equipment to be used, and action levels to be taken for each type of measurement.

Cooling vests and warming equipment will be available to minimize stress from climatic conditions. As outlined in the CGMP Health and Safety Plan, emergency equipment including fire extinguishers, first aid kits, blankets, and eye wash kits will be available for emergency treatment.

4.2.3. General Safety Practices and Mitigation Measures

As stated in the CGMP Health and Safety Plan, some hazards can be minimized through the implementation of specific procedures, use of special equipment, training of personnel, or availability of emergency response equipment in the event of

an accident. The general requirements listed in the CGMP Health and Safety Plan will be observed during all Rocky Flats Plant site characterizations (remedial investigations).

Work that may involve resuspension of contaminants into the air will be suspended when the wind speed exceeds 15 miles per hour.

Morning meetings for all personnel involved in sampling will be held daily. These meetings will be used to express health and safety concerns related to the day's activities. Standard safe working practices, described in Section 4 of the CGMP Health and Safety Plan, will be followed. Appendix A provides a list of potential chemical and hazards radiological and their respective method of detection and Threshold Limit Value (TLV). A detailed description of hazards and hazardous materials which could be encountered at each site will be provided in each SSMP Health and Safety Plan. The SSMP Health and Safety Plans will also provide site-specific safety practices and mitigative measures.

4.3. SITE ACCESS CONTROL

4.3.1. Restricted Access Zones

As stated in the CGMP Health and Safety Plan, control zones will be established prior to commencement of work at contaminated sites to protect employees and the general public from unnecessary exposure to toxic materials and/or radiation, and to prevent inadvertent spread of contamination. The control (exclusion) zones will be designated in each SSMP Health and Safety Plan based on the nature, magnitude, and extent of contamination, and the potential for contaminant migration. Decontamination is required for personnel, equipment, and vehicles moving from an exclusion zone to a clean zone.

The decontamination of equipment and personnel will be conducted in steps starting at exclusion zones, proceeding through contamination reduction zones, and ending at clean zones. The size and number of contamination reduction zones will be determined on a site-specific basis and will be provided in each SSMP Health and Safety Plan. Exclusion criteria, protection requirements, contact person, and other relevant information will be posted at the access station of each exclusion zone.

4.3.2. Decontamination

At Rocky Flats Plant, decontamination will follow the general procedures described in Section 4 of the CGMP Health and Safety Plan. Each SSMP Health and Safety Plan will clearly define decontamination procedures for specific contaminants of concern.

Decontamination solutions used will be selected according to contaminants encountered on a site-specific basis. Radionuclides anticipated at Rocky Flats Plant can be removed from personnel and equipment using dilute soap and water solutions. Organic compounds and solvents will require use of slightly stronger detergents for effective removal. Following decontamination, verification measurements will be made to ensure that contaminants have been removed to safe levels. For articles or personnel contaminated by low energy beta emitters, swipe-samples will be collected and analyzed using liquid scintillation detectors. For alpha and high energy beta emitters, a survey meter will be used to evaluate decontamination. Following this "frisking," swipes will be collected and analyzed using a gross alpha/beta counting meter.

4.4. WORKER TRAINING

As described in the CGMP Health and Safety Plan, health and safety training will be conducted and documented for all members of site characterization (remedial investigation) field teams. The level of training for each team will be commensurate with job functions and potential hazards in work areas and comply with the RCRA part B Operating Permit Application, Section H. This will be in addition to completion of any surcontractor basic health and safety training, or the equivalent, that must be approved prior to site assignment. At least two field members of each field team will be required to have current certification in American Red Cross Multi-Media First Aid and Cardio Pulmonary Resuscitation (or the equivalent). In addition, training for all field team members will meet right-to-know requirements and will follow the outline in Appendix A, which includes

- radiological safety,
- hazard identification and recognition,
- potential health effects and symptoms of exposure,
- protective equipment requirements and proper use,
- decontamination procedures,

- controlled area restrictions, and
- emergency response requirements.

4.5. EMPLOYEE MEDICAL PROGRAM

As stated in the CGMP Health and Safety Plan, site characterization (remedial investigation), subcontractor field team members shall participate in an employee medical examination program. Their suitability for conducting field sampling activities (including possible respirator use) will be evaluated and documented by a physician. Medical programs must comply with requirements of DOE Order 5480.1A Chapter VIII.

4.6. RECORDS AND REPORTING REQUIREMENTS

Subcontractors will maintain health and safety records and submit reports, as required by DOE Orders, to the Subcontractor CEARP Project Manager. These will include the following:

- DOE Form 5484.3 Supplementary Record of Occupational Injuries and Illnesses
- DOE Form 5484.4 Tabulation of Property Damage Experience
- DOE Form 5485.5 Report of Property Damage or Loss
- DOE Form 5484.6 Annual Summary of Whole Body Exposures to Ionizing Radiation
- DOE Form 5484.7 Summary of Exposures Resulting in Internal Body Depositions of Radioactive Materials for CY
- DOE Form 5484.8 Termination Occupational Exposure Report
- DOE Form OSHA-200 Log of Occupational Injuries and Illness
- DOE Form EV-102A Summary of Department of Energy and Department of Energy Contractor Occupational Injuries and Illnesses
- DOE Form 5821.1 Unplanned Releases Form.

The Subcontractor Project Manager will distribute copies of the reports to Los Alamos National Laboratory, the DOE-Albuquerque Operations Office, and the

Rockwell International Health and Safety Department, as appropriate. Specific reporting responsibilities are given in the following subsection.

4.6.1. Exposure and Medical Records

Subcontractors will maintain confidential medical records for each field team member as indicated by the employee medical program. These records will identify individuals by name, date of birth, social security number, and additional identifiers as desired by the subcontractor. The employee's accident record and history of exposures and/or possible exposures to hazardous physical, chemical, or biological agents will be included with the medical records.

The Subcontractor Site Health and Safety Coordinator will prepare, and submit to the Subcontractor Project Manager and the Rockwell International CEARP Manager, radiation exposure reports as required in DOE Order 5484.1. Form 5484.8, "Termination Occupational Exposure Report," will be completed for any employee included in a radiation monitoring program upon termination of employment. Forms 5484.7, "Summary of Exposures Resulting in Internal Body Depositions of Radioactive Materials for CY 19XX," and 5484.6, "Annual Summary of Whole Body Exposures to Ionizing Radiation," will be submitted annually by March 31 for monitored employees. These reporting requirements are currently under revision by DOE, and the Subcontractor Site Health and Safety Coordinator shall comply with the new requirements when they become final.

4.6.2. Accident/Incident Reports

The Subcontractor Site Health and Safety Coordinator will notify the Subcontractor Project Manager and the Rockwell International CEARP Manager of any accidents or incidents that occur during site characterizations (remedial investigations) at Rocky Flats Plant. The Subcontractor Site Health and Safety Coordinator will also submit a completed DOE Form F 5484.X for any of the following incidents.

(1) "Recordable" occupational injuries or illnesses are defined below:

> OCCUPATIONAL INJURY is any injury such as a cut, fracture, sprain, or amputation that results from a work accident or from an exposure involving a single incident in the work environment.

NOTE: Conditions resulting from animal or insect bites, or one-time exposure to chemicals, are considered to be injuries.

OCCUPATIONAL ILLNESS of an employee is any abnormal condition or disorder, other than one resulting from an occupational injury, caused by exposure to environmental factors associated with employment. It includes acute and chronic illnesses or diseases which may be caused by inhalation, absorption, ingestion, or direct contact with a toxic material.

(2) PROPERTY DAMAGE LOSSES of $1,000 or more are reported as follows: accidents which cause damage to DOE property, regardless of fault, or accidents wherein DOE may be liable for damage to a second party, are reportable if damage is $1,000 or more. Include damage to facilities, inventories, equipment, and properly parked motor vehicles. Exclude damage resulting from a DOE reportable vehicle accident.

(3) GOVERNMENT MOTOR VEHICLE ACCIDENTS resulting in damages of $250 or more, or involving an injury, are reported unless the Government vehicle is not at fault, damage of less than $250 is sustained by the Government vehicle, and no injury is inflicted on the Government vehicle occupants. Accidents are also reportable to DOE if

- damage to a Government vehicle, not properly parked, is greater than or equal to $250;
- damage to DOE property is greater than or equal to $250 and the driver of a Government vehicle is at fault;
- damage to any private property or vehicle is greater than or equal to $250 and the driver of a Government vehicle is at fault; and
- any person is injured and the driver of a Government vehicle is at fault.

4.7. EMPLOYEE INFORMATION

The Subcontractor Site Health and Safety Coordinator shall ensure that the following DOE forms are posted where field team members can easily read them:

- Form F 5480.2 Occupational Safety and Health Protection,
- Form F 5480.4 Occupational Safety and Health Complaint Form.

Also, the Rocky Flats Plant Health and Safety Standard concerning employee right-to-know shall be provided in each SSMP and appropriately posted.

5. EMERGENCY RESPONSE AND NOTIFICATION

This section provides guidelines for responses to emergency situations.

5.1. EMERGENCY CONTACTS

Names of persons to contact in case of emergencies will be provided in the format found in Figure 5.1. This emergency contact form will be copied and posted in prominent locations at the work sites. Additional contacts are given in the Safety Evaluation Form (Appendix A).

5.2. CONTINGENCY PLANS

Field team leaders, with assistance from the Subcontractor Site Health and Safety Coordinator, shall have responsibility and authority for coordinating all emergency response activities until proper authorities arrive and assume control. A copy of these plans shall be available at the work site at all times, and all personnel working on the site shall be familiar with the plans. Evacuation plans and routes shall be on a job-specific basis, and all personnel shall be familiar with them.

5.2.1. Fire/Explosion

Any fire emergency will be handled by immediately notifying the fire department. Only if the fire appears to be small and easily extinguishable will personnel attempt control with fire extinguishers available in the work area. Otherwise, immediate evacuation of the area is indicated.

If combustible gas/oxygen meters show explosive gas or oxygen concentrations approaching 25% of the lower explosive limits, all personnel will be evacuated and the fire department will be notified. In the event of an explosion, all personnel shall be evacuated and no one shall re-enter the area until it has been cleared by explosives safety personnel.

5.2.2. Personnel Injuries

In case of injuries to personnel, first aid treatment will be initiated immediately by trained personnel. In case of serious injuries, the victim will be transported to the Rocky Flats Plant medical center as soon as possible. Minor injuries may be treated onsite, but all injuries will be examined by trained medical personnel. Victims of serious bites or stings will be taken to the Rocky Flats Plant medical center. In the event that an injured person is contaminated with chemicals or radionuclides, the person shall be taken as soon as possible to the Rocky Flats Plant medical center. Decontamination shall be performed to prevent further exposure only if it will not aggravate the injury. Treatment of life threatening or serious injuries will always be considered first.

5.2.3. Accidental Releases of Radionuclides to the Environment

In case of releases of radionuclides to the environment (such as a spill of samples being transported for analysis), emergency response shall be in accordance with Rocky Flats Plant procedures. The Subcontractor Site Manager or Field Team Leader shall notify the Rockwell International CEARP Manager of such an event.

5.3. NOTIFICATION REQUIREMENTS

Reporting and notification of emergency situations shall be carried out in accordance with requirements in DOE Order 5484.1. The Field Team Leader shall notify the Subcontractor Site Manager. The Subcontractor Site Manager will notify appropriate emergency assistance personnel (e.g., fire, police, ambulance at ext. 2911), and the Rockwell International CEARP Manager. The responsibility of the Subcontractor Site Health and Safety Coordinator for Rocky Flats Plant is to implement notification and reporting requirements of DOE Order 5484.1.

Site Health and Safety Coordinator--

Name: Call: _____

Installation Health and Safety Officer--

Name: _____ Call: _____

24-Hour Installation Health/Safety Coordinator--

Call: _____

FIRE-- Call: _____

AMBULANCE-- Call: _____

POISON CENTER-- _____

SECURITY-- Call: _____

POLICE-- Call: _____

YOU ARE LOCATED AT: _____

_____

THE NEAREST TELEPHONE IS LOCATED AT:

_____

THE NEAREST EMERGENCY MEDICAL SERVICES ARE LOCATED AT:

_____

_____

Figure 5.1. Emergency Contacts

6. ENVIRONMENTAL MONITORING

Environmental impacts from CEARP site characterizations (remedial investigations) are expected to be negligible. Additional sampling to supplement Rocky Flats Plant routine monitoring activities is not considered necessary. Monitoring of air quality for personnel protection will provide data to re-evaluate the need for environmental monitoring. Additional guidance and detail regarding monitoring during site characterizations (remedial investigations) will be provided in SSMP Sampling Plans.

WORK LOCATION PERSONNEL PROTECTION
AND SAFETY EVALUATION FORM

Attach Pertinent Documents/Data

Fill in Blanks_____

WO #_____ Reviewed by_____

Division_____ Date_____

Office_____ Approved by_____

Prepared by_____ Date_____

Date_____

A. Work Location Description

1. Name_____ 2. Location_____

_____ _____

3. Type: HW Site ( ) Industrial ( )

Spill ( ) Construction ( )

( ) Existing work Location

Other ( ) Describe_____

_____

4. Status_____

5. Anticipated activities:_____

_____

6. Size_____

7. Surrounding Population_____

8. Buildings/Homes/Industry_____

_____

9. Topography_____

_____

10. Anticipated Weather_____

11. Unusual Features_____

_____

12. Site History_____

_____

_____

B. Hazard Description

1. Background Review: Complete ( ) Partial ( )

If partial, why?_____

2. Hazard Levels:* A ( ) B ( )

Unknown ( ) C ( ) D ( )

Justification_____

3. Types of Hazards: (Attach additional sheets as necessary)

A. Chemical ( ) Inhalation ( ) Explosive ( )

Biological ( ) Ingestion ( ) O_2 Def. ( )

Skin Contact ( ) toxic ( )

Describe_____

_____

_____

B. Physical ( ) Cold Stress ( ) Noise ( )

Heat Stress ( ) Other ( )

Describe_____

_____

_____

C. Radiation ( )

Describe_____

_____

_____

4. Nature of Hazards:

Air ( ) Describe_____

_____

Soil ( ) Describe_____

_____

Surface Water ( ) Describe_____

_____

Ground Water ( ) Desribe_____

_____

Other ( ) Describe_____

_____

5. Chemical Hazards of Concern

6. Radiological Hazards of Concern

7. Work Location Instrument Readings ( ) N/A

Location _____

% O_2 _____ % LEL _____

Radioactivity _____ PID _____

FID _____ Other _____

Other _____ Other _____

Location _____

% O_2 _____ % LEL _____

Radioactivity _____ PID _____

FID _____ Other _____

Other _____ Other _____

Location _____

% O_2 _____ % LEL _____

Radioactivity _____ PID _____

FID _____ Other _____

Other _____ Other _____

Location _____

% O_2 _____ % LEL _____

Radioactivity _____ PID _____

FID _____ Other _____

Other _____ Other _____

8. Hazards expected in preparation for work assignment.
( ) N/A

Describe: _____

_____

_____

To be Completed For Site-Specific Health and Safety Plans

C. Personnel Protective Equipment

1. Level of Protection

To Be Completed For Site-Specific Health and Safety Plans

A ( ) B ( ) C ( ) D ( ) Location/Activity:

_____

A ( ) B ( ) C ( ) D ( ) Location/Activity:

_____

2. Protective Equipment (specify probable quantity required)

Respiratory ( ) N/A

( ) SCBA, Airline

( ) Full Face Respirator (Cart. _____)

( ) Escape Mask

( ) None

( ) Other_____

( ) Other_____

_____

Clothing ( ) N/A

( ) Fully Encapsulating Suit

( ) Chemically Resistant Splash Suit

( ) Apron, Specify_____

( ) Tyvek Coverall

( ) Saranex Coverall

( ) Coverall, Specify_____

( ) Other_____

( ) Other_____

_____

Head & Eye ( ) N/A

( ) Hard Hat

( ) Goggles

( ) Face Shield

( ) Chemical Eyeglasses

Hand Protection ( ) N/A

( ) Undergloves_____ Type

( ) Gloves_____ Type

( ) Overgloves Type

( ) None

( ) None

( ) Other_____ ( ) Other_____

_____ _____

Foot Protection ( ) N/A

( ) Safety Boots

( ) Disposable Overboots

( ) Other_____ To Be Completed For Site-Specific Health and Safety Plans

3. Monitoring Equipment ( ) N/A

( ) CGI ( ) PID

( ) O_2 Meter ( ) FID

( ) Rad Survey ( ) Other_____

( ) Detector Tubes _____

Type:_____ ( ) Other_____

_____ _____

D. Personnel Decontamination (Attach Diagram)

Required ( ) Not Required ( )

Equipment Decontamination (Attach Diagram)

Required ( ) Not Required ( )

If required, describe and list equipment_____

_____

_____

_____

_____

_____

E. Personnel

Name	Work Location Title/Task	Medical Current	Fit Test Current	Certification Level
1.		( )	( )	( )
2.		( )	( )	( )
3.		( )	( )	( )
4.		( )	( )	( )
5.	To Be Completed For	( )	( )	( )
6.	Site-Specific Health and	( )	( )	( )
7.	Safety Plans	( )	( )	( )
8.		( )	( )	( )
9.		( )	( )	( )
10.		( )	( )	( )

Site Safety Coordinator_____

F. Activities Covered Under This Plan

Task No.	Description	Preliminary Schedule

TO BE COMPLETED FOR SITE-SPECIFIC HEALTH AND SAFETY PLANS

G. Subcontractor's Health and Safety Program Evaluation ( ) N/A

Name and Address of Subcontractor: _____

Activities to be conducted by Subcontractor: _____

Item	EVALUATION CRITERIA Adequate	Inadequate	Comments
Medical Surveillance Program	( )	( )	_____
Personal Protective Equipment Availability	( )	( )	_____
Onsite Monitoring Equipment Availability	( )	( )	_____
Safe Working Procedures Specificiation	( )	( )	_____
Training Protocols	( )	( )	_____
Ancillary Support Procedures (if needed)	( )	( )	_____
Emergency Procedures	( )	( )	_____
Evaluation Procedures Contingency Plan	( )	( )	_____
Decontamination Procedures Equipment	( )	( )	_____
Decontamination Procedures Personnel	( )	( )	_____

GENERAL HEALTH AND SAFETY PROGRAM EVALUATION: ADEQUATE ( ) INADEQUATE ( )

ADDITIONAL COMMENTS: _____

EVALUATION CONDUCTED BY: _____ DATE: _____

H. Contingency Contacts

Agency	Contact	Phone Number
Fire Department	_____	
Fire Department	_____	_____
Police Department	_____	_____
Health Department	_____	_____
Poison Control Center	_____	_____
State Environmental Agency	_____	_____
EPA-Regional Office	_____	_____
EPA-ERT. ICOM	_____	_____
Spill Contractor	_____	_____
State Police	_____	_____
F.A.A.	_____	_____
Civil Defense	_____	_____
Onsite Coordinator	_____	_____
Site Telephone	_____	_____
Nearest Telephone	_____ Location	

Other _____

I. Contingency Plans

Spills, Accidental Release; Describe _____

_____

Fire Explosion; Describe _____

_____

Other; Describe _____

_____

Exit Routes, Communication Systems; Describe_____

_____

MEDICAL EMERGENCY

Name of Hospital_____

Address:_____ Phone No._____

Name of Contact_____

Addresses:_____ Phone No._____

Route to Hospital: (Attach Map)_____

_____

_____

_____

_____

Travel Time
From Site (Minutes)_____

Distance to
Hospital (Miles)_____

Name/Number of 24-Hr. Ambulance Service_____

HEALTH AND SAFETY PLAN
APPROVAL/SIGN OFF FORMAT

I have read, understood, and agreed with the information set forth in the Health and Safety Plan (and attachments) and discussed in the Personnel Health and Safety briefing.

Name	Signature	Date
Name	Signature	Date
Name	Signature	Date
Name	Signature	Date
Name	Signature	Date
Site Safety Co-ordinator	Signature	Date
Director, Corporate Health and Safety	Signature	Date
Project Manager	Signature	Date
Project Director/ Department Manager	Signature	Date

Personnel Health and Safety Briefing Conducted By:

Name	Signature	Date

Table A-1. Chemical Hazards of Concern

Contaminant	TLV	I.D.L.H.	Source/Quantity Characteristics	Instrument Used To Monitor Contaminant
1,1,-dichloroethylene	200ppm	4000ppm	in groundwater	H-nu, detector tubes explosimeter
1,1-dichloroethane	200ppm	4000ppm	in groundwater	H-nu, detector tubes explosimeter
Acetone	750ppm	20,000ppm	unknown	Charcoal;GC
Asbestos	.5 fibers> um/cc	Ca	fine slender, flaxy fibers	NIOSH 77-157A
Beryllium (Be)	$2mg/m^3$	Ca	unknown	NIOSH 77-157A
Cadmium (Cd)	$0.05mg/m^3$	$40mg/m^3$,Ca	Variable	filter,acid,AA
Cadmium Cyanide	$0.5mg/m^3$	--	Variable	filter,bub.,OH,1SE
Carbon tetrachloride	5ppm	300ppm	in groundwater	H-nu, detector tubes
Chloroform	10ppm	1000ppm	in groundwater	H-nu, detector tubes
Chromic Acid (CrO_3)	$0.1mg/m^3$	$30mg/m^3$	Variable	filter,H_2SO_4, diphenyl-carbazide, color
Chromium (Cr)	$1mg/m^3$	$500mg/m^3$	Variable	filter,acid,AA
Copper (Cu)	$1mg/m^3$	NA	dusts,mists	filter,acid,AA
Fuel Oil	N/A	N/A	in soil	H-nu, explosimeter
Lead (Pb)	$0.05mg/m^3$	Variable	Variable	Filter,HNO_3,AA
Mercury (Hg)	$0.05mg/m^3$	$28mg/m^3$	Silvery, liquid	AA

Table A-1. (Continued)

Contaminant	TLV	I.D.L.H.	Source/Quantity Characteristics	Instrument Used To Monitor Contaminant
Nickel	0.1mg/m^3	Ca	Variable	filter,acid,AA
PCB's	0.5mg/m^3	5mg/m^3,Ca	unknown	filter,GC
Sodium Hydroxide	2mg/m^3	200mg/m^3	unknown	filter,HCl,titration
Solvents	NA	NA	unknown	Charcoal,GC
Tetrachloroethylene	50ppm	500ppm	in groundwater	H-nu, detector tubes
Tin (Sn)	0.1 mg/m^3	200mg/m^3	Variable	NIOSH 77-157A
Trichloroethane	350ppm	1000ppm	in groundwater	H-nu, detector tubes
Trichloroethylene	50ppm	1000ppm	in groundwater	H-nu, detector tubes explosimeter
Vinyl chloride	1ppm	--	in groundwater	N-nu, detector tubes explosimeter

*Where Ca appears, it is recommended that the substance be treated as a potential human carcinogen.

N/A - not applicable

Table A-2. Radiological Hazards of Concern

ISOTOPE	RADIATIONS	AIR MPC (uCi/CC) WORKERS	MPBB (uCi)	CO	HALF-LIFE RADIOACTIVE	HALF-LIFE BIOLOGICAL DAYS	MONITORING INSTRUMENT
H-3	beta	$5x10^{-6}$	1000	body tissue	12.262y	12	Scintillation-liquid
Pu-238	alpha, gamma	$2x10^{-12}$	0.04	Bone	86.4y	73,000	Scintillometer
Pu-239	alpha, gamma	$2x10^{-12}$	0.04	Bone	24,390y	73,000	Scintillometer
Sr-90	beta,D	$1x10^{-9}$	2	Bone	27.7y	18,000	G-M
U-238	alpha,X,D	$7x10^{-11}$	0.005	Kidney	$4.51x10^{-9}$y	15	Scintillometer

MPC - maximum permissable concentration in air for radiation workers on a 40-hour work week
MPBB - the amount of the isotope maintained in the body which will deliver the maximum permissible dose equivalent rate to the limiting organ
Critical organ - the organ that receives the highest dose equivalent from a sustained intake
D - daughter radiations with half-lives less than 25 years
X - x-radiations from orbital electrons

Training Outline

I. Training Purpose and Objectives

II. Identification and Recognition of Health and Safety Hazards at the Rocky Flats Plant Facility

A. Physical Hazards
- o noise
- o heat
- o cold
- o structures

B. Chemical Hazards
- o volatile organics
- o asbestos
- o beryllium

C. Radiological Hazards
- o plutonium
- o americium
- o tritium
- o uranium

D. Summary of Principal Hazards and Health Effects
- o chemical exposures
- o external exposures to radionuclides
- o internal exposures to radionuclides
- o potential health effects for women and fetuses

III. Radiological Safety and Monitoring Requirements

A. Controlled Area Restrictions
- o eating/drinking
- o smoking
- o chewing
- o access control points

B. Protective Equipment Requirements
- o clothing: hard hats, boots, gloves, coveralls
- o respiratory protection

C. Procedures for Using Protective Equipment
- o respiratory fit-test and use
- o impermeable clothing

D. Personnel Contamination Monitoring and Decontamination

IV. Emergency Response Requirements

A. Locations and Methods of Accessing Emergency Assistancae

B. Emergency Notification Procedures

V. Hazard Communication Information (Right-to-Know)

A. List of Hazardous Materials

DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
ENVIRONMENT, SAFETY AND HEALTH DIVISION
ENVIRONMENTAL PROGRAMS BRANCH

COMPREHENSIVE ENVIRONMENTAL ASSESSMENT AND RESPONSE PROGRAM

PHASE 2:
ROCKY FLATS PLANT
INSTALLATION GENERIC MONITORING PLAN
(Comprehensive Source and Plume Characterization Plan)

QUALITY ASSURANCE/QUALITY CONTROL PLAN

February 1987

DRAFT

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QUALITY ASSURANCE/QUALITY CONTROL PLAN

1. INTRODUCTION

CEARP Phase 2 consists of CEARP Phase 2a, Monitoring Plan, and CEARP Phase 2b, Site Characterization (Remedial Investigation). This Quality Assurance/ Quality Control (QA/QC) Plan is one component of the Monitoring Plan for Rocky Flats Plant. The Monitoring Plan typically consists of five parts: Synopsis, Sampling Plan, Technical Data Management Plan, Health and Safety Plan, and Quality Assurance/Quality Control Plan. Because of the Compliance Agreement made by the State of Colorado, Environmental Protection Agency, and the DOE, this Monitoring Plan also includes a Feasibility Study Plan. The Synopsis provides a discussion of the current situation and serves as an introduction to the other plans.

CEARP uses a three-tiered approach in preparing the monitoring plans: the CEARP Generic Monitoring Plan (CGMP) (DOE, 1986b), the Installation Generic Monitoring Plan (IGMP), and the Site-Specific Monitoring Plans (SSMPs). The CGMP Quality Assurance/Quality Control (QA/QC) Plan provides the generic guidelines and procedures that will be employed during CEARP Phase 2 site characterization (remedial investigation) to ensure the reliability of data collected at CEARP sites. It is intended to establish a general quality assurance/quality control policy and to provide the framework for more specific quality assurance/quality control requirements to be employed at each installation and at each site. This IGMP Quality Assurance/Quality Control Plan provides installation generic information and procedures, whereas the SSMPs will provide site-specific detail regarding locations, types and number of samples.

This IGMP is the Comprehensive Source and Plume Characterization Plan required by the Compliance Agreement. Therefore, the acronym used to refer to this plan is IGMP/CSPCP.

According to DOE policy, DOE activities shall maintain programs of quality assurance (DOE Order 5700.6B). In the area of environmental protection, quality assurance plans must be integrated with the DOE implementation of CERCLA (DOE Order 5480.14).

CEARP Phase 2b site characterizations (remedial investigations) will be implemented using procedures to assure that the precision, accuracy, completeness, and representativeness of data are known and documented. At a minimum, this will include adherence to the CEARP CGMP, IGMP/CSPCP, and SSMP Quality Assurance/Quality Control Plans, and may include preparation of written Quality Assurance/Quality Control Plans covering each aspect of the project performed.

This IGMP/CSPCP Quality Assurance/Quality Control Plan presents the organization, objectives, functional activities, and specific quality assurance and quality control activities associated with the CEARP Phase 2b site characterizations (remedial investigations) at Rocky Flats Plant. The Quality Assurance/Quality Control Plan is designed to achieve specific data quality goals for CEARP Phase 2b site characterizations (remedial investigations). Appendix A includes the quality assurance protocols for all laboratory services to be provided under CEARP Phase 2b site characterizations (remedial investigations).

A brief description of the CEARP Phase 2b site characterization (remedial investigation) and background can be found in the Synopsis. For a more in-depth background description, see the CEARP Phase 1 report.

2. PROJECT ORGANIZATION AND RESPONSIBILITY

Project organization and responsibility are divided among DOE, Los Alamos National Laboratory, and Rockwell International as described below. Los Alamos National Laboratory has the primary responsibility to implement CEARP under the guidance of DOE-Albuquerque Operations Office. However, operational responsibilities have been assigned to Rockwell International at Rocky Flats Plant for the site characterizations (remedial investigations). The DOE-Rocky Flats Plant Area Office is responsible for the function of the Rocky Flats Plant. Because of this responsibility, the DOE-Rocky Flats Plant Area Office will provide additional guidance to its contractor, Rockwell International, in implementation of the CEARP Phase 2b site characterizations (remedial investigations).

Project organization is shown in Figure 2.1. The responsibilities of the various personnel can be divided into operational, laboratory, and quality assurance responsibilities, as follows.

2.1. OPERATIONAL RESPONSIBILITIES

Assistant Secretary for the Environment. The DOE Assistant Secretary for the Environment appoints Headquarters investigation boards and establishes the scope of Headquarters investigations (DOE Order 5484.1). DOE-wide Environmental Surveys and Audits originate from the Assistant Secretary.

Environmental Surveys and Audits. Headquarters Environmental Survey Teams have been directed to conduct one-time environmental surveys and sampling of DOE facilities. These surveys are independent of CEARP activities at Rocky Flats Plant, but data from survey team sampling will be utilized in the CEARP characterization of Rocky Flats Plant. A Headquarters environmental survey team visited the Rocky Flats Plant site in 1986. The results of the survey will be used as an internal management tool by the Secretary and Undersecretary of DOE.

Audits are a function of the Office of the Assistant Secretary for the Environment. Audit teams provide quality control for the implementation of environmental monitoring at DOE facilities. Although independent of CEARP, audit teams complement CEARP activities by providing additional quality assurance.

DOE-Albuquerque Operations Office Environmental Programs Branch. The DOE-Albuquerque Operations Office, Environmental Programs Branch, is responsible for overseeing all environmental programs within DOE-Albuquerque Operations and conducting special assessments such as CEARP.

DOE-Rocky Flats Area Office. The DOE Rocky Flats Area Office is responsible for the missions of the Rocky Flats Plant, including environmental protection. The DOE Rocky Flats Area Office oversees the integration of Rocky Flats Plant resources with CEARP activities at Rocky Flats Plant.

Rockwell International. Rockwell International, as prime contractor to DOE, provides support to DOE in accomplishing the mission of Rocky Flats Plant, including environmental protection. Rockwell International will perform the CEARP Phase 2b site characterizations (remedial investigations) at Rocky Flats Plant.

Los Alamos National Laboratory. Los Alamos National Laboratory manages the CEARP program, providing direction, oversight and review, and preparing final reports.

2.2. ANALYTICAL LABORATORY RESPONSIBILITIES

Analytical laboratory responsibilities include performing analytical services, and providing quality assurance. Rockwell International will perform the CEARP Phase 2b site characterizations (remedial investigations) at Rocky Flats Plant. This IGMP/CSPCP provides guidance for quality assurance programs to be implemented by

- field laboratory operations
- analytical laboratories
- geotechnical laboratories
- radiological laboratories.

2.3. QA RESPONSIBILITY

Quality assurance responsibilities are to monitor and review the procedures used to perform all aspects of site characterizations (remedial investigations), including data collection, analytical services, data analysis, and report preparations. Primary responsibility for project quality rests with the Rockwell International CEARP Manager. Ultimate responsibility for project quality rests with DOE.

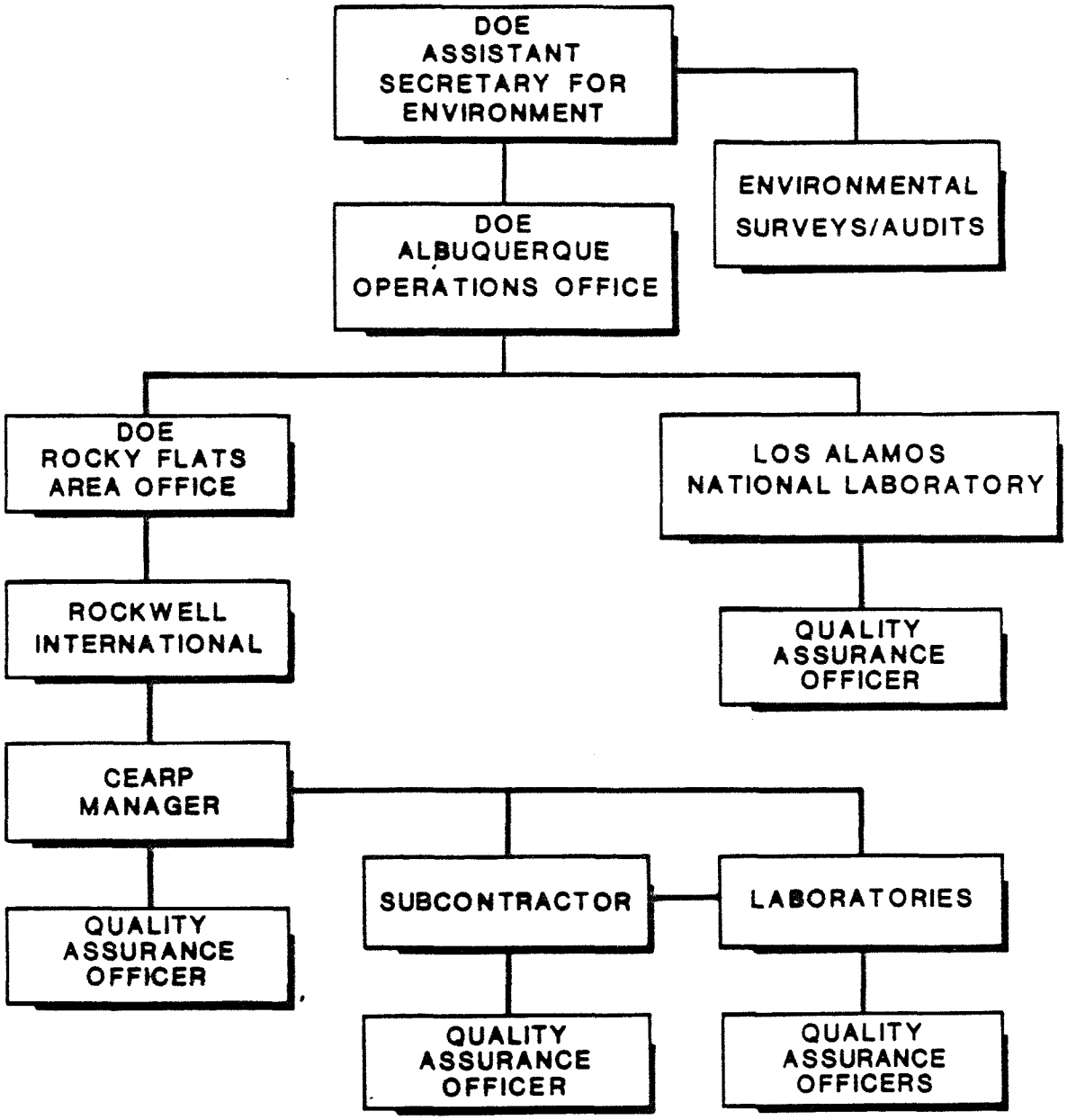

Figure 2.1. Quality Assurance/Quality Control Organization Chart.

3. QUALITY ASSURANCE OBJECTIVES FOR MEASUREMENT DATA

The overall quality assurance objective is to develop and implement procedures for field sampling, field testing, chain of custody, laboratory analysis, and reporting that will assure quality as specified in DOE orders governing quality assurance and environmental protection. Specific procedures to be used for sampling, chain-of-custody, audits, preventive maintenance, and corrective actions are described in other sections of this IGMP Quality Assurance/Quality Control Plan. The purpose of this section is to define quality assurance goals for accuracy; precision and sensitivity of analysis; and completeness, representativeness, and comparability of measurement data from all analytical laboratories. Quality assurance objectives for field measurements are also discussed.

For some field activities, samples will not be collected, but measurements will be taken where quality assurance concerns are appropriate (e.g., field measurements of pH, temperature, and elevations). The primary quality assurance objective in activities where samples are not collected is to obtain reproducible measurements to a degree of accuracy consistent with their intended use and to document measurement procedures.

3.1. REGULATORY AND LEGAL REQUIREMENTS

Data used to evaluate compliance with the National Interim Primary Drinking Water Standards, State of Colorado water-quality standards, or water-quality criteria for agricultural or industrial use will have method detection limits as specified by the analytical method used, as appropriate.

3.2. LEVEL OF QUALITY ASSURANCE EFFORT

Field duplicates, field blanks, and trip blanks will be taken and submitted to the analytical laboratories to provide a means to assess data quality resulting from field sampling. Duplicate samples will be analyzed to check for sampling reproducibility. Field and trip blanks will be analyzed to check for procedural contamination and/or ambient site conditions that are causing sample contamination. Trip blanks will be analyzed to check for contamination during packaging and shipment.

Because volatile organic compounds are a class of contaminants most likely to be introduced to the sample by the sample container, there will be one trip blank per batch of samples designated for volatile organic compound analysis (shipping container). There will be one duplicate and one field blank for every 10 investigative samples collected. For laboratory organic analysis, matrix spikes and matrix spike duplicates will be used. The general level of quality assurance effort for organic analysis will be one matrix spike and one matrix spike duplicate prepared for every 20 samples of similar concentration and/or similar sample matrix, whichever is greater. In addition to field check samples, water samples of known concentration traceable to either EPA or NBS standards will be prepared for inorganic and radiological analyses. The general level of quality assurance effort for inorganic analyses will be one duplicate known sample and one duplicate field sample for every 10 investigative samples to check analytical reproducibility.

Soil samples selected for geotechnical testing will include one field duplicate for each 20 analyses being performed, if possible, but will not include blanks.

The groundwater, surface water, and soil samples collected at Rocky Flats Plant during CEARP Phase 2 will be analyzed using the analytical methods specified in Tables 3.1, 3.2, 3.3, and 3.4. The level of laboratory quality assurance effort will correspond to the procedures outlined in Appendix A.

3.3. ACCURACY, PRECISION, AND SENSITIVITY OF ANALYSES

The fundamental quality assurance objective with respect to accuracy, precision, and sensitivity of laboratory analytical data is to achieve the quality control acceptance criteria of the analytical protocols. Sensitivities required for analyses of radionuclides, organics, metals, and other inorganic compounds, in both aqueous and solid matrices will be the detection limits shown in Tables 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6. Achieving these detection limits depends on the sample matrix. Highly contaminated samples requiring dilution will have detection limits higher than those detected.

The accuracy of field laboratory measurements of groundwater and surface water pH will be assessed through pre-measurement calibrations and post-measurement verifications using at least two standard buffer solutions. The two measurements must each be within +0.05 standard units of buffer solution values. Precision will be

assessed through replicate measurements of every tenth sample. The standard deviation of four replicate measurements must be less than or equal to 0.1 standard units. (The electrode will be withdrawn, deionized-rinsed and re-immersed between each replicate. The calibration and verification will be done before the first replicate and after the last replicate.) The instrument used will be capable of providing measurements to 0.01 standard units.

The geotechnical and field data will be considered accurate if the quality assurance criteria with respect to equipment, solutions, and calculations are met, and if adherence to appropriate methods can be documented during a systems audit.

3.4. COMPLETENESS, REPRESENTATIVENESS AND COMPARABILITY

The laboratories will provide data meeting quality control acceptance criteria as described in Appendix A. Laboratories will provide completely valid data (IGMP/CSPCP QA/QC Plan, Section 8); the reasons for any variances from 100 percent completeness will be documented in writing.

3.5. FIELD MEASUREMENTS

Measurement data will be generated in many field activities. These activities may include, but are not limited to, the following:

- using geophysical surveys
- documenting time and weather conditions
- locating and determining the elevation of sampling stations
- measuring pH, conductivity, and temperature of water samples
- qualitative organic vapor screening of solid samples using a photoionization detector (PID) or an organic vapor analyzer (OVA)
- measuring water levels in a borehole or well
- standard penetration testing
- calculating pumping rates
- verifying well-development and presampling purge volumes
- performing hydraulic conductivity tests

The general quality assurance objective for such measurement data is to obtain reproducible and comparable measurements to a degree of accuracy consistent with the intended use of the data through the documented use of standardized procedures. Procedures for performing these activities and standardized formats for documenting them are presented in the CGMP and IGMP/CSPCP Sampling Plans. These procedures may be incorporated by reference (EPA methods) or included as appendices. Standardized formats for documenting data collection are included in the Technical Data Management Plan.

Table 3.1. Analysis Plan for Aqueous Samples*

Analyte	Method	Detection Limit	Sample Container	Sample Volume	Preservations	Holding Time (days)	Reporting Units
HSL Volatile	Ref. 1	X[3]	40 ml vial (2) w/teflon lined silicone rubber septum	40 ml	Cold, 4^oC[9]	14	ug/L
HSL Base/Neutral/Acid[1]	Ref. 2	X[3]	Amber G, 1L	1 L	Cold, 4^oC[9]	7/40[7]	ug/L
HSL Pesticide/PCB	Ref. 3	X[3]	Amber G, 1L	1 L	Cold, 4^oC[9]	7/40	ug/L
HSL Inorganic[2]	EPA 200.7[8]	X[3]	P, G, 1L	1 L	pH<2, w/HNO_3[9]	180	ug/L
Cyanide	EPA 335[8]	X[3]	P, G, 1L	0.5 L	pH>11, w/NaOH[9]	14	ug/L
pH[4]	EPA 150.1[8]	0.1 pH unit	P, G	N/A	None	Field Meas.	pH unit
Sp. Conductivity[4]	EPA 120.1[8]	1	P, G	N/A	None	Field Meas.	umho/cm
Temperature [4]	EPA 170.1[8]	0.1	P, G	N/A	None	Field Meas.	$_oC$
Diss. Oxygen[4]	EPA 360.1[8]	0.5	G	N/A	None	Field Meas.	mg/l
TDS	EPA 160[8]	5	P, G 1L	0.1 L	Cold 4^oC[9]	7	mg/l
TSS	EPA 160[8]	10	P, G 1L	0.1 L	Cold 4^oC[9]	7	mg/l
Total Phosphate	EPA 365.4[8]	0.01	P, G 1L	1 L	Cold 4^oC, pH<2[9] w/H_2SO_4	28	mg/l

Table 3.1. (Continued)

Analyte	Method	Detection Limit	Sample Container	Sample Volume	Preservations	Holding Time (days)	Reporting Units
Chloride, Sulfate	EPA 352.2[8] 375.2[8]	5	P, G, 1L	1 L	Cold 4°C[9]	28	mg/l
Carbonate/Biocarbonate[5]	S.M. 403[6]	10	P, G, 1L	1 L	Cold 4°C[9]	14	mg/l
Nitrate	EPA 300.0[8]	5	P, G, 1L	1 L	Cold 4°C[9]	2	mg/l
Hexavalent Chromium	S.M. 312B[6]	0.01	P, G, 1L	1 L	Cold 4°C[9]	1	mg/l

[1]The HSL Base/Neutral/Acid fractions analytical parameters are the HSL semivolatites.
[2]Includes Cesium, Molybdenum, Strontium which are non-HSL metals.
[3]See Tables 3.5 and 3.6.
[4]Field Measurements.
[5]These are reported as carbonate and biocarbonate alkalinity.
[6]Standard Methods for Examination of Water and Wastewater, 15th Edition.
[7]7 days to extraction, analysis within 40 days of extraction.
[8]Methods for Chemical Analysis of Water and Wastes, 1983; EPA 600/4-79-020.
[9]All samples with the exception of VOA's will be filtered within 4 hours of sample collection, and preservatives added to the filtrate as specified. All samples will be kept at 4°C until delivered to the laboratory.
*The SSMP Sampling Plans will define the actual suite of parameters to be analyzed for specific samples.

Method References

Ref. 1. Method 624 - "Methods for Organic Chemical Analysis of Municipal and Industrial Waste Water," EPA 600/4-82-057 plus additions, 1984.

Ref. 2. Method 625 - "Methods for Organic Chemical Analysis of Municipal and Industrial Waste Water," EPA 600/4-82-057 plus additions, 1984.

Ref. 3. Method 608 - "Methods for Organic Chemical Analysis of Municipal and Industrial Waste Water," EPA 600/4-82-057 plus additions, 1984.

Table 3.2. Analysis Plan for Soil/Sediment/Waste Samples*

Analyte	Method	Detection Limit	Sample Container	Sample Volume	Preservations	Holding Time (days)	Reporting Units
HSL Volatile	Ref. 2	X[2]	40-ml vial (2) w/teflon lined silicon rubber septa	5	Cold, 4°C	14	ug/kg
HSL Base/Neutral/Acid	Ref. 3	X[2]	Amber G, 1 l	10-30	Cold, 4°C	7/40[3]	ug/kg
HSL Pesticide/PCB	Ref. 4	X[2]	Amber G, 1 L	10-30	Cold, 4°C	7/40[3]	ug/kg
HSL Inorganic[1]	Ref. 5	X[2]	P G, 1 L	200	Cold, 4°C	180	mg/kg
Reactivity	Ref. 6	Ref. 8	Amber G	---	Cold 4°C	N/A	ug/l
EP Toxicity	Ref. 7	Ref. 9	Amber G	100 g	Cold 4°C	N/A	ug/l in leachate
Chloride	EPA 300.0[5]	60 ug/g[6]	G, 1 L	20	Cold, 4°C	N/A	mg/kg
Sulfate	EPA 300.0[5]	60 ug/g[6]	G, 1 L	20	Cold, 4°C	N/A	mg/kg
Nitrate	EPA 300.0[5]	60 ug/g[6]	G, 1 L	20	Cold, 4°C	N/A	mg/kg
Cyanide	Ref. 1	X[2]	G, 1 L	200	Cold, 4°C	14	mg/kg
Hexavalent Chromium	S. M. 312B[7]	1 ug/g[6]	G, 1 L	100	Cold 4°C	1	mg/kg

[1] Includes Cesium, Molybdenum, and Strontium which are non-HSL metals.
[2] See Tables 3.5 and 3.6.
[3] Extract within 7 days, analysis within 40 days of extraction.
[4] Reported as dry weight, % moisture reported separately.
[5] Soil/Sediments will be leached with Laboratory Reagent Water (20 g soil to 50 ml water) and water extract analyzed using referenced procedure. Procedure reference: Methods for Chemical Analysis of Water and Wastes, 1983; EPA 600/4-79-020.

Table 3.2. (Continued)

[6]These are estimated detection limits.

[7]Soil/sediment will be leached with Laboratory Reagent Water (5 g soil and 100 ml of water) by shaking for 2 hours, and the water extract filtered and subsequently analyzed. This is in accordance with method 312B in Standard Methods for Examination of Water and Wastewater, 15th Edition.

*The SSMP Sampling Plans will define the actual suite of parameters to be analyzed for specific samples.

Method References

Ref. 1. Method 9010 - "Test Methods for Evaluating Solid Wastes," Office of Solid Waste and Emergency Response, Washington, DC 20460, Revised April 1984.

Ref. 2. Method 8240 - "Test Methods for Evaluating Solid Wastes," Office of Solid Waste and Emergency Response, Washington, DC 20460, Revised April 1984.

Ref. 3. Method 8270 - "Test Methods for Evaluating Solid Wastes," Office of Solid Waste and Emergency Response, Washington, DC 20460, Revised April 1984.

Ref. 4. Method 8080 - "Test Methods for Evaluating Solid Wastes," Office of Solid Waste and Emergency Response, Washington, DC 20460, Revised April 1984.

Ref. 5. Method 6010 or 7000 Series Methods - "Test Methods for Evaluating Solid Wastes," Office of Solid Waste and Emergency Response, Washington, DC 20460, Revised April 1984.

Ref. 6. Method 9010, 9030 - "Test Methods for Evaluating Solid Wastes," Office of Solid Waste and Emergency Response, Washington, DC 20460, Revised April 1984.

Ref. 7. Method 1310 - "Test Methods for Evaluating Solid Wastes," Office of Solid Waste and Emergency Response, Washington, DC 20460, Revised April 1984.

Table 3.3. Analysis Plan for Radiological Analysis for Aqueous Samples

Analyte	Method*	Detection Limit**	Sample Container	Sample Volume	Preservations	Holding Time (days)	Reporting Units
Gross alpha/beta	1,2,3,4,6,7, 8,9	Gross a = 2pCi/L	P, 1 gal	0.2 L	HNO_3 to pH <2	180	pCi/L
Tritium	1,2,3,8	400 pCi/L	G, 100 ml	0.008 L	No preservation	NA	pCi/L
Pu-239	10,11	0.3 pCi/L	P, 1 gal	1.000 L	HNO_3 to pH <2	180	pCi/L
Am-241	11,12	0.4 pCi/L	P, 1 gal	1.000 L	HNO_3 to pH <2	180	pCi/L
Isotopic U	1,3,4,7,8,9	U-233 + 234 = 0.6 pCi/L U-238 = 0.6 pCi/L	P, 1 gal	0.500 L	HNO_3 to pH <2	180	pCi/L
Sr-90	1,3,4,8	1 pCi/L	P, 1 gal	1.000 L	HNO_3 to pH <2	180	pCi/L

*See Attachment 1
**See Attachment 2

ATTACHMENT 1

Method References

1. U.S. Environmental Protection Agency, 1979, Radiochemical Analytical Procedures for Analysis of Environmental Samples, Report No. EMSL-LY-0539-1, Las Vegas, NV, U.S. Environmental Protection Agency.

2. American Public Health Association, American Water Works Association, Water Pollution Control Federation, 1985. Standard Methods for the Examination of Water and Wastewater, 16th ed., Washington, D.C., Am. Public Health Association.

3. U.S. Environmental Protection Agency, 1976. Interim Radiochemical Methodology for Drinking Water, Report No. EPA-600/4-75-008. Cincinnati U.S. Environmental Protection Agency.

4. Harley, J. H., ed., 1975, HASL Procedures Manual, HASL-300; Washington, D.C., U.S. Energy Research and Development Administration.

5. Misaqi, Fazlelleh L., Monitoring Radon-222 Content of Mine Waters Informational Report 1026, U.S. Department of Interior, Mining Enforcement and Safety Administration, Denver, CO, 1975.

6. "Radioassay Procedures for Environmental Samples," 1967, USDHEW, Section 7.2.3.

7. "Handbook of Analytical Procedures," USAEC, Grand Junction Lab. 1970, page 196.

8. "Prescribed Procedures for Measurement of Radioactivity in Drinking Water," EPA-600/4-80-032, Auguat 1980, Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

9. "Methods for Determination of Radioactive Substances in Water and Fluvial Sediments," U.S.G.S. Book 5, Chapter A5, 1977.

10. "Acid Dissolution Method for the Analysis of Plutonium in Soil," EPA-600/7-79-081, March 1979, U.S. EPA Environmental Monitoring and Support Laboratory, Las Vegas, Nevada, 1979.

11. "Procedures for the Isolation of Alpha Spectrometrically Pure Plutonium, Uranium and Americium," by E. H. Essington and B. J. Drennon, Los Alamos National Laboratory, a private communication.

12. "Isolation of Americium from Urine Samples," Rocky Flats Plant, Health, Safety, and Environmental Laboratories.

ATTACHMENT 2

Lower Limits of Detection

The detection limits presented were calculated using the formula in N.R.C. Regulatory Guide 4.14, Appendix Lower Limit of Detection, pg. 21, and follow:

$$LLD = \frac{4.66 \left(\frac{BKG}{DUR}\right)^{1/2}}{(2.22)\,(Eff)\,(CR)\,(SR)\,(e\text{-}xt)\,(Aliq)},$$

Where

LLD	=	Lower Limit of Detection in pCi per sample unit
BKG	=	Instrument Background in counts per minute (cpm)
DUR	=	Duration of sample counting in minutes
Eff	=	Counting efficiency in cpm/disintegration per minute (dpm)
CR	=	Fractional radiochemical yield
SR	=	Fractional radiochemical yield of a known solution
x	=	The radioactive decay constant for the particular radionuclide
t	=	the elapsed time between sample collection and counting.

In that LLD is a function of many variables including sample matrix, sample volume, and other factors, the limits presented are only intended as guides to order-of-magnitude sensitivities and, in practice, can easily change by a factor of two or more even for the conditions specified.

Table 3.4. Analysis Plan for Radiological Analysis for Soils/Sediments

Analyte	Method*	Detection Limit**	Sample Container	Sample Size (g)	Preservations	Holding Time (days)	Reporting Units
Gross alpha/beta	1,2,3,4,6,7, 8,9	Gross a = 4 pCi/g Gross b = 10 pCi/g	G, 1 L	0.1	NA	NA	pCi/g
Pu-239	10,11	0.3 pCi/g	G, 1 L	1	NA	NA	pCi/g
Am-241	11,12	0.3 pCi/g	G, 1 L	1	NA	NA	pCi/g
Isotopic U	1,3,4,7,8,9	U-233 + 234 = 0.3 pCi/g U-238 = 0.3 pCi/g	G, 1 L	1	NA	NA	pCi/g
Sr-90	1,3,4,8	1 pCi/g	G, 1 L	1	NA	NA	Pci/g

*See Attachment 1
**See Attachment 2

ATTACHMENT 1

Method References

1. U.S. Environmental Protection Agency, 1979, Radiochemical Analytical Procedures for Analysis of Environmental Samples, Report No. EMSL-LY-0539-1, Las Vegas, NV, U.S. Environmental Protection Agency.

2. American Public Health Association, American Water Works Association, Water Pollution Control Federation, 1985. Standard Methods for the Examination of Water and Wastewater, 16th ed., Washington, D.C., Am. Public Health Association.

3. U.S. Environmental Protection Agency, 1976. Interim Radiochemical Methodology for Drinking Water, Report No. EPA-600/4-75-008. Cincinnati U.S. Environmental Protection Agency.

4. Harley, J. H., ed., 1975, HASL Procedures Manual, HASL-300; Washington, D.C., U.S. Energy Research and Development Administration.

5. Misaqi, Fazlelleh L., Monitoring Radon-222 Content of Mine Waters Informational Report 1026, U.S. Department of Interior, Mining Enforcement and Safety Administration, Denver, CO, 1975.

6. "Radioassay Procedures for Environmental Samples," 1967, USDHEW, Section 7.2.3.

7. "Handbook of Analytical Procedures," USAEC, Grand Junction Lab. 1970, page 196.

8. "Prescribed Procedures for Measurement of Radioactivity in Drinking Water," EPA-600/4-80-032, Auguat 1980, Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

9. "Methods for Determination of Radioactive Substances in Water and Fluvial Sediments," U.S.G.S. Book 5, Chapter A5, 1977.

10. "Acid Dissolution Method for the Analysis of Plutonium in Soil," EPA-600/7-79-081, March 1979, U.S. EPA Environmental Monitoring and Support Laboratory, Las Vegas, Nevada, 1979.

11. "Procedures for the Isolation of Alpha Spectrometrically Pure Plutonium, Uranium and Americium," by E. H. Essington and B. J. Drennon, Los Alamos National Laboratory, a private communication.

12. "Isolation of Americium from Urine Samples," Rocky Flats Plant, Health, Safety, and Environmental Laboratories.

ATTACHMENT 2

Lower Limits of Detection

The detection limits presented were calculated using the formula in N.R.C. Regulatory Guide 4.14, Appendix Lower Limit of Detection, pg. 21, and follow:

$$LLD = \frac{4.66 \left(\frac{BKG}{DUR}\right)^{1/2}}{(2.22)\,(Eff)\,(CR)\,(SR)\,(e\text{-}xt)\,(Aliq)},$$

Where

LLD	=	Lower Limit of Detection in pCi per sample unit
BKG	=	Instrument Background in counts per minute (cpm)
DUR	=	Duration of sample counting in minutes
Eff	=	Counting efficiency in cpm/disintegration per minute (dpm)
CR	=	Fractional radiochemical yield
SR	=	Fractional radiochemical yield of a known solution
x	=	The radioactive decay constant for the particular radionuclide
t	=	the elapsed time between sample collection and counting.

In that LLD is a function of many variables including sample matrix, sample volume, and other factors, the limits presented are only intended as guides to order-of-magnitude sensitivities and, in practice, can easily change by a factor of two or more even for the conditions specified.

Table 3.5. Hazardous Substance List (HSL) and Contract Required Detection Limits (CRDL)**

Volatiles	CAS Number	Detection Limits* Low Water[a] ug/L	Low Soil/Sediment[b] ug/Kg
1. Chloromethane	74-87-3	10	10
2. Bromomethane	74-83-9	10	10
3. Vinyl Chloride	75-01-4	10	10
4. Chloroethane	75-00-3	10	10
5. Methylene Chloride	75-09-2	6	5
6. Acetone	67-64-1	10	10
7. Carbon Disulfide	75-15-01	5	5
8. 1,1-Dichloroethene	75-35-4	5	5
9. 1,1-Dichloroethane	75-35-3	5	5
10. trans-1,2-Dichloroethene	156-60-5	5	5
11. Chloroform	67-66-3	5	5
12. 1,2-Dichloroethane	107-06-2	5	5
13. 2-Butanone	78-93-3	10	10
14. 1,1,1-Trichloroethane	71-55-6	5	5
15. Carbon Tetrachloride	56-23-5	5	5
16. Vinyl Acetate	108-05-4	10	10
17. Bromodichloromethane	75-27-4	5	5
18. 1,1,2,2-Tetrachloroethane	79-34-5	5	5
19. 1,2-Dichloropropane	78-87-5	5	5
20. trans-1,3-Dichloropropene	100061-02-6	5	5
21. Trichloroethene	79-01-6	5	5
22. Dibromochloromethane	124-48-1	5	5
23. 1,1,2-Trichloroethane	79-00-5	5	5
24. Benzene	71-43-2	5	5
25. cis-1,3-Dichloropropene	10061-01-5	5	5
26. 2-Chloroethyl Vinyl Ether	110-75-8	10	10
27. Bromoform	75-25-2	5	5
28. 2-Hexanone	591-78-6	10	10
29. 4-Methyl-2-pentanone	108-10-1	10	10
30. Tetrachloroethene	127-18-4	5	5
31. Toluene	108-88-3	5	5
32. Chlorobenzene	108-90-7	5	5
33. Ethyl Benzene	100-41-4	5	5
34. Styrene	100-42-5	5	5
35. Total Xylenes	100-42-5	5	5

Table 3.5. (Continued)

Semi-Volatiles	CAS Number	Detection Limits* Low Water[c] ug/L	Low Soil/Sediment[d] ug/Kg
36. N-Nitrosodimethylamine	62-75-9	10	330
37. Phenol	108-95-2	10	330
38. Aniline	62-53-3	10	330
39. bis(2-Chloroethyl) ether	111-44-4	10	330
40. 2-Chlorophenol	95-57-8	10	330
41. 1,3-Dichlorobenzene	541-73-1	10	330
42. 1,4-Dichlorobenzene	106-46-7	10	330
43. Benzyl Alcohol	100-51-6	10	330
44. 1,2-Dichlorobenzene	95-50-1	10	330
45. 2-Methylphenol	95-48-7	10	330
46. bis(2-Chloroisopropyl ether	39638-32-9	10	330
47. 4-Methylphenol	106-44-5	10	330
48. N-Nitroso-Dipropylamine	621-64-7	10	330
49. Hexachloroethane	67-72-1	10	330
50. Nitrobenzene	98-95-3	10	330
51. Isophorone	78-59-1	10	330
52. 2-Nitrophenol	88-75-5	10	330
53. 2,4-Dimethylphenol	105-67-9	10	330
54. Benzoic Acid	65-85-0	50	1600
55. bis(2-Chloroethoxy) methane	111-91-1	10	330
56. 2,4-Dichlorophenol	120-83-2	10	330
57. 1,2,4-Trichlorobenzene	120-82-1	10	330
58. Naphthalene	91-20-1	10	330
59. 4-Chloroaniline	106-47-8	10	330
60. Hexachlorobutadiene	87-68-3	10	330
61. 4-Chloro-3-methylphenol (para-chloro-meta-cresol)	59-50-7	10	330
62. 2-Methylnaphthalene	91-57-6	10	330
63. Hexachlorocyclopentadiene	77-47-4	10	330
64. 2,4,6-Trichlorophenol	88-06-2	10	330
65. 2,4,5-Trichlorophenol	95-95-4	50	1600
66. 2-Chloronaphthalene	91-58-7	10	330
67. 2-Nitroaniline	88-74-4	50	1600
68. Dimethyl Phthalate	131-11-3	10	330
69. Acenaphthylene	208-96-8	10	330
70. 3-Nitroaniline	99-09-2	50	1600

Table 3.5. (Continued)

Semi-Volatiles	CAS Number	Detection Limits* Low Water[c] ug/L	Low Soil/Sediment[d] ug/Kg
71. Acenaphthene	83-32-9	10	330
72. 2,4-Dinitrophenol	51-28-5	50	1600
73. 4-Nitrophenol	100-02-7	50	1600
74. Dibenzofuran	132-64-9	10	330
75. 2,4-Dinitrotoluene	121-14-2	10	330
76. 2,6-Dinitrotuluene	606-20-2	10	330
77. Diethylphthalate	84-66-2	10	330
78. 4-Chlorophenyl Phenyl ether	7005-72-3	10	330
79. Fluorene	86-73-7	10	330
80. 4-Nitroaniline	100-01-6	50	1600
81. 4,6-Dinitro-2-methyl-phenol	534-52-1	50	1600
82. N-nitrosodiphenylamine	86-30-6	10	330
83. 4-Bromophenyl Phenyl ether	101-55-3	10	330
84. Hexachlorobenzene	118-74-1	10	330
85. Pentachloropphenol	87-86-5	50	1600
86. Phenanthrene	85-01-8	10	330
87. Anthracene	120-12-7	10	330
88. Di-n-butylphthalate	84-74-2	10	330
89. Fluoranthene	206-44-0	10	330
90. Benzidine	92-87-5	50	1600
91. Pyrene	129-00-0	10	330
92. Butyl Benzyl Phthalate	85-68-7	10	330
93. 3,3'-Dichlorobenzidine	91-94-1	20	660
94. Benzo(a)anthracene	56-55-3	10	330
95. bis(2-ethylhexyl) phthalate	117-81-7	10	330
96. Chrysene	218-01-9	10	330
97. Di-n-octyl Phthalate	117-84-0	10	330
98. Benzo(b)fluoranthene	205-99-2	10	330
99. Benzo(k)fluoranthene	207-08-9	10	330
100. Benzo(a)pyrene	50-32-8	10	330
101. Indeno(1,2,3-cd)pyrene	193-39-5	10	330
102. Dibenz(a,h)anthracene	53-70-3	10	330
103. Benzo(g,h,i)perylene	191-24-2	10	330

Table 3.5. (Continued)

Pesticides	CAS Number	Detection Limits* Low Water[e] ug/L	Low Soil/Sediment[f] ug/Kg
104. alpha-BHC	319-84-6	0.05	8.0
105. beta-BHC	319-85-7	0.05	8.0
106. delta-BHC	319-86-8	0.05	8.0
107. gamma-BHC (Lindane)	58-89-9	0.05	8.0
108. Heptachlor	76-44-8	0.05	8.0
109. Aldrin	309-00-2	0.05	8.0
110. Heptachlor Epoxide	1024-57-3	0.05	8.0
111. Endosulfan I	959-98-8	0.05	8.0
112. Dieldrin	60-57-1	0.10	16.0
113. 4,4'-DOE	72-55-9	0.10	16.0
114. Endrin	72-20-8	0.10	16.0
115. Endosulfan II	33213-65-9	0.10	16.0
116. 4,4'-DDD	72-54-8	0.10	16.0
117. Endrin Aldehyde	7421-93-4	0.10	16.0
118. Endosulfan Sulfate	1031-07-8	0.10	16.0
119. 4,4-'DDT	50-29-3	0.10	16.0
120. Endrin Ketone	53494-70-5	0.10	16.0
121. Methoxychlor	72-43-5	0.5	80.0
122. Chlordane	57-74-9	0.5	80.0
123. Toxaphene	8001-35-2	1.0	160.0
124. AROCLOR-1016	12674-11-2	0.5	80.0
125. AROCLOR-1221	11104-28-2	0.5	80.0
126. AROCLOR-1232	11141-16-5	0.5	80.0
127. AROCLOR-1242	53469-21-9	0.5	80.0
128. AROCLOR-1248	12672-29-6	0.5	80.0
129. AROCLOR-1254	11097-69-1	1.0	160.0
130. AROCLOR-1260	11096-82-5	1.0	160.0

[a]Medium Water Contract Required Detection Limits (CRDL) for Volatile HSL Compounds are 100 times the individual Low Water CRDL.
[b]Medium Soil/Sediment Contract Required Detection Limits (CRDL) for Volatile HSL Compounds are 100 times the individual Low Soil/Sediment CRDL.
[c]Medium Water Contract Required Detection Limits (CRDL) for Semi-Volatile HSL Compounds are 100 times the individual Low Water CRDL.
[d]Medium Soil/Sediment Contract Required Detection Limits (CRDL) for Semi-Volatile HSL Compounds are 60 times the individual Low Soil/Sediment CRDL.

Table 3.5. (Continued)

[e]Medium Water Contract Required Detection Limits (CRDL) for Pesticide HSL Compounds are 100 times the individual Low Water CRDL.
[f]Medium Soil/Sediment Contract Required Detection Limits (CRDL) for Pesticide HSL compounds are 60 times the individual Low Soil/Sediment CRDL.

*Detection limits listed for soil/sediment are based on wet weight. The detection limits calculated by the laboratory for soil/sediment, calculated on dry weight basis, as required by the contract, will be higher.
**These are the EPA detection limits under the Contract Laboratory Program. Specific detection limits are highly matrix dependent. The detection limits listed herein are provided for guidance and may not always be achievable.

Table 3.6. Elements Determined by Inductively Coupled Plasma Emission or Atomic Absorption Spectroscopy

Element	Contract Required Detection Level[1,2] (ug/L)
Aluminum	200
Antimony	60
Arsenic	10
Barium	200
Beryllium	5
Cadmium	5
Calcium	5000
Chromium	10
Cobalt	50
Copper	25
Iron	100
Lead	5
Magnesium	5000
Manganese	15
Mercury	0.2
Nickel	40
Potassium	5000
Selenium	5
Silver	10
Sodium	5000
Thallium	10
Vanadium	50
Zinc	20
Cesium	200
Molybdenum	40
Strontium	200
Cyanide	10

Note: Detection limits in soil/sediment are numerically equivalent to those listed above with concentration units of mg/kg.

[1]Higher detection levels may also be used in the following circumstances.

If the sample concentration exceeds two times the detection limit of the instrument or method in use, the value may be reported even though the instrument or method detection limit may not equal the contract required detection limit. This is illustrated in the example below:

Table 3.6. (Continued)

For lead:

Method in use - ICP
Instrument Detection Limit (IDL) = 40
Sample Concentration = 85
Contract Required Detection Limit (CRDL) = 5

The value of 85 may be reported even though instrument detection limit is greater than required detection level. The instrument or method detection limit must be documented.

[2]These CRDL are the instrument detection limits obtained in pure water. met using the procedure in Exhibit E. The detection limits for samples may be considerably higher depending on the sample matrix.

6. CALIBRATION PROCEDURES AND FREQUENCY

Standard commercial calibration procedures will be used by the analytical laboratories, as specified in Appendix A.

Calibration of equipment used to perform geotechnical testing will be in accordance with that specified in the ASTM Method D 422-63 for hydrometer and sieve analyses (Annual Book of ASTM Standards, Volume 04.08, 1984). The equipment calibrations, including those for ovens, thermometers and balances, shall be done at a minimum of every six months and prior to large scale testing.

Field instruments will be calibrated according to procedures presented in Appendixes A and B of the IGMP/CSPCP Sampling Plan. A calibration log book will be assigned to each field instrument, and all calibrations will be documented in the log books.

8. DATA REDUCTION, VALIDATION, AND REPORTING

Analytical laboratories will provide results to the Rockwell International CEARP Manager, the Subcontractor Project Manager, and Quality Assurance Officers. These data will include results and documentation for blanks and duplicates, matrix spikes, and forms summarizing analytical precision and accuracy.

Analytical data, including quality control sample analysis, will be entered into the technical data base. The analyses will be grouped into lots, with quality control samples associated with a particular lot. The analyses of quality control samples will be compared to theoretical known concentrations of those samples. If analyses do not meet acceptance criteria, the analytical laboratory may be asked to re-analyze the samples for parameters which do not exceed holding times. Analyses which cannot meet acceptance criteria, will be labelled as unacceptable. All parameter-specific values for a lot in which the quality control analyses did not meet acceptance criteria, will be removed from the technical data base.

Acceptance criteria for analyses of parameters for quality control samples (knowns) will be based on the theoretical known value furnished by the laboratory that prepared the sample. The theoretical known value is stated as a range of values. The analysis of the sample must be within the stated range of the theoretical known, plus or minus 10% of the range. An exception is analyses at or near the limit of detection. If the lower limit of the range of the theoretical known value is less than twice the limit of detection, an acceptable analysis includes the range from the limit of detection to the upper limit of the theoretical range, plus 10%.

Analytical reports from a field laboratory, if used, and the geotechnical laboratory will include all raw data, documentation of reduction methods, and related quality assurance/quality control data. These data will be assessed by verification of reduction results and confirmation of compliance with quality assurance/quality control requirements.

Raw data from field measurements and sample collection activities used in project reports will be appropriately identified. Where data have been reduced or summarized, the method of reduction will be documented.

The Quality Assurance Officers will review results of Quality Control-acceptance evaluations and will document acceptance or non-acceptance of data. The Quality Assurance Officers will maintain records of quality control-acceptance tests. These records will be subject to independent audit, which may include Los Alamos National Laboratory.

9. INTERNAL QUALITY CONTROL PROCEDURES

Internal quality control procedures for the laboratory are those specified in Appendix A. These specifications include types of audits required (e.g., sample spikes, surrogate spikes, reference samples, controls, and blanks), frequency of audits, compounds to be used for sample spikes and surrogate spikes, and quality control acceptance criteria for audits.

The quality control checks and acceptance for data from a field laboratory, if used, and the geotechnical laboratory are described above in Sections 3.2 and 3.3. Quality control procedures for field measurements (pH, conductivity, and temperature) are limited to checking the reproducibility of the measurement in the field by obtaining multiple readings and/or by calibrating the instruments (where appropriate). Quality control of field sampling will involve collecting field duplicates and blanks.

10. PERFORMANCE AND SYSTEMS AUDITS

For each activity where samples are collected, a performance audit investigating conformance with quality control procedures will be conducted (Appendix A) at the discretion of the Rockwell International CEARP manager, Subcontractor Project Manager, and Quality Assurance Officers. This audit will be scheduled to allow oversight of as many different field activities as possible. This audit will be performed by the Quality Assurance Officers or their designees. A written report of the results of this audit, along with a notice of nonconformity (if necessary), will be submitted to the following individuals:

- Rockwell International CEARP Manager
- Subcontractor Project Manager
- Subcontractor Site Manager

At least one systems audit will be performed during the project. The audit will verify that a system of quality control measures, procedures, reviews, and approvals was established for all activities and is being used by project personnel. It will also verify that the system for project documentation is being used and that all quality control records, along with required quality control reviews, approvals, and activity records are being maintained. A standard checklist for systems audits will be used. The systems audit will be conducted by the Quality Assurance Officers and/or Los Alamos National Laboratory. A final report will be prepared which summarizes any deviations from approved methods and their impacts on the project results.

After consultation with the CEARP Manager (and Subcontractor Project Manager), the Quality Assurance Officers may schedule systems audits of the participating laboratories. At a minimum, the systems audit would include inspection of laboratory notebooks, control sheets, logsheets, computer files, and equipment calibration and maintenance records. If scheduled, system audits will be executed by individuals identified in Section 2.3 of this document.

Performance and systems audits of analytical laboratories will be scheduled and executed by the laboratory Quality Assurance Officers. Performance audits are conducted at least semiannually.

11. PREVENTIVE MAINTENANCE

This section applies solely to field equipment. Preventive maintenance will be addressed by checks of equipment prior to initiation of field operations, to allow time for replacement of malfunctioning equipment. The Subcontractor Site Manager will be responsible for implementing and documenting these procedures on a weekly basis during the period of use.

12. LABORATORY DATA ASSESSMENT PROCEDURES

Analytical data from laboratories is assessed for accuracy, precision and completeness by the laboratory Quality Assurance Officers, using standard procedures.

Assessment of data generated by analytical laboratories is initiated and continued at three administrative levels. The bench chemist directly responsible for the test knows current operating acceptance limits. He/she can directly accept or reject generated data and consult with his/her immediate supervisor for any corrective action. Once the bench chemist has reported the data as acceptable, he/she initials the report sheet. Any out-of-control results are flagged and a note is made as to why the results were reported.

The chief chemist receives the data sheets and reviews the quality control data that accompanied the sample run. After checking the reported data for completeness and quality control results, the chief chemist either initials the report sheet or sends it back to the bench chemist for rerunning of samples. The Quality Control Coordinator reviews data forwarded to him/her as acceptable by the chief chemist. Any remaining out-of-control results that, in the opinion of the Quality Control Coordinator, do not necessitate rerunning of the sample, are flagged, and a memo is written to the data user regarding utility of the data. Data generated from all analyses are given a final review by the laboratory Quality Assurance Officers.

13. CORRECTIVE ACTION PROCEDURES

The Quality Assurance Officers and their audit teams will prepare a report describing the results of the performance and/or system audits. If unacceptable conditions (e.g., failure to have/use procedures), unacceptable data, nonconformity with the quality control procedures, or a deficiency are identified, the Quality Assurance Officers will notify the Rockwell International CEARP Manager of the results of the audit in writing. They will also state if the nonconformity is of significance for the program and recommend appropriate corrective actions. The Rockwell International CEARP Manager will be responsible for ensuring that correcitve is developed and initiated and that, if necessary, special expertise not normally available to the project team is made available. The subcontractor will be responsible for carrying out corrective actions. The subcontractor will also ensure that additional work is not performed until the nonconformity is corrected. Corrective action may include

- reanalyzing the samples if holding time permits,
- resampling and reanalyzing,
- evaluating and amending the sampling and analytical procedures, and
- accepting the data and acknowledging its level of uncertainty.

The Rockwell International CEARP Manager will be responsible for ensuring that corrective action was taken, and that it adequately addressed the nonconformity.

After corrective action is taken, the Quality Assurance Officer responsible for the audit will document its completion in a written report. The report will indicate any identified findings, corrective action taken, follow-up action, and final recommendations. The report will be sent to the Rockwell International CEARP Manager. Project staff will be responsible for initiating reports on suspected nonconformities in field activities and deliverables or documents.

14. QUALITY ASSURANCE REPORTS

The Rockwell International CEARP Manager will rely on written reports/memoranda documenting data assessment activities, performance and systems audits, nonconformity notices, corrective action reports, and quality assurance notices to enforce quality assurance requirements. The Los Alamos National Laboratory will be issued a written quality assurance report at the end of each stage of site characterization (remedial investigation) by the Rockwell International CEARP Manager.

Records will be maintained to provide evidence of quality assurance activities. Proper maintenance of quality assurance records is essential to provide support for evidential proceedings and to assure overall quality of the investigation. A quality assurance records index will be started at the beginning of the project. All information received from outside sources or developed during the project will be retained by the project team. Upon termination of an individual task or work assignment, working files will be processed for storage as quality assurance records. Upon termination of the project, complete documentation records (for example, chromatograms, spectra, and calibration records) will be archived as required by DOE Order 1324.2A (Records Deposition). The Rockwell International CEARP Manager and the Los Alamos National Laboratory CEARP Rocky Flats Plant Team Leader will be responsible for ensuring that the Quality Assurance records are being properly stored and that they can be retrieved.

1. LABORATORY QA/QC PROGRAM

This appendix to the quality assurance/quality control plan describes the organization and procedures used to produce reliable analytical data. These procedures are applicable to performing chemical, radiological, and geotechnical analyses on waste or environmental samples as appropriate.

The ultimate responsibility for the generation of reliable laboratory data rests with the laboratory management. Laboratory management is vested with the authority to establish those policies and procedures to ensure that only data of the highest attainable caliber are produced. Laboratory management, as well as the laboratory Quality Assurance/Quality Control Officer are responsible for the implementation of the established policies and procedures.

Laboratory management has the following responsibilities:

- direct implementation of the quality assurance program,
- ensure that their personnel are adequately trained to perform analyses,
- ensure that equipment and instrumentation under their control are calibrated and functioning properly, and
- review and perform subsequent corrective action on internal and external audits.

The Quality Assurance/Quality Control Officer has the following responsibilities:

- on-going review of individual quality assurance procedures,
- providing assistance in the development and implementation of specific quality assurance plans for special analytical programs,
- coordination of internal and external quality assurance audits,
- coordination of quality assurance training,
- review of special project plans for consistency with organizational requirements and advising laboratory management of inconsistencies, and
- overall coordination of the laboratories' quality assurance program manual.

1.2. SAMPLE MANAGEMENT

On notification of the sampling and analyses effort, the laboratory will create a file to maintain records associated with the activity. In addition to administrative information, requests for sample containers, preservatives, and required analyses will be included in the file.

Sample bottles will be prepared by the laboratory and made available to the sampling team. The bottles will be prepared according to the analysis plan procedures and will include sample preservatives appropriate to the analytes and matrices of concern. Addition of preservatives to sample shall be recorded on chain-of-custody forms.

Samples received at the laboratories will be inspected for integrity, and any field documentation will be reviewed for accuracy and completeness.

Chain-of-custody and sample integrity problems will be noted and recorded on the chain-of-custody forms during sample log-in. Chain-of-custody forms and deficiency notices will be maintained in the file. Any deficiencies will be brought to the attention of the Rockwell International CEARP Manager who will advise the laboratory on the desired disposition of the samples.

Each sample that is received by the laboratory will be assigned a unique sequential sample number which will identify the sample in the laboratory's internal tracking system. References to a sample in any communication will include the assigned sample number.

Samples will be stored in a locked refrigerator at $4^{o}C$. The temperature of the storage refrigerators will be monitored and recorded daily by the sample custodian. Sample fractions and extracts will also be stored under these same conditions.

1.3. ANALYTICAL SYSTEMS

1.3.1. Instrument Maintenance

Instruments will be maintained in accordance with manufacturers' specifications. More frequent maintenance may be dictated dependent on operational performance. Instrument logs will be maintained to document the date, type, and reason for any maintenance performed.

Contracts on major instruments with manufacturers and service agencies may be used to provide routine preventive maintenance and to ensure rapid response to emergency repair service.

1.3.2. Instrument Calibration

Before any instrument is used, it will be calibrated using known reference materials. All sample measurements will be made within the calibrated range of the instrument. A record of calibration will be kept in an equipment log.

1.3.3. Personnel Training

Prior to conducting analyses on an independent basis, analysts will be trained by experienced personnel in the complete performance of the analytical method. Analysts may require training at instrument manufacturers' training courses. The analyst will be required to independently generate data on several method and/or matrix spikes to demonstrate proficiency in that analytical method. The type of data to be generated will be dependent on the analytical method to be performed. Results of this "certification" will be reviewed by laboratory management for adequacy.

Method blanks and method spikes will be required in every lot of samples analyzed, thus performance on a day-to-day basis can be monitored. Laboratory management and the Laboratory Quality Assurance/Quality Control Officer are responsible for ensuring that samples are analyzed by only competent analysts.

1.4. ANALYTICAL METHODS

1.4.1. Gas Chromatography/Mass Spectroscopy

Mass spectrometers will be tuned on a daily basis to manufacturer's specifications with FC-43. In addition, once per shift (8 hours) these instruments will be tuned with decafluorotriphenylphosphine (DFTPP) or 4-bromo-fluorobenzene (BFB) for semi-volatiles or volatiles, respectively. Ion abundance will be within the window dictated by the requirements of the specific protocols. Once an instrument has been tuned, initial calibration curves for analytes (appropriate to the analyses to be performed) will be generated for at least three solutions containing known concentrations of authentic standards of compounds of concern.

The calibration curve will bracket the anticipated working range of analyses.

Calibration data, to include the correlation coefficient, will be entered into laboratory notebooks to maintain a permanent record of instrument calibrations.

During each operating shift, a midpoint calibration standard will be analyzed to verify that the instrument responses are still within the initial calibration determinations. The calibration check compounds will be those analytes used in the EPA contract laboratory program's multicomponent analyses (e.g., priority pollutants and hazardous substances list) with the exception that benzene will be used in place of vinyl chloride (volatiles) and di-n-octyl phthalate will be deleted from the semi-volatile list.

The response factor drift will be calculated and recorded. If significant (>30%) response factor drift is observed, appropriate corrective action will be taken to restore confidence in the instrumental measurements.

All GC/MS analyses will include analyses of a method blank, a method spike, and a method spike duplicate in each lot of samples. In addition, appropriate surrogate compounds specified in EPA methods will spiked into each sample. Recoveries from method spikes and surrogate compounds will be calculated and recorded on control charts to maintain a history of system performance.

Duplicate samples will be analyzed for analytical lots of twenty (20) or more samples.

Audit samples will be analyzed periodically to compare and verify laboratory performance against standards prepared by outside sources.

1.4.2. Gas Chromatography and High Performance Liquid Chromatography

Gas chromatographs and high performance liquid chromatographs will be calibrated prior to each day of use. Calibration standard mixtures will be prepared from appropriate reference materials and will contain analytes appropriate for the method of analysis.

Working calibration standards will be prepared fresh daily. The working standards will include a blank and a minimum of three concentrations to cover the anticipated range of measurement. At least one of the calibration standards will be at or below the desired instrument detection limit. The correlation coefficient of the plot of "known" versus "found" concentrations must be at least 0.996 in order to consider the responses linear over a range. If a correlation coefficient of 0.996 cannot be obtained, additional standards must be analyzed to define the calibration curve. A midpoint calibration check standard will be analyzed each operating shift (8 hours) to confirm the validity of the initial calibration curve. The check standard must be within twenty (20) percent of the initial response curve to demonstrate that the initial calibration curve is still valid.

Calibration data, to include the correlation coefficient, will be entered into laboratory notebooks to maintain a permanent record of instrument calibrations.

At least one method blank and two method spikes will be included in each laboratory lot of samples. Regardless of the matrix being processed, the method spikes and blanks will be in aqueous media. Method spikes will be at a concentration of approximately five (5) times the detection limit.

The method blanks will be examined to determined if contamination is being introduced in the laboratory. The method spikes will be examined to determine both precision and accuracy.

Accuracy will be measured by the percent recovery of the spikes; precision will be measured by the reproducibility of method spikes.

1.4.3. Atomic Absorption Spectrophotometry

Atomic absorption spectrophotometers will be calibrated prior to each day of use.

Calibration standards will be prepared from appropriate reference materials, and working calibration standards will be prepared fresh weekly. The working standards will include a blank and a minimum of five concentrations to cover the anticipated range of measurement.

Duplicate injections will be made for each concentration. At least one of the calibration standards will be at or below the desired instrument detection limit. The correlation coefficient of the plot of "known" versus "found" concentrations will be at least 0.996 in order to consider the responses linear over a range. If a correlation coefficient of 0.996 cannot be achieved, the instrument will be recalibrated prior to analysis of samples. Calibration data, to include the correlation coefficient, will be entered into laboratory notebooks to maintain a permanent record of instrument calibrations.

At least one method blank and two method spikes will be included in each laboratory lot of samples. Regardless of the matrix being processed, the method spikes and blanks will be in aqueous media. Method spikes will be at a concentration of approximately five (5) times the detection limit.

The method blanks will be examined to determine if contamination is being introduced in the laboratory and will be introduced at a frequency of one per analytical lot or five (5) percent of the samples, whichever is more. The method spikes will be examined to determine both precision and accuracy. Accuracy will be measured by the percent recovery of the spikes. The recovery must be within the range of 75-125 percent to be considered acceptable.

Precision will be measured by the reproducibility of both method spikes. Results must agree within twenty (20) percent in order to be considered acceptable.

1.4.4. Spectrophotometric Methods

Spectrophotometers will be calibrated prior to each day of use. Calibration standards will be prepared from reference materials appropriate to the analyses being performed, and working standards will include a blank and a minimum of five (5) concentrations to cover the anticipated range of measurement. At least one of the calibration standards will be at or below the desired instrument detection limit. The correlation coefficient of the plot of "known" versus "found" concentration will be at least 0.996 in order to consider the responses linear over a range. If a correlation coefficient of 0.996 cannot be achieved, the instrument will be recalibrated prior to the analysis of samples.

Calibration data, to include the correlation coefficient, will be entered into laboratory notebooks to maintain a permanent record of instrument calibrations.

At least one method blank and two method spikes will be included in each laboratory lot of samples. Regardless of the matrix being processed, the method spikes will be at a concentration of approximately five (5) times the detection limit.

The method blanks will be examined to determine if contamination is being introduced in the laboratory.

Accuracy will be measured by the percent recovery of the spikes. The recovery must be in an acceptable range (based on EPA data for the method of interest) in order to be considered acceptable. Precision will be measured by the reproducibility of both method spikes.

Results must agree within acceptable limits (based on EPA data) in order to be considered acceptable.

1.5. REFERENCE MATERIALS

Whenever possible, primary reference materials will obtained from the National Bureau of Standards (NBS) or the U.S. Environmental Protection Agency (EPA). In absence of available reference materials from these organizations, other reliable sources may be sought. Reference materials will be used for instrument calibrations, quality control spikes, and/or performance evaluations. Secondary reference material

may be used for these functions provided that they are traceable to an NBS standard or have been to an NBS standard within the laboratory.

1.6. REAGENTS

Laboratory reagents will be of a quality to minimize or eliminate background concentrations of the analyte to be measured. Reagents must also not contain other contaminants that will interfere with the analyte of concern.

1.7. CORRECTIVE ACTIONS

When an analytical system is deemed to be questionable or out-of-control at any level of review, corrective action will be taken. If possible, the cause of the out-of-control situation will be determined, and efforts will be made to bring the system back into control. Demonstration of the restoration of a reliable analytical system will normally be accomplished by generating satisfactory calibration and/or quality control sample data. The major consideration in performing corrective action will be to ensure that only reliable data are reported from the laboratory. The Rockwell International CEARP Manager will be informed of the problem and all corrective actions taken.

1.8. DATA MANAGEMENT

1.8.1. Data Collection

All data will be recorded in laboratory notebooks. Laboratory notebooks will contain:

- Date and time of processing
- Sample numbers
- Project
- Analyses or operation performed
- Calibration data
- Quality control samples included
- Concentrations/dilutions required
- Instrument readings
- Special observations
- Analyst's signature.

Copies of laboratory notebooks will be provided to the Rockwell International CEARP Manager on request.

1.8.2. Data Reduction

Data reduction will be performed by the individual analysts. The complexity of the data reduction will be dependent on the specific analytical method and the number of discrete operations (extractions, dilutions, and concentrations) involved.

For those methods utilizing a calibration curve, sample responses will be applied to the linear regression line to obtain an initial raw result which will be factored into equations to obtain the estimate of the concentration in the original sample. Rounding will not be performed until after the final result is obtained, to minimize rounding errors, and results will not normally be expressed in more than two (2) significant figures.

Copies of all raw data and the calculations used to generate the final results will be retained in the laboratory file to allow reconstruction of the data reduction process at a later date. Copies of these records will be provided to the Rockwell International CEARP Manager on request.

1.8.3. Data Review

System reviews will be performed at all levels. The individual analyst will review the quality of data through calibration checks, quality control sample results, and performance evaluation samples. These reviews will be performed prior to submission of data to the laboratory management.

Laboratory management will review data for consistency and validity to determine if program requirements have been satisfied. Selected hard copy output of data (chromatograms, spectra, etc.) will be reviewed to ensure that results are interpreted correctly. Unusual or unexpected results will be reviewed, and a resolution will be made as to whether the analysis should be repeated. In addition, laboratory management, will recalculate selected results to verify the calculation procedure. Any abnormalities will be brought to the attention of the Rockwell International CEARP Manager.

The Quality Assurance Officer will independently conduct a complete review of results from randomly selected samples to determine if laboratory and program quality assurance/quality control requirements have been met. Deviations from requirements will be reported to the laboratory management and Rockwell International CEARP Manager for resolution.

Non-routine audits may be performed.

1.8.4. Data Reporting

Reports will contain final results (uncorrected for blanks and recoveries), methods of analysis, levels of detection, surrogate recovery data, and method blanks data. In addition, special analytical problems, and/or any modifications of referenced methods will be noted. The number of significant figures reported will be consistent with the limits of uncertainty inherent in the analytical method. Consequently, most analytical results will be reported to no more than two (2) significant figures.

Data will be reported in units commonly used for the analyses performed. Concentrations in liquids will be expressed in terms of weight per unit volume (e.g., milligrams per liter). Concentrations in solid or semi-solid matrices will be expressed in terms of weight per unit weight of sample (e.g., micrograms per grams).

Reported detection limits will be those specified by the analytical method.

1.8.5. Data Archiving

The laboratory will maintain on file all of the raw data (including calibration data), laboratory notebooks, and other pertinent documentation. This file will be maintained at the laboratory for a period of time consistent with Rocky Flats Plant's requirements. At the end of that time frame, all these records will be given to Rocky Flats Plant.

2. PERFORMANCE AND SYSTEM AUDITS

Quality assurance audits will be conducted. System audits will be conducted at random, unscheduled intervals at least annually.

Audits will be planned, organized, and clearly defined before they are initiated. Auditors will identify nonconformances or deficiencies. These will be reported and documented so that corrective actions can be initiated through appropriate channels. Corrective actions will be followed up with a compliance review. A report on each audit will be sent to the Rockwell International CEARP Manager.

2.1. FIELD AUDITS

Unannounced field audits, investigating conformance with QA/QC procedures, will be performed. A typical checklist for this type of audit is shown in Table A-1. A written report on the results of this audit will be submitted to the Rockwell International CEARP Manager.

2.2. CORRECTIVE ACTION

After each audit, auditors will identify nonconformances in a written nonconformance notice and initiate corrective action through the Rockwell International CEARP Manager. The nonconformance notice will describe any nonconforming conditions and set a date for response and corrective action(s). The Subcontractor Project Manager will prepare a written proposal for corrective action for review and approval by the Rockwell International CEARP Manager. When approved, the proposed corrective action(s) will be implemented. Follow-up review will be performed by the auditor to confirm that the corrective actions have been implemented.

Table A.1. Field Audit

Project_____ Site Manager_____

Site Location_____ Field Team Leader_____

Auditor_____ Date_____

Audit Question	Yes	No	Comment/Documentation
1. Was a site-specific sampling and analytical plan followed?			
2. Was a field team leader appointed?			
3. Was the site health and safety coordinator present?			
4. Were field team members familiar with the sampling plan?			
5. Was a briefing held offsite, before any site work was begun, to acquaint personnel with sampling equipment and assign field responsibilities?			
6. Was the daily briefing and safety check conducted?			
7. Was a completed "Site Personnel Protection and Safety Evaluation Form" read and signed by all visitors and personnel entering the site?			
8. Was a field notebook assigned to the field team leader?			
9. Were entries made in the field notebook?			
10. Were sampling stations located correctly?			
11. Did the number and location of samples collected follow the site-specific sampling plan?			

Table A.1. (Continued)

Project_____ Site Manager_____

Site Location_____ Field Team Leader_____

Auditor_____ Date_____

Audit Question	Yes	No	Comment/Documentation
12. Were samples identified as described in the site-specific sampling plan?			
13. Were samples collected following procedures specified in the site-specific plan?			
14. Was a chain-of-custody form filled out for all samples collected? Were all sample transfers documented?			
15. Were samples preserved as specified in the site-specific sampling plan?			
16. Were the number, frequency, and type of samples (including blanks and duplicates) collected as described in the site-specific sampling plan?			
17. Were the number, frequency, and type of measurements and observations taken as specified in the site-specific sampling plan?			
18. Were blank and duplicate samples properly identified?			
19. Was a record maintained of calibration of field equipment?			
20. Was field equipment calibrated as required?			

Table A.1. (Continued)

Project_____ Site Manager_____

Site Location_____ Field Team Leader_____

Auditor_____ Date_____

Audit Question	Yes	No	Comment/Documentation
21. Have any procedures been revised?			
22. Are revisions to procedures adequately documented?			
23. Was the document log for chain-of-custody records and other sample traffic control forms maintained?			
24. Have any accountable documents been lost?			
25. Did drilling and well construction follow procedures outlined in the sampling plan?			
26. Were the activities being conducted compatible with the environmental conditions?			

DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
ENVIRONMENT, SAFETY AND HEALTH DIVISION
ENVIRONMENTAL PROGRAMS BRANCH

COMPREHENSIVE ENVIRONMENTAL ASSESSMENT AND RESPONSE PROGRAM

PHASE 2:
ROCKY FLATS PLANT
INSTALLATION GENERIC MONITORING PLAN
(Comprehensive Source and Plume Characterization Plan)

FEASIBILITY STUDY PLAN

February 1987

DRAFT

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1. INTRODUCTION

CEARP Phase 2 Confirmation consists of CEARP Phase 2a, Monitoring Plan, and CEARP Phase 2b, Site Characterization (Remedial Investigation). The Monitoring Plan typically consists of five parts: Synopsis, Sampling Plan, Technical Data Management Plan, Health and Safety Plan, and Quality Assurance/Quality Control Plan. Because of the Compliance Agreement by the State of Colorado, Environmental Protection Agency, and Department of Energy (DOE), this Monitoring Plan also includes a Feasibility Study Plan. This Feasibility Study Plan is tiered to the CEARP Phase 3 Technological Assessment Plan, Appendix A, that was released to the public in draft form in August 1986.

CEARP uses a three-tiered approach in the preparation of monitoring plans: the CEARP Generic Monitoring Plan (CGMP), the Installation Generic Monitoring Plan (IGMP), and the Site-Specific Monitoring Plans (SSMPs). This IGMP is the Comprehensive Source and Plume Characterization Plan required by the Compliance Agreement. Therefore, the acronym used to refer to this monitoring plan is IGMP/CSPCP.

Because CEARP is the program by which DOE-Albuquerque Operations Office is addressing both CERCLA and RCRA continuing release sites at its installations, CEARP terminology will be used in preparing the CEARP Phase 3 Technological Assessment reports following the guidance provided in this Feasibility Study Plan. This will provide uniformity within the DOE-Albuquerque Operations Office environmental compliance program and allow one document to serve both CERCLA and RCRA continuing release requirements including additional provisions of the Superfund Amendments and Reauthorization Act of 1986 (SARA) as appropriate.

This document provides a work plan for conducting CEARP Phase 3 technological assessments (feasibility studies) at Rocky Flats Plant. In addition, it contains a plan (Appendix B) for performing risk/endangerment assessments as required by the Compliance Agreement. This Risk/Endangerment Assessment Plan addresses both public health and environmental concerns, following guidance provided in the CEARP Phase 3 Technological Assessment Plan (Appendix A), which incorporates portions of EPA's *Handbook: Remedial Action at Waste Disposal Sites* (EPA 1985b).

CEARP Phase 1 identified approximately 70 sites or groupings of sites that could have potentially adverse impacts on the environment (DOE 1986b). Additional data were collected during preparation of the RCRA Part B Operating Permit Application that identified several additional potential sites (DOE 1986f). Appendix 1 of the RCRA Part B Operating Permit Application contains a preliminary list of hazardous and radioactive mixed waste units, identified solid waste management units, and CERCLA areas as required by the Compliance Agreement. All of these units or areas were assigned a solid waste management unit identification number to assist with future planning. The Compliance Agreement stipulates that CEARP Phase 3 technological assessments (feasibility studies) will be prepared as appropriate. This will be done; however, some solid waste management units are being closed under RCRA. The CEARP Phase 3 technological assessments (feasibility studies) for these solid waste management units will be limited to the provisions of the RCRA Post Closure Care Permit Application (DOE 1986g).

As stated in the CEARP Phase 3 Technological Assessment Plan (Appendix A), CEARP Phase 2b site characterizations (remedial investigations) and CEARP Phase 3 technological assessments (feasibility studies) are interdependent. Activities making up these two phases will be performed concurrently to the greatest extent possible. CEARP Phase 2b site characterizations (remedial investigations) will provide the data base for performing CEARP Phase 3 technological assessments (feasibility studies). During CEARP Phase 3, alternative remedial actions will be developed and evaluated in terms of cost, feasibility of proposed engineering, extent of protection to public health and the environment, and environmental impacts during or remaining after implementation.

The EPA has provided guidelines for preparing CEARP Phase 3 technological assessments (feasibility studies) in *Guidance on Feasibility Studies Under CERCLA* (EPA 1985a), which are incorporated in the CEARP Phase 3 Technological Assessment Plan (Appendix A), as appropriate. The guidelines for detailed evaluations of alternatives and selection of recommended actions are intended for sites that fall under CERCLA feasibility study requirements. Similar evaluations will be implemented on a site-by-site basis for CEARP sites at Rocky Flats Plant not meeting CERCLA feasibility study requirements, e.g., inactive waste areas that do not meet the threshold for being listed on the National Priorities List (NPL) and RCRA solid waste management

units. Solid waste management units evaluated under CEARP Phase 3 technological assessments (feasibility studies) must also meet appropriate requirements under RCRA, including the 1984 RCRA Hazardous and Solid Waste Amendments (HSWA). These amendments established broad authorities in the RCRA program to require corrective action for releases of hazardous wastes and constituents at RCRA-regulated facilities. These authorities include:

- corrective action for continuing releases (3004[u]),
- interim/status corrective action orders (3008[h]), and
- corrective action beyond the facility boundary (3004[v]).

EPA is developing a phased process for implementing the corrective action provisions of the 1984 RCRA Hazardous and Solid Waste Amendments that consists of preliminary assessments/site investigations, remedial investigations, and implementation of corrective measures. The phased approach used by CEARP for both CERCLA and RCRA continuing release sites at DOE-Albuquerque Operations Office installations is consistent with EPA guidance.

2. REMEDIAL RESPONSE OBJECTIVES

The objectives of the CEARP Phase 3 technological assessments (feasibility studies) at Rocky Flats Plant are to develop plans for remedial actions by proposing and assessing alternative technologies and approaches to eliminate or control environmental problems characterized by the CEARP Phase 2b site characterizations (remedial investigations). The remedial actions will be defined according to the nature of the site and will address the necessity of source control measures (designed to prevent or minimize migration of hazardous substances from the source) and/or management-of-migration measures (designed to mitigate the impact of contamination that has migrated into the environment).

The guidelines that will be used to develop and screen alternative remedial actions are presented in detail in Sections 3 and 4, and those for detailed analysis of the alternatives are presented in Section 5. The framework for alternative remedial action selection is as follows:

- a technical analysis of the alternative approaches in terms of performance, reliability, ease of implementation, and safety;
- an institutional analysis of the alternative remedial actions in terms of federal, state, or local standards, advisories, or guidelines that must be obtained or considered to protect public health and welfare, and the environment;
- an evaluation of public health exposure;
- an environmental analysis of alternative remedial actions; and
- a cost analysis of alternative remedial actions.

The CEARP Phase 3 technological assessment (feasibility study) will be integrated with the CEARP Phase 2 site characterizations (remedial investigations) to ensure that alternatives are formulated and evaluated using site information. CEARP Phase 3 technological assessment (feasibility study) reports will provide documentation for Phase 3 of DOE CERCLA (DOE 5480.14), two remedial planning program elements of EPA CERCLA (Feasibility Study and Remedial Action Selection), and remedial investigations under the 1984 RCRA Hazardous and Solid Waste Amendments.

3. PRELIMINARY ALTERNATIVE REMEDIAL ACTIONS DEVELOPMENT

As previously stated, the first step of the CEARP Phase 3 technological assessments (feasibility studies) will be to identify general response actions for each site. This will be accomplished by a technology identification and screening procedure that consists of three steps:

1. Identifying CEARP sites and associated problems, including pathways for migration of contamination (CEARP Phases 1 and 2).

2. Identifying general response actions that address site problems and meet clean-up goals and objectives (CEARP Phase 3).

3. Identifying possible technologies in each general response action, and screening the technologies to eliminate inapplicable and infeasible technologies based on site conditions (CEARP Phase 3).

Developing and screening technologies (and alternatives) is an iterative process taking place in CEARP Phases 2 and 3. This process will begin during Phase 2 site characterizations (remedial investigations) to define the field data and pilot study requirements of specific technologies and alternative remedial actions. As more site data are collected, existing technologies and alternative remedial actions may be rescreened, or additional remedial actions developed, to better address the revised objectives resulting from a refined understanding of the site.

3.1. ALTERNATIVE REMEDIAL ACTION IDENTIFICATION

Alternative remedial actions will be identified that fit into one of the four general categories listed in the CEARP Phase 3 Technological Assessment Plan (Appendix A) and taken from the National Contingency Plan. These categories are as follows:

- Alternative remedial actions for offsite treatment or disposal at a facility approved by EPA (including RCRA, TSCA, CWA, CAA, MPRSA, and SDWA approved facilities), as appropriate;

- Alternative remedial actions that <u>attain</u> applicable Federal and State public health or environmental standards;

- Alternative remedial actions that <u>exceed</u> applicable Federal and State public health or environmental standards; and

- A "no action" alternative.

Several potential alternative remedial actions have been identified for sites at Rocky Flats Plant. They are listed in Table 3.1. The list of potential alternative remedial actions may change or combinations of two or more be used at one site. These determinations will be made as data from the site characterizations (remedial investigations) become available. The list of general response actions is adapted from EPA's "Guidance on Feasibility Studies under CERCLA," (EPA 1985a). Two alternatives, alternate water supply and relocation of potentially affected populations, have been eliminated for the present because the preliminary assessment (CEARP Phase 1) found that the concentrations of hazardous constituents outside the installation boundaries were below EPA guideline concentrations (DOE 1986b).

Remedial technologies that will be used for developing response actions are listed in Table 3.2, which is taken from the CEARP Phase 3 Technological Assessment Plan (DOE 1986d). As information from the site characterizations (remedial investigations) becomes available, it will be reviewed to determine if conditions exist that limit or promote the use of certain remedial technologies. The alternatives will be evaluated singly or in combination, and additional alternatives may be identified.

3.2. IDENTIFICATION OF POTENTIAL OPERABLE UNITS

The solid waste management units at Rocky Flats Plant will be combined, as appropriate, for the necessary CEARP Phase 2b site characterizations (remedial investigations). Initially, these groupings of solid waste management units will be treated as independent areas when considering remedial actions. However, in some cases, the individual solid waste management units will contain different constituents. Remedial actions that address individual solid waste management units may be appropriate.

An operable unit is defined by EPA as "a discrete part of a remedial action that can function independently as a unit and contributes to preventing or minimizing a release or threat of release" (EPA 1985a). Individual operable units will be considered if the remedial action is compatible with the long-term solutions under consideration for Rocky Flats Plant. Individual operable units will also be considered if there is an immediate threat to human health or the environment.

Table 3.1. General Response Actions and Associated Remedial Technologies

General Response Action	Typical Technologies
No Action	Some monitoring and analyses may be performed.
Containment	Capping; groundwater containment barrier walls; bulkheads; gas barriers.
Pumping	Groundwater pumping; liquid removal; dredging.
Collection	Sedimentation basins; French drains; gas vents; gas collection systems.
Diversion	Grading; dikes and berms; stream diversion ditches; trenches; terraces and benches; chutes and downpipes; levees; seepage basins.
Complete Removal	Tanks; drums; soils; sediments; liquid wastes; contaminated structures; sewers and water pipes.
Partial Removal	Tanks; drums; soils; sediments; liquid wastes.
Onsite Treatment	Incineration; solidification; land treatment; biological, chemical, and physical treatment.
Offsite Treatment	Incineration; biological, chemical, and physical treatment.
In Situ Treatment	Permeable treatment beds; bioreclamation; soil flushing; neutralization; land farming.
Storage	Temporary storage structures.
Onsite Disposal	Landfills; land application.
Offsite Disposal	Landfills; surface impoundments; land application.

Source: EPA 1985a

Table 3.2. Remedial Technologies

A. Air Pollution Controls

-- Capping:
- Synthetic membranes
    - Clay
    - Asphalt
    - Multimedia cap
    - Concrete
    - Chemical sealants/stabilizers

-- Dust Control Measures:
    - Chemical fixatives
    - Water

B. Surface Water Controls

-- Capping (see A)
-- Grading:
    - Scarification
    - Tracking
    - Contour furrowing

-- Revegetation:
    - Grasses
    - Legumes
    - Shrubs
    - Forbs
    - Trees

-- Diversion and Collection Systems:
    - Dikes and berms
    - Ditches and trenches
    - Terraces and benches
    - Chutes and downpipes
    - Seepage basins
    - Sedimentation basins and ponds
    - Levees
    - Addition of freeboard
    - Floodwalls

Table 3.2. (Continued)

Leachate and Groundwater Controls

-- Capping (see A)
-- Containment Barriers:
  Function Options:
  - Downgradient placement
  - Upgradient placement
  - Circumferential placement
  Material and Construction Options (vertical barriers):
  - Soil-bentonite slurry wall
  - Cement-bentonite slurry wall
  - Vibrating beam
  - Grout curtains
  - Steel sheet piling
  Horizontal Barriers (bottom sealing):
  - Block displacement
  - Grout injection
  - Liners
-- Groundwater Pumping (generally used with capping and treatment):
  Function Options:
  - Extraction and injection
  - Extraction alone
  - Injection alone
  Equipment and Material Options:
  - Well points
  - Deep wells
  - Suction wells
  - Ejector wells
-- Subsurface Collection Drains:
  - French drains
  - Tile drains
  - Pipe drains (dual medial drains)

D. Gas Migration Controls (generally used with treatment)

-- Capping (gas barriers) (see A)
-- Gas Collection and/or Recovery:
  - Passive pipe vents
  - Passive trench vents
  - Active gas collection systems

Table 3.2. (Continued)

Excavation and Removal of Waste and Soil

-- Excavation and Removal:
- Backhoe
- Cranes and attachments
- Front-end loaders
- Scrapers
- Pumps
- Industrial vacuums
- Drum grapplers
- Forklifts and attachments

-- Grading (see B)
-- Capping (see A)
-- Revegetation (see B)

F. Removal and Containment of Contaminated Sediments

-- Sediment Removal:

Mechanical Dredging:
- Clamshell
- Dragline
- Backhoe

Hydraulic Dredging:
- Plain suction
- Cutterhead
- Dustpan

Pneumatic Dredging:
- Airlift
- Pneuma
- Oozer

-- Sediment Turbidity Controls and Containment:
- Curtain barriers
- Coffer dams
- Pneumatic barriers
- Capping

G. In Situ Treatment

-- Chemical Treatment
-- Soil Aeration
-- Solvent Flushing
-- Bioreclamation
-- Permeable Treatment Beds

Table 3.2. (Continued)

Direct Waste Treatment

-- Incineration:
- Rotary kiln
- Fluidized bed
- Multiple hearth
- Liquid injection
- Molten salt
- High temperature fluid wall
- Plasma arc pyrolysis
- Cement kiln
- Pyrolysis/starved combustion
- Wet air oxidation
- Industrial boiler or furnace

-- Gaseous Waste Treatment:
- Activated carbon
- Flares
- Afterburners

-- Treatment of Aqueous and Liquid Waste Streams:

Biological Treatment:
- Activated sludge
- Trickling filters
- Aerated lagoons
- Waste stabilization ponds
- Rotating biological disks
- Fluidized bed bioreactors

Chemical Treatment:
- Neutralization
- Precipitation
- Oxidation
- Hydrolysis
- Reduction
- Chemical dechlorination
- Ultraviolet/ozonation

Physical Treatment:
- Flow equalization
- Flocculation
- Sedimentation
- Activated carbon
- Oil adsorption media
- Ion exchange
- Reverse osmosis
- Liquid-liquid extraction
- Oil-water separator
- Steam distillation
- Air stripping

Table 3.2. (Continued)

- Steam stripping
- Filtration
- Dissolved air flotation

Discharge to Publicly-Owned Treatment Works

-- Handling and Treatment of Solids:

Dewatering:
- Screens, hydraulic classifiers, scalpers
- Centrifuges
- Gravity thickening
- Flocculation, sedimentation
- Belt filter presses
- Drying or dewatering beds
- Vacuum-assisted drying beds

Treatment:
- Neutralization
- Solvent
- Oxidation
- Reduction
- Composting

-- Solidification, Stabilization, or Fixation:
- Cement-based
- Lime-based
- Thermoplastic
- Organic polymer
- Self-cementing techniques
- Surface encapsulation
- Gassification
- Solidification (i.e., to fly ash, polymers, sawdust)

I. Land Disposal Storage

-- Landfills
-- Surface Impoundments
-- Land Application
-- Waste Piles
-- Deep Well Injection
-- Temporary Storage

J. Contaminated Water Supplies and Sewer Lines

-- In situ Cleaning
-- Removal and Replacement
-- Alternative Drinking Water Supplies:
- Cisterns or tanks
- Deeper or upgradient wells
- Municipal water systems
- Relocation of intake

-- Individual Treatment Units

4. ALTERNATIVE REMEDIAL ACTION SCREENING

As stated in the CEARP Phase 3 Technological Assessment Plan (Appendix A), the alternative remedial actions identified will be screened to narrow the range of potential considerations. The factors considered when screening include technical feasibility and reliability, performance criteria related to environmental and public health and safety, and cost of implementation and operation. Security requirements may make a remedial action at a site impractical or difficult to implement. Therefore, in those areas where security is a concern, security requirements will drive the screening process.

The screening process will eliminate remedial actions that are not technically feasible, that do not adequately protect public health and welfare and the environment, or that are more costly and yet do not provide significantly greater protection. The rationale for excluding each inadequate remedial action will be documented.

In some situations, screening may eliminate all remedial actions in one of the four categories listed in Section 3.1, "Alternative Remedial Action Identification." If this occurs, at least one remedial action for the category that was eliminated will be included in the Technological Assessment (Feasibility Study) Report described in Section 7 with an explanation as to why it was eliminated at the screening stage.

4.1. TECHNICAL FEASIBILITY SCREENING

Remedial actions will be evaluated based on performance, reliability, and implementability. Remedial actions that are not based on proven technology or are not compatible with site and waste source conditions, including those that might be difficult to construct under existing site conditions, will be eliminated. Innovative technologies will be considered if they are based on sound principles.

4.2. ENVIRONMENTAL, PUBLIC HEALTH, AND INSTITUTIONAL SCREENING

The purpose of this screening criteria is to eliminate alternatives that do not adequately protect the environment or public health and welfare. Remedial actions will be evaluated to see if implementation may cause a threat to public health or the environment (e.g., possible exposure from contaminated soil associated with excava-

tion activities). Remedial actions will also be reviewed to assess the effect that compliance with institutional issues will have on the implementation of that alternative.

4.3. COST SCREENING

Following the guidance provided in the CEARP Phase 3 Technological Assessment Plan (Appendix A), costs for implementing the various remedial actions will be developed and cost screening conducted after the technical feasibility and environmental/public health/institutional screenings have been performed.

Screening of remedial action costs will be based on both capital and operating and maintenance (O&M) costs. These costs will be estimated using the following resources:

- *Remedial Actions Cost Compendium* (ELI 1984);
- *Handbook: Remedial Action at Waste Disposal Sites* (EPA 1985b);
- Rocky Flats Plant Cost Estimating Group; and
- Standard cost indices.

After developing screening cost data, a present worth analysis will be performed. Details on methods and procedures to be used for cost estimation and present worth analysis are discussed in Section 5.2 of the CEARP Phase 3 Technological Assessment Plan (DOE 1986d) and in the EPA Remedial Action Costing Procedures Manual (EPA 1983).

Remedial actions with excessive costs that do not provide significantly greater protection to the environment or public health and welfare will be eliminated. Remedial actions that are found to be more expensive but that offer substantially greater environmental or public health and welfare benefits will remain under consideration.

5. REMEDIAL ACTION ANALYSIS

5.1. DETAILED DEVELOPMENT OF FEASIBLE REMEDIAL ACTIONS

The remedial actions that remain after the initial screening will be further developed, following the guidance provided in the CEARP Phase 3 Technological Assessment Plan (Appendix A). The description developed may include, but will not be restricted to, the following:

- a description of appropriate treatment and disposal technologies, as well as any required permanent facilities;

- specific engineering considerations required to implement the remedial action (e.g., pilot treatment facilities, and additional studies needed to proceed with final remedial action design);

- environmental impacts and proposed methods for mitigating any adverse effects;

- operation and maintenance/monitoring requirements of the completed remedy;

- offsite disposal needs and transportation plans;

- requirements for safety plans to be followed during remedial action implementation (including both onsite and offsite health and safety considerations);

- a description of how the remedial action may be segmented to allow staged implementation. Both staging and segmenting options will be developed in close consultation with the EPA and Colorado Department of Health (CDH);

- a review of any offsite treatment or disposal facilities to ensure compliance with applicable CERCLA and/or RCRA requirements and EPA policy;

- a determination of what permits would be necessary for each alternative identified and what information is necessary for issuance of these permits;

- the extent to which the remedial actions meet technical requirements and standards of appropriate environmental regulations: this information should be arrayed so that differences among the remedial actions, in terms of how they satisfy such standards, are readily apparent. The kinds of standards applicable at the site may include: (1) CERCLA and/or RCRA design and operating standards, (2) drinking water standards, and (3) environmental discharge standards; and

- community effects: The types of information that should be provided include (1) the extent to which implementing a remedial action would disrupt the community (e.g., traffic, temporary health risks, and relocation) and (2) the likely public reaction.

5.2. TREATABILITY STUDIES

Laboratory and bench scale treatability studies may be necessary to establish the effectiveness of the remedial actions and to develop engineering criteria. A detailed plan for treatability studies will be prepared as needed on a site-specific basis and incorporated into the CEARP Phase 3 technological assessments (feasibility studies) as appropriate.

Several treatability studies have already been performed on soil decontamination methods at Rocky Flats Plant. The studies available are as follows:

- Soil Decontamination at Rocky Flats (Olsen et al. 1980)
- Separation of Transuranic Radionuclides from Soil by Vibratory Grinding (Stevens et al. 1982a)
- Comparative Scrub Solution Tests for Decontamination of Transuranic Radionuclides from Soils (Stevens et al. 1982b)
- Waste Generation Reduction - Nitrates, Comprehensive Report of Denitrification Technologies (Johnson et al. 1986).

5.3. REMEDIAL ACTION ASSESSMENT

Remedial actions will be evaluated in detail on the basis of technical feasibility, protection afforded to public health and the environment, institutional requirements, and cost. The major concern in a detailed evaluation of remedial actions is that the remedial action be appropriate to site conditions.

5.3.1. Technical Analysis

The technical analysis will include an evaluation of the performance of the remedial action, its reliability, its implementability in terms of demonstrated success at a similar site or on a research and development basis, and the effectiveness of the option in achieving safety requirements.

Remedial actions will be evaluated in terms of performance. Any special site or waste conditions that affect performance will be considered, and the preliminary design will be tailored to accommodate those conditions. The evaluation will also consider the effectiveness of combining technologies.

Each remedial action will also be evaluated in terms of the projected service life of its component technologies. Resource availability in the future life of the technology, as well as the appropriateness of the technology, will be considered in estimating the useful life of the project.

The cost to install and operate remedial actions coupled with the need to protect public health and the environment make reliability a serious concern. Technologies that require frequent or complex operations and maintenance activities will be regarded as less reliable than technologies requiring little or straightforward operation and maintenance.

The technical analysis of remedial actions will not be based on the presumed performance of untested methods. An estimate of the probability of failure, in either qualitative or quantitative terms, will be made for each component technology and for the complete alternative. Preference will be given to technologies that have proven effective under waste and site conditions similar to those anticipated. However, innovative or advanced technology will be evaluated as an alternative to conventional technology, if appropriate. If such technology is included in suggested remedial actions, information from research supporting its use and expected reliability will be documented.

Each remedial action will be evaluated with regard to safety. This evaluation will include short-term and long-term threats to the safety of nearby workers, residents, and environs, as well as threats to workers during implementation. Major risks that will be considered are fire, explosion, and exposure to hazardous substances resulting from both onsite and offsite work while the remedial action is being implemented.

5.3.2. Risk/Endangerment Assessment

Appendix B is the risk/endangerment assessment required by the Compliance Agreement. Key components of the risk/endangerment assessment are outlined in the CEARP Phase 3 Technological Assessment Plan (Appendix A) and are summarized here.

Using the "no action" alternative as a baseline, a comparative analysis will be performed on the other remedial actions. This analysis will include an evaluation of the extent to which the remedial actions can be expected to mitigate, minimize damage to, and protect public health and welfare, and the environment. The evaluation will include an analysis of the extent and duration of exposure to contaminants and a comparison of contaminant concentrations to appropriate ambient standards and criteria. Certain actions may not necessarily produce a reduction in risk, particularly during the short-term remedial action period (e.g., removal and offsite disposal of contaminated soils may create an additional exposure pathway).

The environmental assessment will address both the long-term and short-term effects of the remedial action under consideration. The level of detail will depend on the degree of potential impact.

The public health evaluation will consist of the following:

- a baseline site evaluation to provide a preliminary assessment of the public health risks;
- an exposure assessment to analyze the extent and duration of human exposure to site contaminants in the absence of remedial action;
- a standards analysis to compare projected environmental concentrations to appropriate ambient standards or criteria; and
- an evaluation to assess the short- and long-term effects and the efficiency of the proposed remedial action with respect to removal or mitigation exposures identified during the exposure assessment.

5.3.3. Institutional Analysis

This analysis will entail an evaluation of the effect of permit requirements, regulatory agency acceptance, and government infrastructure requirements on implementation of the remedial action.

6. COMPARATIVE EVALUATION OF ACCEPTABLE ALTERNATIVES

Following guidance provided in the CEARP Phase 3 Technological Assessment Plan (Appendix A), a comparative evaluation of acceptable remedial actions will be performed. This evaluation will include developing the relative importance of both cost and noncost criteria. Based on these factors and the alternative assessments, each remedial action will be ranked so that key differences will be evident. Remedial actions that attain or exceed the requirements of applicable environmental regulations will be identified. The comparative evaluation will utilize the detailed information collected during site characterizations (remedial investigations) and will support a remedial action recommendation.

7. CEARP PHASE 3 TECHNOLOGICAL ASSESSMENT (FEASIBILITY STUDY) REPORT

A CEARP Phase 3 technological assessment (feasibility study) report will be prepared that will document the remedial actions considered and explain why each option was eliminated both in preliminary screening and detailed analysis. A description of the recommended remedial action will be included that will cover the following:

- a review of what the remedial action will and will not accomplish;
- a review of how the remedial action addresses the requirements and the intent of the NCP (e.g., placing emphasis on a permanent remedy to the identified site problem(s) utilizing innovative technologies);
- special engineering considerations and special studies needed during the final design;
- operation, maintenance, and monitoring requirements;
- offsite disposal needs and transportation plans, if appropriate;
- temporary storage requirements, if appropriate;
- regulatory permit requirements, if appropriate;
- brief descriptions of the environmental and public health problems that may be encountered during implementation, and
- means of mitigating the associated environmental and public health problems (and their costs), and how identified/determined environmental standards are being met.

At a minimum, CEARP Phase 3 reports will follow guidelines presented in DOE Order 5480.14 as follows:

1. Executive Summary
2. Criteria
3. Evaluation of Remedial Action Alternatives
4. Recommended Remedial Action (Project Proposal)
5. Resource Requirements
6. Proposed Schedule

Additionally, CEARP Phase 3 documentation will be responsive to pertinent elements of EPA Feasibility Study reporting requirements. This documentation must be consistent with requirements under NEPA and other environmental regulations,

8. REFERENCES

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DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
ENVIRONMENT, SAFETY AND HEALTH DIVISION
ENVIRONMENTAL PROGRAMS BRANCH

COMPREHENSIVE ENVIRONMENTAL ASSESSMENT AND RESPONSE PROGRAM

PHASE 3:
TECHNOLOGICAL ASSESSMENT PLAN

August 1986

WORKING DRAFT

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1. INTRODUCTION

The Comprehensive Environmental Assessment and Response Program (CEARP) Technological Assessment Plan for CEARP Phase 3 provides generic guidance and establishes procedures for implementing Phase 3. Guidance issued by the U.S. Environmental Protection Agency (EPA) [e.g., *Federal Facilities Program Manual for Implementing CERCLA Responsibilities of Federal Facilities, final draft* (EPA n.d.) and *Guidance on Feasibility Studies under CERCLA* (EPA 1985a)] is incorporated into this report. The purpose of CEARP Phase 3 is to develop, evaluate, and recommend plans for managing hazardous waste sites. Phase 3 actions will be based on information obtained during CEARP Phases 1 and 2. A site-specific technological assessment will be developed for each individual site (a site or grouping of sites) evaluated under CEARP Phase 3.

1.1. BACKGROUND

Facilities of the U.S. Department of Energy (DOE) are required to operate under a policy of full compliance with applicable environmental regulations while conducting their missions. The DOE Albuquerque Operations Office (AL) initiated the CEARP in mid-1984 to help fulfill that commitment at installations within the AL complex. The CEARP will also assist DOE in setting environmental priorities and will help provide justification for funding to carry out enhancements of existing programs or remedial actions where required. Implementation of CEARP will be realized by combined forces of AL, individual DOE area offices, DOE prime contractors, Los Alamos National Laboratory (LANL), and other assistance as found to be necessary.

1.1.1. Authority

Authority to implement CEARP is derived primarily from the following DOE and AL orders:

- Comprehensive Environmental Response, Compensation, and Liability Act Program (DOE 5480.14);
- Hazardous, Toxic, and Radioactive Mixed Waste Management (DOE 5480.2 and AL 5480.2);

- Prevention, Control, and Abatement of Environmental Pollution (Ch. XII of DOE 5480.1 and AL 5480.1);

- Environmental Protection, Safety, and Health Protection Information Reporting Requirements (DOE 5484.1 and AL 5484.1);

- Implementation of the National Environmental Policy Act (DOE 5440.1C and AL 5440.1B).

1.1.2. Purpose and Scope

The CEARP is a phased program to identify, assess, and correct existing or potential environmental problems. The review covers the major environmental regulations, such as the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), National Environmental Policy Act (NEPA), Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Toxic Substances Control Act (TSCA), Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), with emphasis upon CERCLA and RCRA. Past, current, and future practices to handle and dispose of hazardous substances, as defined under CERCLA, are evaluated. In addition, requirements to control environmental pollution and environmental monitoring programs for hazardous substances are evaluated for adequate understanding of both pathways and regulatory compliance.

1.2. CEARP METHODOLOGY

The CEARP is being implemented in five phases, which exactly parallel DOE CERCLA Order 5480.14. Additionally, EPA has prepared guidelines for federal facilities to carry out their responsibilities under CERCLA. The EPA has outlined its plans and intentions in a series of program elements that are organized in a somewhat different fashion but constitute the same basic approach as CEARP in its *Federal Facilities Program Manual for Implementing CERCLA Responsibilities of Federal Agencies, final draft* (EPA n.d.). The five CEARP phases are linked as indicated in Fig. 1.1. CEARP includes a review of the major federal environmental regulations. The review serves two primary purposes: (1) determines compliance with environmental regulations and (2) evaluates the interaction of CERCLA with other environmental regulations, for example, releases permitted under the CWA or CAA and releases exceeding reportable quantities under CERCLA, or RCRA-related remedial activities

and CERCLA-related remedial activities. The purpose of individual CEARP phases follows.

1.2.1. Phase 1 - Installation Assessment

Phase 1 objectives are to determine present compliance with environmental laws and to ascertain the magnitude of potential environmental concerns. Where insufficient data exist to accomplish this, the additional information necessary to complete the evaluation will be identified. The CEARP Phase 1 report will provide documentation for Phase 1 of the DOE CERCLA Order 5480.14 and for the following EPA CERCLA preremedial activities: (1) Federal Facility Site Discovery and Identification Findings (FFSDIF) (notification of newly discovered sites, including notification of negative findings), (2) Preliminary Assessment (PA), (3) Site Inspection (SI), and (4) Hazard Ranking System (HRS) evaluation.

Sites, which may be CERCLA or RCRA continuing release, are indicated for no further action when CEARP findings include (1) negative findings for the CERCLA FFSDIF process (for example, potential sites that are found not to exist or spills that were removed in the past through remedial action), or (2) sites initially requiring notification for the FFSDIF process, but are later found to pose no threat of release under DOE CERCLA for the EPA CERCLA PA process (for example, potential sites at which the hazardous substance initially identified because of its stability no longer persists in the environment). Consequently, sites that no longer pose a threat of release are not included in the EPA HRS and DOE Modified HRS (MHRS). This procedure is consistent with guidance provided to federal facilities by EPA in its *Federal Facility Program Manual for Implementing CERCLA Responsibilities of Federal Agencies, final draft* (EPA n.d.).

Sites requiring evaluation are scored as follows: (1) nonradioactive sites are scored with the EPA HRS and (2) radioactive sites are scored with the EPA HRS and the DOE MHRS. Sites meeting EPA criteria for being listed on the National Priorities List (NPL) are recommended for future action under DOE CERCLA Program Phase 2 to quantify the potential migration problem. This approach is consistent with CERCLA. Sites that do not meet EPA criteria to be listed on the NPL but exceed other applicable DOE remedial action criteria/guidelines (e.g., guidelines for the DOE Surplus Facilities Management Program) and/or sites posing potential concerns about

regulatory compliance (e.g., RCRA-related remedial activities) are recommended for future action under CEARP. No further action is recommended for sites not meeting these criteria.

1.2.2. Phase 2 - Confirmation

Phase 2 objectives are to (1) obtain additional information identified as necessary during Phase 1, (2) complete an environmental evaluation to confirm the presence or absence of potential environmental concerns identified in Phase 1, and (3) plan and carry out measurement and sampling programs as required to understand potential sources of contaminants and potential environmental pathways. Confirmed problems will be assessed for health or environmental risk as a basis for setting priorities for remedial action or other follow-up actions. The CEARP Phase 2 reports will provide documentation for Phase 2 of the DOE CERCLA Order (CEARP Phase - 2a Monitoring Plan and CEARP Phase 2b - Site Characterization) and for two EPA CERCLA remedial planning program elements (Remedial Investigation Sampling Plan and Remedial Investigation).

1.2.3. Phase 3 - Technological Assessment

Phase 3 objectives are to develop plans for remedial actions or enhancements of existing programs by proposing and assessing alternative technologies and approaches to eliminate or control environmental problems identified as needing correction in CEARP Phase 2. The evaluation will include assessing the effectiveness of technology; the impacts on health, safety, and environment; and a cost-benefit analysis, where appropriate. Phase 3 will include identifying or developing appropriate criteria and performing any evaluation of environmental impact required by National Environmental Policy Act (NEPA). CEARP Phase 3 reports will provide documentation for Phase 3 of DOE CERCLA and for two remedial planning program elements of EPA CERCLA (Feasibility Study and Remedial Action Selection).

1.2.4. Phase 4 - Remedial Action

Phase 4 objectives are to implement recommended site-specific remedial measures identified in Phase 3, which could include engineering design and construction

to remedy or control environmental problems. CEARP Phase 4 will encompass requirements of DOE CERCLA Order (Phase 4) and remedial implementation program elements of EPA CERCLA (Design and Action).

1.2.5. Phase 5 - Compliance and Verification

Phase 5 objectives are to (1) verify and document the adequacy of remedial actions carried out in Phase 4, and (2) identify and plan for any continuing monitoring requirements needed to demonstrate control of migration or adequately recognize future concerns. CEARP Phase 5 will encompass requirements of DOE CERCLA Order (Phase 5) and EPA Final Site Inspection/Close-out and Monitoring.

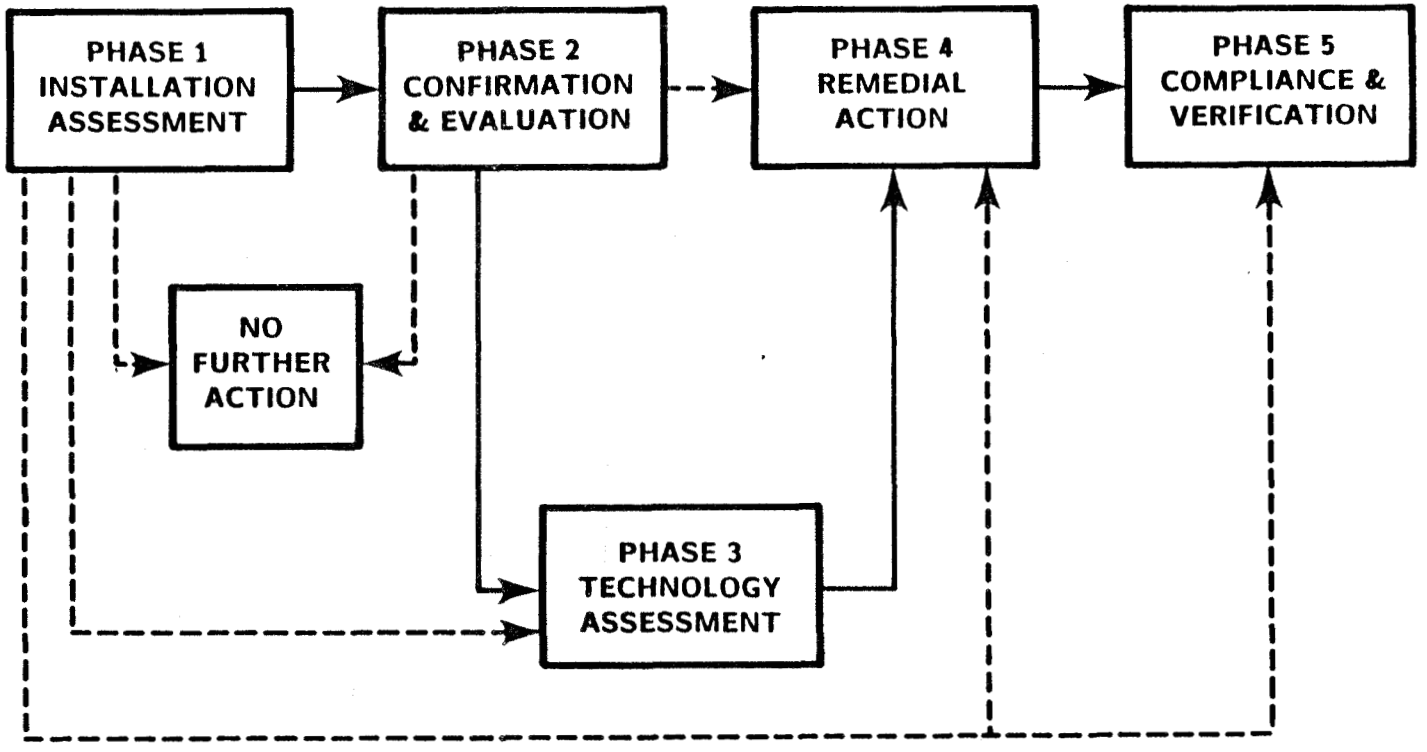

Figure 1.1. CEARP Decision Flow Chart.

2. PHASE 3 - IMPLEMENTATION

2.1. INTRODUCTION

CEARP Phases 2 and 3 are interdependent. Activities composing these two phases should be performed concurrently to the extent appropriate. Phase 2 of CEARP provides site characterization data, which serve as the basis for implementing CEARP Phase 3 (Technological Assessment). During CEARP Phase 3, alternative remedial actions should be developed and evaluated in terms of cost, feasibility of proposed engineering, the extent to which each alternative provides protection to public health and the environment, and environmental impacts during or remaining after implementation. The EPA has provided guidelines for preparing CEARP technological assessments in *Guidance on Feasibility Studies Under CERCLA* (EPA 1985a), which is incorporated in Sections 2 through 8 as appropriate. The guidelines for a detailed evaluation of alternatives and a selection of recommended action are intended for CEARP sites that fall under CERCLA Feasibility Study requirements. The evaluation should be implemented on a site-by-site basis for CEARP sites not meeting those requirements, e.g., inactive waste areas that do not meet the threshold for being listed on the National Priorities List (NPL) and RCRA solid waste management units (SWMU). A SWMU is defined as any unit, which at a minimum, includes any landfill, surface impoundment, waste pile, land treatment unit, ditch, incinerator, tank (including storage, treatment, and accumulation tanks), elementary neutralization unit, transfer station, and recycling unit that receive, or have received, solid or hazardous waste at any time. SWMUs under CEARP Phase 3 must also meet appropriate requirements under RCRA, including the 1984 RCRA Hazardous and Solid Waste Amendments (HSWA). HSWA established broad new authorities in the RCRA program to require corrective action for releases of hazardous wastes and constituents at RCRA-regulated facilities. These new authorities are:

- Corrective action for continuing releases [3004 (u)]
- Interim/status corrective action orders [3008 (h)]
- Corrective action beyond the facility boundary [3004 (v)].

EPA is developing a phased process for implementing the corrective action provisions that consists of preliminary assessments/site investigations, remedial investigations and implementation of corrective measures.

2.2. OVERVIEW OF THE TECHNOLOGICAL ASSESSMENT PROCESS

The first step of Phase 3 is to define the goals and objectives of the Technological Assessment and identify general response actions for each site(s). This step will be based on CEARP Phase 1 and 2 findings. The general response actions should be defined based on the nature of the site and they should address the necessity of source control measures (designed to prevent or minimize migration of hazardous substances from the source) and/or management-of-migration measures (designed to mitigate the impact of contamination that has migrated into the environment). The terms "source control" and "management-of-migration" refer to two general categories of response actions that are useful for developing site-specific alternatives. The term "onsite response actions" refers both to source control and management-of-migration measures.

Section 3 of this Technological Assessment Plan identifies technologies within the general response categories that will be screened for their technical applicability. Guidelines for developing and screening alternative approaches are presented in detail in Sections 4 and 5 and those for detailed analyses of the alternatives are provided in Section 6. The framework for an analysis necessary to select the most appropriate alternative follows:

- A technical analysis of the alternative approaches in terms of performance, reliability, ease to implement, and safety;
- An institutional analysis of the alternatives in terms of the federal, state, or local standards, advisories, or guidelines that must be attained or considered to protect public health, and welfare, and the environment;
- An evaluation of public health exposure;
- An environmental analysis of alternatives;
- A costs analysis of alternatives.

Guidelines are provided for the comparative analysis of alternatives and for an identification of the recommended remedial action in Sections 7 and 8. A list of guidance documents is provided in Section 10 (Bibliography).

2.3. DOCUMENTATION AND REPORTING REQUIREMENTS

Documentation and reporting under CEARP will follow the guidelines set forth in DOE Order 5480.14 (CERCLA Implementation). Additionally, they should be responsive to EPA guidance as appropriate for reporting under CERCLA and for remedial investigations and corrective measures under RCRA at continuing release sites.

Programs (including public relations) should be implemented by AL installations to ensure to the extent practical that remedial actions pursuant to Sections 104 and 106 of CERCLA and other CEARP activities meet the functional equivalent of NEPA as specified in the EPA guidance documents *Federal Facilities Program Manual for Implementing CERCLA Responsibilities of Federal Facilities, final draft* (EPA n.d.) and *Guidance on Feasibility Studies Under CERCLA* (EPA 1985a). The focus of CEARP is broader than that of CERCLA, for example, it includes RCRA continuing release sites and activities under the DOE Surplus Facilities Management Program, which may not meet criteria established for implementing CERCLA remedial activities. Therefore, implementation of programs designed to meet the functional equivalent of NEPA and comply with NEPA (e.g., the DOE-equivalent of a memo-to-file for clearly insignificant activities, an environmental assessment, and an environmental impact statement) will be established on a site-by-site basis. CEARP NEPA-related documentation and documentation for other environmental requirements, such as, floodplain/wetland involvement, should be consistent with the guidance provided in DOE Order 5440.1C and AL Order 5440.1B (Implementation of the National Environmental Policy Act) and the DOE *Environmental Compliance Guide* (DOE 1981). This includes coordination with appropriate parties and public hearings. Appropriate coordination with federal agencies, as specified under CERCLA, the National Contingency Plan (NCP), and Executive Order 12316, should be implemented. Additional details/guidelines for establishing public relations programs (including public hearings) and meeting the functional equivalent of NEPA are provided in Section 6. To provide uniformity LANL will complete CEARP Phase 3 Technological Assessment reports for AL.

2.3.1. Documentation for CEARP Phase 3 - Technological Assessment

At a minimum, CEARP Phase 3 reports will follow guidelines presented in DOE Order 5480.14 as follows:

1. Executive Summary
2. Criteria
3. Evaluation of Remedial Action Alternatives
4. Recommended Remedial Action (Project Proposal)
5. Resource Requirements
6. Proposed Schedule

Additionally, CEARP Phase 3 documentation should be responsive to pertinent elements of the EPA Feasibility Study reporting requirements (Table 2.1). Documentation must also be consistent with requirements under NEPA and other environmental regulations, DOE Order 5440.1C and AL Order 5440.1B, and the DOE *Environmental Compliance Guide* (DOE 1981).

2.3.2. Documentation for CEARP Phases 4 and 5

Documentation and reporting requirements for CEARP Phases 4 and 5 will be given in documents prepared during subsequent phases of CEARP. These documents will address those program elements required to perform mitigation of adverse environmental impacts at sites requiring further action. In addition, guidelines will be provided on future monitoring requirements to fulfill compliance and verification needs under CERCLA or RCRA continuing release provisions.

2.3.3. Reference Archive

The documentation prepared under CEARP will be placed into the archives at LANL for AL to provide access for reference, including subsequent phases of CEARP, and to meet requirements of DOE Order 1324.2A (Records Disposition).

Table 2.1. Elements of EPA Feasibility Study Report

- Introduction
  - Site Background Information
  - Nature and Extent of Problem(s)
  - Objectives of Remedial Action
- Screening of Remedial Action Technologies
  - Technical Criteria
  - Remedial Action Alternatives Developed
  - Environmental and Public Health Criteria
  - Other Screening Criteria
  - Cost Criteria
- Remedial Action Alternatives
  - Alternative 1 (no action)
  - Alternative 2
  - Alternative N
- Analysis of Remedial Action Alternatives
  - Noncost Criteria Analysis
    - Technical Feasibility
    - Environmental Evaluation
    - Institutional Requirements
    - Public Health Evaluation
  - Cost Analysis
- Summary of Alternatives
- Recommended Remedial Action (optional)
- Responsiveness Summary (in final version only)

Source: EPA 1985a

3. IDENTIFYING AND SCREENING REMEDIAL TECHNOLOGIES

3.1. OVERALL APPROACH

The recommended technology identification and screening procedure consists of three steps:

1. Identify CEARP sites and associated problems, including pathways for migration of contamination (CEARP Phases 1 and 2).

2. Identify general response actions that address site problems and meet clean-up goals and objectives (CEARP Phase 3), Section 3.2.

3. Identify possible technologies in each general response action, then screen the technologies to eliminate inapplicable and infeasible technologies based on site conditions (CEARP Phase 3), Section 3.3.

Developing and screening technologies (and alternatives) is an iterative process taking place in CEARP Phases 2 and 3. The process begins during Phase 2 - Confirmation to define the field data and pilot study requirements of specific technologies and alternatives. As more site data are collected, existing technologies and alternatives may be rescreened, or additional alternatives developed, to better address the revised objectives resulting from a refined understanding of the site.

3.2. GENERAL RESPONSE ACTIONS AND REMEDIAL TECHNOLOGIES

General response actions and their associated remedial technologies should be identified to address significant site problems reported during CEARP Phases 1 and 2. Site problems can generally be placed in one or more of the following categories: (1) air pollution; (2) contamination of the soil and unsaturated zone; (3) surface water transport, infiltration, or contamination; (4) generation of leachate and contaminated groundwater; (5) gas migration; (6) wastes in drums, lagoons, etc.; (7) contaminated sediments; and (8) contaminated utilites (e.g., water supply and sewer lines and other conduits).

General response actions should address the objectives at the site for remedial action. Some general response actions are shown in Table 3.1. Guidelines for screening and evaluating remedial responses are provided by EPA in *Handbook: Remedial Action at Waste Disposal Sites* (EPA 1985b).

3.3. IDENTIFYING AND SCREENING POTENTIAL TECHNOLOGIES

Remedial technologies must be chosen for each general response action identified, recognizing that there may be compatible and incompatible combinations of source control and management-of-migration measures. Table 3.1 contains a partial list of technologies appropriate to the general response actions, also listed in Table 3.1. Technologies that prove extremely difficult to implement, do not achieve the remedial objective in a reasonable time, or are unproven should be modified or eliminated.

Table 3.2 lists remedial technologies classified according to the site hazards they are intended to mitigate (EPA 1985a). While identifying and screening technology, using this list will help ensure that most remedial technologies are considered.

Site data must be reviewed to identify conditions that may limit or promote the use of certain remedial technologies. Such information will generally be gathered during CEARP Phase 2. Table 3.3 identifies important site characteristics that should be considered part of the screening process. There are also waste characteristics that can limit the effectiveness and/or feasibility of remedial technologies and they are shown in Table 3.4. Important considerations in selecting remedial technologies are the level of development of the technology, performance record of the technology, and inherent construction, operation, and/or maintenance problems associated with it (EPA 1985b).

Table 3.1. General Response Actions and Associated Remedial Technologies

General Response Action	Typical Technologies
No Action	Some monitoring and analyses may be performed.
Containment	Capping; groundwater containment barrier walls; bulkheads; gas barriers.
Pumping	Groundwater pumping; liquid removal; dredging.
Collection	Sedimentation basins; French drains; gas vents; gas collection systems.
Diversion	Grading; dikes and berms; stream diversion ditches; trenches; terraces and benches; chutes and downpipes; levees; seepage basins.
Complete Removal	Tanks; drums; soils; sediments; liquid wastes; contaminated structures; sewers and water pipes.
Partial Removal	Tanks; drums; soils; sediments; liquid wastes.
Onsite treatment	Incineration; solidification; land treatment; biological, chemical, and physical treatment.
Offsite Treatment	Incineration; biological, chemical, and physical treatment.
In Situ Treatment	Permeable treatment beds; bioreclamation; soil flushing; neutralization; land farming.
Storage	Temporary storage structures.
Onsite Disposal	Landfills; land application.
Offsite Disposal	Landfills; surface impoundments; land application.
Alternative Water Supply	Cisterns; above-ground tanks; deeper or upgradient wells; municipal water system; relocation of intake structure; individual treatment devices.
Relocation	Relocate residents temporarily or permanently.

Source: EPA 1985a

Table 3.2. Remedial Technologies

A. Air Pollution Controls
--Capping:
- Synthetic membranes
- Clay
- Asphalt
- Multimedia cap
- Concrete
- Chemical sealants/stabilizers

--Dust Control Measures:
- Chemical fixatives
- Water

B. Surface Water Controls
--Capping (see A)
--Grading:
- Scarification
- Tracking
- Contour furrowing

--Revegetation:
- Grasses
- Legumes
- Shrubs
- Forbs
- Trees

--Diversion and Collection Systems:
- Dikes and berms
- Ditches and trenches
- Terraces and benches
- Chutes and downpipes
- Seepage basins
- Sedimentation basins and ponds
- Levees
- Addition of freeboard
- Floodwalls

C. Leachate and Groundwater Controls
--Capping (see A)
--Containment Barriers:
Function Options:
- Downgradient placement
- Upgradient placement
- Circumferential placement

Material and Construction Options (vertical barriers):
- Soil-bentonite slurry wall
- Cement-bentonite slurry wall
- Vibrating beam
- Grout curtains
- Steel sheet piling

Source: EPA 1985a

Table 3.2. (Continued)

Horizontal Barriers (bottom sealing):
- Block displacement
- Grout injection
- Liners

--Groundwater Pumping (generally used with capping and treatment):

Function Options:
- Extraction and injection
- Extraction alone
- Injection alone

Equipment and Material Options:
- Well points
- Deep wells
- Suction wells
- Ejector wells

--Subsurface Collection Drains:
- French drains
- Tile drains
- Pipe drains (dual media drains)

D. Gas Migration Controls (generally used with treatment)

--Capping (gas barriers) (see A)

--Gas Collection and/or Recovery:
- Passive pipe vents
- Passive trench vents
- Active gas collection systems

E. Excavation and Removal of Waste and Soil

--Excavation and Removal:
- Backhoe
- Cranes and attachments
- Front end loaders
- Scrapers
- Pumps
- Industrial vacuums
- Drum grapplers
- Forklifts and attachments

--Grading (see B)

--Capping (see A)

--Revegetation (see B)

F. Removal and Containment of Contaminated Sediments

--Sediment Removal:

Mechanical Dredging:
- Clamshell
- Dragline
- Backhoe

Hydraulic Dredging:
- Plain suction
- Cutterhead
- Dustpan

Table 3.2. (Continued)

Pneumatic Dredging:
- Airlift
- Pneuma
- Oozer

--Sediment Turbidity Controls and Containment:
- Curtain barriers
- Coffer dams
- Pneumatic barriers
- Capping

G. In Situ Treatment
--Chemical Treatment
--Soil Aeration
--Solvent Flushing
--Bioreclamation
--Permeable Treatment Beds

H. Direct Waste Treatment
--Incineration:
- Rotary kiln
- Fluidized bed
- Multiple hearth
- Liquid injection
- Molten salt
- High temperature fluid wall
- Plasma arc pyrolysis
- Cement kiln
- Pyrolysis/starved combustion
- Wet air oxidation
- Industrial boiler or furnace

--Gaseous Waste Treatment:
- Activated carbon
- Flares
- Afterburners

--Treatment of Aqueous and Liquid Waste Streams:
Biological Treatment:
- Activated sludge
- Trickling filters
- Aerated lagoons
- Waste stabilization ponds
- Rotating biological disks
- Fluidized bed bioreactors

Chemical Treatment:
- Neutralization
- Precipitation
- Oxidation
- Hydrolysis
- Reduction
- Chemical dechlorination
- Ultraviolet/ozonation

Table 3.2. (Continued)

Physical Treatment:
- Flow equalization
- Flocculation
- Sedimentation
- Activated carbon
- Kneensorb
- Ion exchange
- Reverse osmosis
- Liquid-liquid extraction
- Oil-water separator
- Steam distillation
- Air stripping
- Steam stripping
- Filtration
- Dissolved air flotation

Discharge to Publicly Owned Treatment Works

--Handling and Treatment of Solids:

Dewatering:
- Screens, hydraulic classifiers, scalpers
- Centrifuges
- Gravity thickening
- Flocculation, sedimentation
- Belt filter presses
- Drying or dewatering beds
- Vacuum-assisted drying beds

Treatment:
- Neutralization
- Solvent
- Oxidation
- Reduction
- Composting

--Solidification, Stabilization, or Fixation:
- Cement-based
- Lime-based
- Thermoplastic
- Organic polymer
- Self-cementing techniques
- Surface encapsulation
- Gassification
- Solidification (i.e., to fly ash, polymers, sawdust)

I. Land Disposal Storage

--Landfills
--Surface Impoundments
--Land Application
--Waste Piles
--Deep Well Injection
--Temporary Storage

Table 3.3. Site Characteristics That May Affect Selection of Remedial Technology

Waste volume and areal extent	Thickness of unsaturated zone
Site Area	Depths to groundwater
Site configuration	Depth to bedrock
Climate (precipitation, temperature evaporation	Depth to aquicludes
Topography	Degree of contamination of unsaturated zone, surface water and groundwater
Soil texture and permeability	Direction and rate of groundwater flow
Soil moisture	Receptors/discharge areas
Surface drainage	Water use
Site geology	Surface water
Land use	Ecological areas
Vegetation	Risk Assessment

Table 3.4. Waste Characteristics That May Affect Selection of Remedial Technology

Quantity/concentration	Infectiousness
Chemical composition	Solubility
Acute toxicity	Volatility
Persistence	Density
Biodegradability	Partition coefficient
Radioactivity	Compatibility with other chemicals
Ignitability	Treatability
Reactivity/corrosivity	

4. DEVELOPMENT OF ALTERNATIVES

4.1. PREFERENCE

Preference should be given to remedial actions that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances and to alternatives that either recycle or reuse wastes or are otherwise advanced or innovative. For CEARP investigations falling under CERCLA Feasibility Study requirements, at least one of the alternatives analyzed after screening should be of this type.

Advanced, innovative, or alternate technologies include the following:

- Use of an existing environmental technology for handling different wastes or types of sites.
- Development of new or improved designs for existing technologies.
- Use of a developed technology that is not fully proven (e.g., based upon documented research and demonstration projects showing promise of benefits that outweigh potential risks).

These technologies should accomplish at least one or a combination of the following:

- Permanent destruction
- Reuse or recycle
- Elimination of contaminant discharge
- Waste minimization.

4.2. ALTERNATIVES

Technologies that have passed the technology screening are then assembled into alternatives by combining in various appropriate combinations the developed source control and management-of-migration remedies. At least one alternative that addresses each of the following considerations should be evaluated for CEARP investigations falling under CERCLA Feasibility Study requirements. The CEARP Technological Assessment (Phase 3) should discuss those situations in which no feasible alternative can be identified for a given category:

(a) Alternatives for treatment or disposal at an offsite facility approved by EPA (including RCRA, TSCA, CWA, CAA, Marine Protection Resource and Sanctuaries Act, and SDWA approved facilities), as appropriate;

(b) Alternatives that attain applicable and relevant federal public health or environmental standards;

(c) As appropriate, alternatives that exceed applicable and relevant public health or environmental standards;

(d) A no action alternative.

A single alternative may fit more than one category, and several alternatives may be developed for each category.

5. SCREENING ALTERNATIVES

Guidelines for screening alternatives are intended for CEARP sites falling under CERCLA Feasibility Study requirements. They should be implemented on a site-by-site basis as appropriate for CEARP sites not meeting those requirements. After developing alternatives, the next step involves a preliminary screening of alternatives based on an evaluation of (1) environmental criteria, (2) public health criteria, and (3) order of magnitude cost. This screening process permits an initial assessment of the feasibility of each alternative relative to the others.

The screening process eliminates alternatives that do not adequately protect public health and welfare, and the environment, or are much more costly than others without providing significantly greater protection. When alternatives are eliminated from further consideration, the CEARP Phase 3 Technological Assessment must document the rationale for excluding each dropped alternative.

In some situations, screening may eliminate all alternatives in one of the five categories listed in Section 4, "Development of Alternatives." When this occurs, at least one alternative for the category that was eliminated should be included in the "Summary of Alternatives" described in Section 7 and should be presented in the report with an explanation as to why it was eliminated at the screening stage.

5.1. SCREENING FOR IMPACT ON ENVIRONMENT AND PUBLIC HEALTH

Adverse impacts on the environment or on public health and welfare, which may preclude the use of each alternative, must be identified. Alternatives that will have significant adverse impacts or do not adequately protect the environment and public health should be eliminated. At this point, adequate protection should be thought of as a comprehensive response that addresses all identified pathways and points of exposure. In preparation for the cost screening, alternatives should be ranked in terms of benefits to the environment and to public health and welfare.

5.2. COST SCREENING

The object of cost screening is to eliminate alternatives that have costs significantly greater than other alternatives, but do not provide greater benefits or

reliability. The total should include the cost of implementing the alternatives and the cost of their operation and maintenance. The cost screening should be conducted only after the environmental/public health and technical feasibility screenings have been performed.

In preparing cost estimates for screening, certain limiting factors should be considered to control the level of effort expended in compiling the estimates. These factors include accessibility of data sources, time available, and degree of accuracy to be achieved. The following guidelines can be utilized when defining the level of effort in cost screening:

- Data sources should be limited to the *Remedial Actions Cost Compendium* (ELI 1984), *Handbook: Remedial Action at Waste Disposal Sites* (EPA 1985a), CEARP Phase 2 (for revising design assumptions where necessary), standard costs indices, and other readily available information.

- The time to prepare screening cost estimates should be limited to a few days.

- The objective in calculating the costs is to achieve an accuracy within -50 to +100 percent.

The screening can be divided into three basic tasks: (1) estimation of costs, (2) present worth analysis, and (3) cost screening.

5.2.1. Estimation of Costs

Alternatives are screened on the basis of both capital costs and operating and maintenance costs. These costs should reflect site-specific conditions and should be revised using the cost compendium (ELI 1984) or other standard cost guidance references.

Capital costs should include the following as applicable:

- Relocation (including transportation)
- Land acquisition or obtaining permanent easements
- Land and site development
- Buildings and services
- Equipment
- Replacement
- Disposal
- Engineering

- Construction
- State and local legal fees, licenses, and permits
- Contingency allowances
- Startup and shake-down
- Anticipated health and safety requirements during construction.

Operation and maintenance costs should include the following, when applicable:

- Operating labor
- Maintenance materials and labor
- Auxiliary materials and energy
- Purchased service
- Administrative services
- Insurance, taxes, and licensing
- A maintenance reserve and contingency fund.

5.2.2. Present Worth Analysis

After developing cost data, the user must determine the present worth of both the capital and other expenditures. Discounting to present worth is necessary when operation and maintenance costs are anticipated for one or more alternatives. Present worth (or present value) analysis enables the user to compare sets of costs by computing the current value of all costs incurred, whether they are incurred in the present or future. The present worth analysis conducted during screening relies on less refined cost data but is otherwise identical to the present worth analysis conducted during detailed cost estimation. As an example, this analysis could be based on the 10 percent discount rate prescribed by the Office of Management and Budget (OMB 1982). However, a calculation of alternative discount rates may be desirable (e.g., 4 or 7 percent) to observe the sensitivity of overall estimates to discount rates. This check is most useful in cases that involve replacement costs. In some instances, wastes removed from a site, such as fuel oils or other hydrocarbons, may be reusable. In such cases, revenues from the sale of removed materials should be considered in the present worth analysis. The procedures for conducting a present worth analysis are discussed in detail in the EPA *Remedial Action Costing Procedures Manual* (EPA 1983a).

5.2.3. Cost Screening

Present worth costs of competing alternatives should be evaluated and compared with benefits to the environment and to public health and welfare. Alternatives should be eliminated if they are significantly more expensive and offer similar or smaller benefits but no greater reliability than competing alternatives. Alternatives that are more expensive but offer substantially greater environmental and/or health benefits should not be eliminated.

6. DETAILED EVALUATION OF THE ALTERNATIVES

The guidelines for evaluating the alternatives in detail are intended for CEARP sites falling under CERCLA Feasibility Study requirements. The evaluation should be implemented on a site-by-site basis as appropriate for CEARP sites not meeting these requirements. The major concern in a detailed evaluation of alternatives is that the suggested alternatives be appropriate to site conditions. Following the preliminary screening, the remaining feasible alternatives should be subjected to a detailed analysis with respect to the following six criteria:

- Technical Feasibility
- Institutional Requirements
- Public Health Concerns
- Environmental Concerns
- Installation Operation Impacts
- Cost.

6.1. TECHNICAL ANALYSIS

Each remedial alternative should be evaluated for performance, reliability, implementability, and safety. EPA's *Handbook: Remedial Action at Waste Disposal Sites* (EPA 1985b) provides useful information.

6.1.1. Performance

Effectiveness and useful life determine the desirability of a remedial alternative. Effectiveness refers to the degree to which an action will prevent or minimize substantial danger to public health and welfare, or to the environment. The useful life is the length of time this level of effectiveness can be maintained.

Effectiveness - Remedial alternatives should be evaluated in terms of their ability to perform intended functions, such as containment, diversion, removal, destruction, or treatment. The effectiveness of alternatives should be determined either through design specifications or by performance evaluation. Any special site or waste conditions that affect performance should be considered, and the design should be tailored to accommodate those conditions. The evaluation should also consider the effectiveness of combining technologies. Standards, criteria, or guidelines are not

available for all situations at hazardous waste sites. In such cases, performance specifications based on acceptable engineering practice must be developed and used in evaluating alternatives.

The evaluation of onsite alternatives should include an analysis of factors at the site that could impact their effectiveness. Important factors include those listed in Table 3.3 and they should be considered to determine if onsite alternatives can be effective. Engineering modifications may be necessary to mitigate adverse conditions at the site.

Useful Life - Most remedial technologies, with the possible exception of destruction (e.g., incineration), deteriorate with time. Often, deterioration can be slowed through proper operation and maintenance, but the technology may nevertheless eventually require replacement. Each alternative should be evaluated in terms of the projected service life of its component technologies. Resource availability in the future life of the technology, as well as the appropriateness of the technology, must be considered in estimating the useful life of the project.

6.1.2. Reliability

The cost to install and operate remedial alternatives and the importance of protecting public health and the environment make reliability a serious concern. Information about the reliability of remedial technologies can come from their operational and maintenance requirements and their demonstrated reliability at similar sites.

Operational and Maintenance Requirements - Evaluations of remedial alternatives should emphasize the frequency and complexity of operational and maintenance requirements. Technologies requiring frequent or complex operational and maintenance activities should be regarded as less reliable than technologies requiring little or straightforward operation and maintenance. The availability and cost of labor and materials should also be considered.

Demonstrated Reliability - The technical analysis of remedial alternatives should not be based on the presumed performance of untested methods. An estimate of the probability of failure, in either qualitative or quantitative terms, should be

made for each component technology and for the complete alternative. Preference should be given to technologies that have proven effective under waste and site conditions similar to those anticipated. However, innovative or advanced technology should be evaluated as an alternative to conventional technology, if appropriate. If such technology is included in suggested remedial alternatives, information from research supporting its use and expected reliability should be documented. Sometimes bench-scale studies will be necessary to determine actual performance characteristics. These studies should be initiated as early as possible, preferably during CEARP Phase 2 - Confirmation.

6.1.3. Implementability

Another important aspect of remedial alternatives is their implementability; i.e., the relative ease of installation and the time required to achieve a given level of response. Ease of installation, often known as constructability, is determined by conditions both internal and external to the site. The time requirement consists of the time required to implement a technology and the time required before results are actually realized.

Constructability - The ability to actually build, construct, or implement the remedial technology on the site is fundamental to the technical analysis of alternatives. Conditions external to the site that affect implementability include the availability and acceptability of offsite disposal sites and the equipment available for construction. Also, public acceptance of the alternative can be of fundamental importance in determining whether the action can be implemented.

Time Requirements - The time element of remedial actions is an important aspect of remedial planning for a site. The emphasis should be on quickly eliminating exposure to hazardous substances. The time required to implement a remedy and the time required to realize beneficial effects should be addressed. However, the importance of timing depends on the nature of the hazard. Speed is more important at sites presenting immediate, rather than long-term, hazards.

Implementation time includes the time required for special studies, design, construction, and any other technical steps required. Time estimates should take into consideration normal weather conditions, unanticipated site conditions, and necessary

safety precautions. Alternatives should be evaluated in terms of the most likely construction schedule, based on experience at similar sites or on a standard engineering procedure, like critical path analysis.

Some remedial alternatives achieve instantaneous results (e.g., surface clean-up or the provision of alternative water supplies). Often, though, considerable time is required from the beginning of construction until the desired results are achieved. During this period, temporary measures, such as providing alternative potable water supplies are commonly taken to mitigate the threat. Alternatives should be evaluated in terms of the time required to produce beneficial results in the environment, exclusive of measures that provide temporary protection.

6.1.4. Safety

DOE has the responsibility for health, safety, and environmental protection programs at DOE-owned, contractor operated facilities. It is the policy of DOE to assure that DOE operations are conducted in a manner that will (1) limit risks to the health and safety of the public and employees, and (2) adequately protect property and the environment (DOE Order 5481.1A).

Each remedial alternative should be evaluated with regard to safety. This evaluation should include short-term and long-term threats to the safety of nearby workers, residents, and environments, as well as threats to workers during implementation. Major risks to consider are fire, explosion, and exposure to hazardous substances resulting from both onsite and offsite work while the remedial action is being implemented.

Prepared to ensure the health and safety of workers at uncontrolled hazardous waste sites, the joint guidelines of the EPA, the Occupational Safety and Health Administration (OSHA), and the National Institute for Occupational Safety and Health (NIOSH) may be used to determine risk to the health and safety of workers during implementation. Alternatives should be designed to minimize risk during implementation and should be evaluated in terms of such safety.

6.2. INSTITUTIONAL ANALYSIS

6.2.1. Compliance with Environmental and Public Health Statutes

DOE policy is to comply with applicable environmental and public health standards, guidelines, and criteria to the extent possible during remedial actions. Consideration of the alternatives presented in the CEARP Phase 2 - Confirmation and Phase 3 - Technological Assessment studies should give primary emphasis to alternatives that attain or exceed applicable environmental and public health standards, guidelines, and criteria.

DOE anticipates that most CEARP remedial actions will attain or exceed applicable standards. There may be situations in which a remedy is selected that exceeds a standard rather than simply attains it if, under the circumstances, a more protective level is appropriate. However, at times, applicable standards may not be able to be attained. This could occur in the following situations:

1. The selected alternative is not the final action and will become part of a more comprehensive action.

2. All of the alternatives that meet applicable standards fall into one of the following categories:

   - Technological impracticality: achievement of the standard at the site is technologically impractical from an engineering standpoint;

   - Unacceptable environmental impacts: all alternatives that attain standards would have unacceptable environmental or public health consequences.

If one of these situations exists, an alternative may be selected that does not completely attain all applicable or relevant environmental or public health standards. In such a situation, the alternative that most closely approaches the standard will be selected, and the reasons for not meeting the standard will be fully documented.

6.2.2. National Environmental Policy Act (NEPA)

Remedial actions taken pursuant to Sections 104 and 106 of CERCLA are generally exempt from NEPA, based on numerous court decisions holding that the EPA

carries out the functional equivalent of a NEPA review in its permitting and regulatory activities (EPA 1985a). CEARP Phase 3 will be implemented following EPA guidance under CERCLA to accomplish the functional equivalent of NEPA. Many elements of CERCLA remedial planning are also integral to NEPA review, i.e., evaluation of alternatives, analysis of environmental impacts, and public involvement. Therefore, steps to avoid duplicating the environmental requirements under CERCLA and NEPA should be taken for National Priorities List (NPL) sites. Consolidating documents, cross referencing (CEARP Phase 2)/feasibility study (CEARP Phase 3) public review periods are among the actions that can be taken to minimize duplication (EPA n.d.). The following steps should be implemented as appropriate to help ensure that proposed CEARP remedial actions achieve the functional equivalent of NEPA:

1. The process for determining the extent of the remedy required by CERCLA Section 105(3) and described in Section 300.68 of the NCP will be followed. This process includes the necessary and appropriate investigation and analysis of environmental factors as they specifically relate to a site, and alternatives that are being considered to correct the situation.

2. A meaningful opportunity for public comment on environmental issues will be provided before the final selection of a remedial alternative. To meet this requirement, DOE will allow both the opportunity and adequate time for the public to review the Technological Assessment. This should be accomplished as part of the community relations program, which will be established by each installation.

The focus of CEARP is broader than that of CERCLA (e.g., RCRA continuing release sites and activities under the DOE Surplus Facilities Management Program, which may not have to be addressed under criteria established for implementing CERCLA remedial activities). Therefore, implementation of programs designed to meet the functional equivalent of NEPA and comply with NEPA (e.g., the DOE-equivalent of a memo-to-file for clearly insignificant activities, an environmental assessment, and an environmental impact statement for more significant actions) will be established on a site-by-site basis. CEARP NEPA-related documentation and documentation for other environmental requirements (e.g., floodplain/wetland involvement) should be consistent with the guidance provided in DOE Order 5440.1C and AL Order 5440.1B (Implementation of the National Environmental Policy Act) and the DOE *Environmental Compliance Guide* (DOE 1981).

6.2.3. Coordination with Other Agencies

CERCLA, the NCP, and Executive Order 12316 delegate the authority to manage certain aspects of CERCLA responses to various federal agencies. (For example, the Federal Emergency Management Agency is authorized to manage relocations.) If coordination is required for any remedial alternative, the CEARP Phase 3 Technological Assessment should indicate that the appropriate agency has been or will be contacted and that the needed coordination mechanism either is in place or can be developed. Certain other agencies may also give advice useful in planning and implementing remedial actions.

6.2.4. Community Relations

Community relations are an integral part of every remedial action, regardless of the choice of remedial alternatives. The EPA's *Community Relations in Superfund: A Handbook* (EPA 1983b) provides procedural guidelines on planning and implementing effective community relations programs. The EPA guidance should be implemented as appropriate under CEARP to accomplish the functional equivalent of NEPA.

In evaluating remedial alternatives, the public's perception of the alternatives should be considered. A community relations plan is a management and planning tool, which outlines the specific communications activities to be used during a response and the integration of these activities with technical work at the site. The plan should be based on interaction with local officials, civic leaders, community residents and leaders, and public interest groups, as appropriate. Steps should be taken to address public concerns and incorporate citizen input when feasible.

6.3. PUBLIC HEALTH ANALYSIS

The remedial action selected for a hazardous waste site must adequately protect public health and welfare. This requires documenting that the action minimizes the long-term effects of any residual contamination and protects the public both during and after the action. EPA's Office of Research and Development (ORD) (risk assessments) or the Agency for Toxic Substances and Disease Registry (ATSDR) (human

health studies, health assessments, health advisories) may be contacted for help in evaluating the effect on public health at a site.

A public health evaluation should be made for each site, although the form and extent of the assessment will depend on the situation. The evaluation should consist of the following steps:

- A baseline site evaluation to provide a preliminary assessment of the public health conditions at the site;
- An exposure assessment to analyze the extent and duration of human exposure to site contaminants in the absence of remedial action;
- A standards analysis to compare projected environmental concentrations to appropriate ambient standards or criteria;
- An evaluation to assess the short- and long-term effects and the efficiency of the proposed remedial alternatives with respect to removal or mitigation exposures identified during the exposure assessment.

6.3.1. Baseline Site Evaluation

The baseline site evaluation is the first step in the public health evaluation for all sites. First, the available data relevant to a public health evaluation should be collected, organized, and reviewed. This information should include background data, disposal history (and records, if available), types of remedial technologies considered, onsite and offsite hazardous substance data, environmental data (e.g., topography and hydrogeology), information on local demography, and information on human health effects (if available). Sources should include preliminary assessment data and reports, field reports, confirmation scoping documentation, and analytical data and reports available from ongoing studies for site characterization and alternatives screening.

Of particular importance in this initial review is the information used to define the type of action likely to be taken at a site and the level of detail required for the exposure assessment. Sites involving contamination that has not migrated much beyond the source generally require relatively simple source control measures. Sites that have evidence of contaminant migration beyond the source (e.g., into groundwater) may require source control options as well as management of migration alternatives. Some sites may have such extensive migration of contaminants that only

management-of-migration options are suitable. This distinction is important in determining the extent of analysis and evaluation required for each alternative. Thus, all data on the extent of contamination, contaminant mobility and migration, and types of remedial alternatives should be carefully reviewed. The result of the baseline evaluation is a determination of the data necessary to conduct the exposure assessment and the level of detail required in this assessment.

To be considered a source control situation, the site and the remedial alternatives must meet all of the following conditions:

- The known and suspected chemical contamination at the site is restricted to the proximity of its original location;
- The remedial alternatives considered include both onsite control measures and removal and offsite disposal or treatment at a facility approved under RCRA or other environmental laws including TSCA, CWA, CAA, MPRSA, or SDWA, as appropriate;
- The remedial alternatives will prevent or minimize releases of contaminants.

Management-of-migration measures should be evaluated if these conditions are not met.

6.3.2. Exposure Assessment

For sites at which only source control remedial measures are being evaluated, a qualitative assessment of the potential threats to public health in the absence of remedial action is generally all that is required. An in-depth quantitative analysis is not warranted in situations in which (1) contamination has not migrated into any medium of transport capable of producing human exposures and (2) the only actions under consideration are those that prevent such migration. However, at a minimum, a qualitative exposure analysis is required to evaluate the types, amounts, and concentrations of hazardous substances at the site, their toxic effects, the proximity of target populations, the likelihood of chemical release and migration from the site, and the potential for exposure.

For sites at which management-of-migration options are being considered, a quantitative exposure assessment should be undertaken. The objective of this exposure assessment is to estimate the frequency, magnitude, and duration of human exposure to hazardous substances released from a site. Several tasks are required in this assessment:

- Identifying chemicals present at the site and selecting indicator chemicals (based on toxicity, radiation, persistence, mobility, and quantitative present);
- Identifying points of potential human exposure and exposure pathways for each remedial alternative considered;
- Characterizing populations potentially at risk;
- Estimating the environmental concentrations of each indicator substance at key exposure points;
- Assessing risk to relate exposure and/or regulated as background levels to expected health consequences as epidemiological estimates.

In some situations, there may only be a small number of hazardous substances present and all substances may be evaluated. For sites at which there are a large number of hazardous substances, specific indicator substances may be selected to facilitate a manageable analytical and design effort. These indicators should represent the most toxic, persistent, mobile, and prevalent substances at the site.

Table 6.1 provides a list of questions that should be answered in an exposure assessment. These questions apply to both qualitative and quantitative assessments. Because extreme uncertainties are likely, a critical part of all exposure assessments is documenting assumptions and other sources of uncertainty.

6.3.3. Environmental Standards

To formulate alternatives requires that standards, criteria, or guidelines be determined. Following the exposure assessment, estimated environmental concentrations of the indicator chemicals selected for a particular site should be compared with these standards, criteria, and guidelines. This comparison must be made for each alternative considered. A listing of standards, criteria, and guidelines can be found in Table 5.2 in EPA 1985a. In completing the public health evaluation, the extent to

which each alternative attains or exceeds standards, criteria, advisories, or guidelines should be carefully documented.

As a result of various technical aspects of standards development, some concentration limits may require adjustment before being applied to a specific site. The first step is to determine whether each concentration limit is directly applicable or must be adjusted for the specific site conditions. Relevant or applicable ambient concentration limits are not available for many hazardous substances commonly found at sites. When no relevant or applicable standards are available, EPA should be consulted on a case-by-case basis for further guidance.

6.4. ENVIRONMENTAL ANALYSIS

In keeping with DOE's resolve to comply with the intent of NEPA and the NCP, an environmental analysis must be included in the CEARP Phase 3 Technological Assessment documents. This will eliminate duplication of paperwork and still serve to analyze those environmental components of primary concern.

6.4.1. Overview of the Environmental Analysis

An analysis of the environmental effects of all alternatives should be performed for all sites. The analysis must include the current site situation and also the environmental conditions anticipated if no remedial actions are taken (no action alternative). The analysis will (1) determine the value and/or uses of the areas that are contaminated, threatened with contamination, or otherwise affected, (2) identify and quantify to the extent necessary the impacts that are likely, (3) identify mitigations to minimize adverse impacts, and (4) assess the significance of the mitigated impacts.

6.4.2. Evaluation of Alternatives

The environmental analysis should address the effects of each remedial alternative under consideration, including long-term (i.e., post-construction) and short-term (i.e., construction) effects. The level of detail in the environmental analysis should depend on the degree of actual or potential impact on the various environmental components. An appropriate level of detail will allow a meaningful comparison of

the benefits expected from different alternatives and a determination of the impacts from remedial construction and operations. Factors generally considered in determining the detail required include (1) effects on environmentally sensitive areas, (2) violation of environmental standards, (3) short- and long-term effects, and (4) irreversible commitments of resources.

Findings should be presented to allow comparing the environmental effects of alternatives. Environmental impacts of remedial alternatives may include effects on hydrology, geology, air quality, biology, socioeconomics, land use, and on archaeological and historic sites. In general, each alternative will be evaluated by considering the beneficial effects of the response, such as minimization of long-term health effects, elimination/reduction of the release of contaminants, improving final environmental conditions, and improving the biological environment and the resources that people use. Expected adverse effects of remedial construction or operations should also be considered.

6.4.3. Mitigative Measures

If any alternative might have inevitable or irreversible effects, the DOE will state the mitigative measures to be taken in conjunction with the alternative. The statement will discuss the technology to be employed and its expected mitigating effects. The impacts expected to remain after mitigative measures are taken should be clearly identified for each alternative.

6.5. COST ANALYSIS

This section outlines the approach recommended to develop and analyze costs for each of the remedial action alternatives. More detailed costing procedures can be found in the *Remedial Action Costing Procedures Manual* (EPA 1983a). In developing detailed cost estimates, the following steps should be performed:

1. Estimation of costs: estimate capital costs and costs of operation and maintenance for remedial action alternatives.

2. Present worth analysis: using estimated costs, calculate annual costs and present worth for each remedial action alternative.

3. Sensitivity analysis: evaluate the sensitivity of cost estimates to changes in key parameters, such as discount rates.

4. Summary of alternatives analysis: summarize data used in the alternatives analysis to use to select a remedial action alternative.

6.5.1. Estimation of Costs

All capital and operational and maintenance costs for each remedial action alternative must be identified and estimated. However, distinguishing capital costs from operational and maintenance costs is not easy for response activities.

Capital costs consist of direct (construction) and indirect (nonconstruction and overhead) costs. Direct costs include expenditures for equipment, labor, and materials necessary to install remedial technologies. Indirect costs include expenditures for engineering, financial, and other services not part of actual installation activities but required to complete the remedial alternatives. The remedial action phase may include expenditures that traditionally have been considered operational and maintenance costs, when construction by itself will not achieve clean-up goals. For example, a remedial action addressing groundwater contamination may involve pumping, treating, and reinjecting groundwater in order to achieve site clean-up. In general, the following criteria should be used to define remedial actions:

- Remedial actions include measures that (1) control contamination at or near the source of the release, (2) result in the initial mitigation of a release to levels protecting public health and welfare and the environment, (3) have a definable endpoint based on contaminant levels, (4) are related to the initial construction effort (i.e., capping) or are of limited duration (usually less than 4 years).

Operational and maintenance costs are post-construction costs necessary to ensure the continued effectiveness of a remedial action. They may be defined as follows:

- Post-closure activities include measures that (1) are required to maintain releases at levels protective of public health and welfare and the environment, (2) require long-term implementation, (3) have no definable endpoint, (4) maintain the physical integrity of the remedy, or (5) provide for scheduled monitoring or repair.

- Post-closure activities occur after completing the remedial action and include continued operations necessary to stop releases.

Direct capital costs may include:

- Construction - costs of materials, labor (including fringe benefits and worker's compensation), and equipment required to install a remedial technology;

- Equipment - costs of remedial action and service equipment necessary to accomplish the remedy; these materials remain until the site remedy is complete;

- Land and site development - expenses associated with purchasing land and developing existing property;

- Buildings and services - costs of process and nonprocess building, utility connections, purchased services, and disposal;

- Relocation - costs of temporary or permanent accommodations for affected nearby residents;

- Disposal - costs to transport and dispose of waste materials, such as drums and contaminated soils.

Indirect capital costs may include:

- Engineering - costs of administration, design, construction supervision, drafting, and testing of remedial action alternatives;

- Legal and license or permit - administrative and technical costs necessary to obtain licenses and permits for installation and operation;

- Startup and shakedown - costs incurred during remedial action startup;

- Contingency - funds to cover costs resulting from unforeseen circumstances, such as adverse weather conditions, strikes, and inadequate site characterization.

Operational and maintenance costs may include:

- Operating labor - wages, salaries, training, overhead, and fringe benefits associated with the labor needed for post-construction operations;

- Maintenance materials and labor - costs for labor, parts, and other resources required for routine maintenance of facilities and equipment;

- Auxiliary materials and energy - costs of such items as chemicals and electricity for treatment plant operations, water and sewer service, and fuel;

- Purchased services - sampling costs, laboratory fees, and professional fees for which the need can be predicted;

- Administrative - costs associated with administering remedial action operation and maintenance not included under other categories;

- Insurance, taxes, and licensing - costs of such items as liability and sudden accidental insurance; real estate taxes on purchased land or rights-of-way; licensing fees for certain technologies; and permit renewal and reporting costs;

- Maintenance and contingency - annual payments into escrow funds to cover (1) costs of anticipated replacement or rebuilding of equipment and (2) any large unanticipated operational and maintenance costs;

- Rehabilitation - costs to maintain equipment or structures that wear out over time;

The following sources may be used to estimate costs:

- Vendor estimates

- Estimates for similar projects

- Standard costing guidance

- Labor and energy cost data published by the Bureau of Labor Statistics (Department of Labor) and DOE, respectively.

Cost estimates are frequently based on data several years old and must be updated for the current year. Appropriate cost indices include the following:

- Engineering News Record Construction Cost Index (capital costs of construction)

- Marshall and Stevens Index (for treatment facility costs)

- American City and County Municipal Cost Index (manpower costs)

- The "Producer Price Index for Finished Goods," published by the Department of Labor in the Monthly Labor Review.

The accuracy of costs developed for a CEARP Phase 2 Confirmation or Phase 3 Technological Assessment must be considered. Typically, these "study estimate" expense provide an accuracy of -30 to +50 percent and are prepared at relatively low expense using data available from the Phase 2 - Confirmation. Costs developed with accuracies other than -30 to +50 percent should be identified.

6.5.2. Present Worth Analysis

Present worth analysis is a standard method used to evaluate expenditures that occur over different time periods by discounting all future costs to a common base year, usually the present. This allows the cost of remedial action alternatives to be compared on the basis of a single figure representing the amount of money, that, if invested in the base year and disbursed as needed, would be sufficient to cover all costs associated with the remedial action over its planned life.

In conducting the present worth analysis, assumptions must be made regarding the discount rate and the period of performance. For the first, a discount rate of 10 percent before taxes and after inflation should be assumed, as outlined in OMB Circular No. A-94 (OMB 1982). In addition to using a discount rate of 10 percent, sensitivity analyses using other discount rates (e.g., 4 percent, 7 percent) should be conducted. The period of performance should not exceed 30 years for the purpose of detailed feasibility analysis.

6.5.3. Sensitivity Analysis

After the present worth of each remedial action alternative has been calculated, each cost should be evaluated through sensitivity analysis for effects of variations in assumptions. A sensitivity analysis assesses the effect that variations in specific assumptions associated with the design, implementation, operation, discount rate, and effective life of an alternative can have on the estimated cost of the alternative. These assumptions depend on the accuracy of the data developed during Phase 2 - Confirmation and on predictions of the future behavior of the remedial technology and are subject to varying degrees of uncertainty. The sensitivity of costs to these uncertainties can be observed by varying these assumptions and noting the effects on estimated costs. Sensitivity analysis can also be used to optimize the design of a remedial action alternative, particularly when design parameters are interdependent (e.g., treatment plant capacity for contaminated groundwater and the length of the period of performance).

A sensitivity analysis is especially concerned with factors that can significantly change overall costs with only small changes in the values of the factors.

Other factors chosen for analysis should be those for which the value is most uncertain. The results of the analysis can be used to identify "worst case" scenarios and to revise estimates of contingency or reserve funds.

The following factors should be primary candidates to consider in conducting sensitivity analysis:

- Effective life of remedial action (replacement)
- Operation and maintenance costs
- Duration of clean-up (period of performance)
- Extent of clean-up, given uncertainty about site conditions
- Other design parameters
- Discount rate.

6.5.4. Summary of Alternatives Cost Analysis

Data developed in the cost estimation and present worth analysis stages are compiled in a summary table to describe the alternatives. Cost-effectiveness determinations must have a common basis for comparing costs when evaluating various remedial action alternatives. Therefore, three critical cost elements should be developed and assembled for input into the cost-effectiveness analysis: (1) total capital cost, (2) present worth costs, and (3) the cash flow over the life of the remedial action alternative.

The cash flow of a remedial action alternative presents a tally of the anticipated costs for each year of the remedial action alternative, adjusted to present worth. The presentation of costs in this manner allows the identification and assessment of future capital and operational and maintenance outlays, which are important in planning budgets.

The presentation of the costs for each alternative should include all costs associated with implementing the alternative. Costs common to all alternatives must be included with each alternative so that the total estimated cost for each is readily apparent.

Table 6.1. Questions in Exposure Assessment

1. Hazardous Substance Identification

   * What hazardous substances are known or suspected to have been disposed of at the site?
   * What quantities of each chemical were disposed of?
   * How were they disposed of (bulk dumping, drums, bulk storage)?
   * Which hazardous substances are now in the environment (air, land, surface water, groundwater)?
   * What are the ambient levels of these hazardous substances in the air, groundwater, surface water, and soil?
   * What conditions or events could affect contamination levels on- and offsite?
   * What hazardous substances can be used as indicators of the overall risk at the site?

2. Surrounding Population

   * Describe the population surrounding the site:
     - How many people are potentially exposed?
     - Who are they (especially high-risk groups, e.g., children, the elderly, or the ill)?
     - Where is the population located relative to the site?
     - Is the area mainly for residence or business?
     - What type of access is there to the site?
     - What normal activities might be affected by contamination (e.g., farming by contaminated soil)?
   * What, if any health-related complaints have been received? Have these been documented or proven to be related to the site?

3. Potential Exposure Routes

   * Unavoidable onsite exposure (residences, etc.)
     - How are people exposed?
     - What are the routes of exposure (through inhalation, the skin, or ingestion)?
     - To what hazardous substances are people exposed?
     - To what levels are they exposed (use monitoring data and modeling if appropriate)?
     - How many people are exposed at these levels (i.e., through each pathway)?
   * Voluntary onsite exposure
     - How are people exposed?
     - What are the routes of exposure (through inhalation, the skin, or ingestion)?
     - To what hazardous substances are people exposed?
     - To what levels are they exposed (use monitoring data and modeling if appropriate) and how many people are exposed at these levels (i.e., through each pathway)?
     - Can this exposure be prevented?

Table 6.1. (Continued)

* Offsite exposure (actual and potential)
  - What environmental routes must hazardous substances take for exposure?
  - How likely are these routes of exposure?
  - When is exposure expected to occur?
  - How are people exposed (through inhalation, the skin, or ingestion)?
  - To what hazardous substances are people exposed?
  - To what levels are they exposed (use monitoring data and modeling if appropriate)?
  - How many people are exposed at these levels (i.e., through each pathway)?
* Other nonwaste-related exposures
  - Is the population, or are segments of the population, exposed to any of these hazardous substances from other routes, e.g., in the workplace?
  - Are the ambient environmental levels of any of the hazardous substances known?
  - Are they suspected to be abnormally high for any reason?

4 The Effect of Not Taking Action

* Technical Issues
  - What will happen if no action is taken (e.g., lagoon failure, aquifer contamination, drum failure, air contamination)?
  - What hazardous substances will be of concern?
* Exposure Issues
  - What exposure will result from not taking action?
  - Will exposure increase indefinitely?
  - Will exposure rise and then fall? Over what time?
  - What is the predicted range of eventual contamination and exposure?
  - What are the means and reliability of quantitative factors for relating exposures to potential health effects (e.g., radiation dose-effect risk factors are generally better known than those for organic chemicals).

7. COMPARATIVE EVALUATION OF ALTERNATIVES

Pertinent information on costs, health risks, environmental effects, technical reliability, implementability and other factors should be summarized for each remedial alternative, including the no-action alternative, so that the key differences among them are evident. Remedial alternatives that attain or exceed the requirements of applicable environmental regulations should be identified. The summary's precision should be consistent with the extent of knowledge about the problems at the site and the expected results of remedies.

The following information, at a minimum, should be summarized for each remedial alternative:

(1) Present worth of total costs: The net present value of capital and operating and maintenance costs.

(2) Health information: For the no-action alternative, a quantitative statement including an estimated range of maximum individual risks or cumulative population group risks where appropriate should be presented. For source control options, a quantitative risk assessment is not required. For management-of-migration measures, a quantitative risk assessment, including an estimated range of maximum individual risks or cumulative population group, is required.

(3) Environmental effects: To simplify the evaluation, only the most important effects should be summarized. Reference can be made to supplemental information in a separate table, if necessary.

(4) Technical aspects of the alternative: This information may strongly influence the selection of a remedial alternative, and it is important to describe carefully the technical advantages and disadvantages of alternatives. Such information generally is based on the professional opinion of engineers familiar with the site and with the technologies included in the alternatives.

(5) The extent to which alternatives meet the technical requirements and environmental standards of appropriate environmental regulations: This information should be arrayed so that differences among the alternatives, in terms of how they satisfy such standards, are readily apparent. The kinds of standards applicable at the site may include: (1) RCRA design and operating standards, (2) drinking water standards, and (3) environmental discharge standards.

(6) Community effects: The types of information that should be provided include (1) the extent to which implementing an alternative

would disrupt the community (e.g., traffic, temporary health risks, and relocation) and (2) the likely public reaction.

(7) Remedies involving removal of materials for offsite disposal: This information should document compliance with EPA policy on selecting offsite facilities for disposal of materials from CEARP sites.

(8) Other factors: This category of information should include institutional factors that may inhibit implementing a remedial alternative and other important site-specific factors.

8. RECOMMENDED REMEDIAL ACTION

A remedial action will be recommended for the site(s), based upon the detailed evaluation of the candidate alternatives, including appropriate consideration of input resulting from public review. Selection of the recommended remedial action will be based upon meeting the technical objectives to solve the environmental problems at a site(s), balanced with the impacts and costs. A description of the recommended remedial action will be included and should include the following as appropriate:

- A review of what the remedial action will and will not accomplish;
- A review of how the remedial action addresses the requirements and the intent of the NCP, for example, placing an emphasis on a permanent remedy to the identified site problem(s), utilizing innovative technologies;
- Special engineering considerations and special studies needed during the final design;
- Operation, maintenance, and monitoring requirements;
- Offsite disposal needs and transportation plans;
- Temporary storage requirements;
- Regulatory permit requirements;
- Brief descriptions of the environmental and public health problems that may be encountered during implementation, and maintenance of the remedial alternative, and;
- Means of mitigating the associated environmental and public health problems (and their costs) and addressing the identified/determined standards.
- Criteria necessary for the Phase 4 design of selected remedial actions, including conceptual designs and preliminary engineering, as required.

Additionally, resource requirements should be identified for CEARP Phase 4, including proposed finding level, schedule, land requirements, availability of required equipment, materials, supplies, and labor.

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APPENDIX B

RISK/ENDANGERMENT ASSESSMENT PLAN

1. INTRODUCTION

1.1. BACKGROUND

This Risk/Endangerment Assessment Plan documents a conservative approach for determining the upper boundary of risk to the "maximally exposed" and "average exposed" individual associated with present contamination at Rocky Flats Plant. It is designed to identify risks that could be incurred from a particular site if the "no action" plan were taken, plus feasible remedial actions. The technical direction for the performance of this study comes from several sources, including *Guidance on the Performance of Endangerment Assessments (EPA 1985), Handbook of Endangerment Assessments (EPA 1985), and The Superfund Public Health Evaluation Manual (EPA 1986).*

Risk estimates will be dependent on assumptions about the mechanisms of contamination release, dispersion, and pathways by which contaminants may be inhaled, ingested, or absorbed by the population surrounding the site, and the health effects caused by exposure to these substances.

Risk to public health is a function of several factors. In order for chemicals to pose a risk, two factors must exist simultaneously. The substance must be toxic to a particular receptor at a specified concentration and there must be some chance that an individual can come into contact with a sufficient amount of the toxic substance.

The risk/endangerment assessment will address the toxicity and amounts of substances released at Rocky Flats Plant, and the chance and degree of human exposure. Existing data will be used to assess risk. All data collected under the CEARP site characterizations (remedial investigations) will be included. Additional data will be collected if warranted.

1.2. REQUIREMENTS

Stringent requirements are necessary to provide an unbiased risk/endangerment assessment.

These requirements are as follows:

- an unbiased comprehensive investigation with no preconceptions as to the significance of individual sources,
- a series of decision points to evaluate progress and, if necessary, redirect efforts on an iterative basis,
- definitive conclusions that support the selection of an alternative remedial action, and
- a well documented Quality Assurance Program.

1.2.1. Quality Assurance and Quality Control Considerations

When errors in sampling, preservation, or analytical method execution are identified, results will be rejected following the guidance provided in the IGMP/CSPCP Quality Assurance/Quality Control Plan.

1.2.2. Exposed Population Analysis

The analysis of potential exposure to contamination will address both onsite and offsite populations. Employees have executed waivers of liability to work at DOE-Albuquerque Operations Office facilities; however, these work forces are being included in the risk/endangerment assessments following the guidance provided in the DOE CERCLA order (DOE Order 5480.14).

2. TECHNICAL WORK PLAN

2.1. OVERVIEW

The objective of this risk assessment is to determine if potential harm to public health and the environment is posed by release of hazardous substances from Rocky Flats Plant. An assessment will be made for the plant as a whole and for solid waste management units as appropriate. This will be accomplished by identifying and characterizing the following data:

- hazardous substances and/or wastes present in all relevant media (e.g., air, surface water, sediment, groundwater, and soil),
- environmental fate and transport mechanisms within specified environmental media (e.g., chemical and biological degradation processes),
- exposure pathways and extent of expected exposure,
- populations at risk,
- intrinsic toxicological properties of specified hazardous substances, and
- extent of expected harm and the likelihood of such harm occurring (i.e., risk characterization).

The risk/endangerment assessment process will have five separate components:

- contamination characterization
- environmental fate and transport assessment
- exposure assessment
- toxicity assessment
- risk characterization.

A brief description of the major technical components of the risk assessment are discussed below. Figure B.1 provides a schematic of the risk assessment process and the relationship of its components.

2.2. CONTAMINATION CHARACTERIZATION

The purpose of the contamination characterization is to provide a framework for establishing background descriptions and contamination history. It identifies and

quantifies the contaminants present at the site. "Contaminants of Concern" (those that best represent the range of physiochemical and toxicological properties) will be selected during the contamination assessment.

Objective: Determine the extent and concentrations of contaminants at and around the facility.

2.2.1.. Review of Available Data

Available sampling data will be reviewed to determine whether additional data need to be collected to thoroughly characterize the concentrations and physical distribution of installation/site-related contaminants. General recommendations will be made for the collection of additional samples, if warranted.

Technical Elements

- Review all available sampling data and associated quality assurance/quality control information for the installation/sites.
- Determine data adequacy with regard to locations sampled, number of samples taken, and parameters analyzed.
- Propose recommendations for additional sampling and analysis.

2.2.2. Contamination Description

A description of the contaminant concentration levels found in environmental media at and near the installation/sites will be presented. Concentration contour maps will be provided where applicable and will be in a format directly comparable to other pathways data. The technical elements of this task will involve the preparation of a "Contamination Description" worksheet.

Technical Elements

- Identify the chemical contaminants present on the installation/sites.
  - Acquire, compile, and process available data to describe chemicals that represent potential contaminants.
- Determine the extent of chemical contamination.

- For each of the listed chemicals, determine the ranges of concentrations in the affected media, and the geographic area in which they are distributed.

- When possible, compare monitoring data to background concentrations. Eliminate chemicals that do not exceed background from the list.

- Determine how the substances are distributed in the environment.

  - For each of the listed chemicals, identify the media (air, water, soil, groundwater) affected.

2.2.3. Identification of "Contaminants of Concern"

"Contaminants of Concern," also known as "indicator chemicals," represent the site-related contaminants that pose the greatest hazard to human health or to the environment. They will be selected according to their (1) intrinsic toxicity, (2) magnitude (concentration and/or quantity) of contamination, (3) mobility in the environment, and (4) environmental persistence.

Technical Elements

- For nonradioactive contaminants, the contaminants of concern will be selected using guidelines described in the Superfund Public Health Evaluation manual (U.S. EPA 1985). These steps include, but are not limited to, the following activities:

  1) Calculation of indicator scores (based on concentration and toxicity) for nonradioactive chemicals.

  2) Initial selection of nonradioactive indicator chemicals based on indicator scores.

  3) Final selection of indicator chemicals based on consideration of other factors, including relevant chemical properties (e.g., water solubility, vapor pressure, organic carbon partition coefficient, and persistence).

     - All radioactive substances measured at levels above natural background will be considered contaminants of concern.

2.3. ENVIRONMENTAL FATE AND TRANSPORT ASSESSMENT

This assessment describes the potential for offsite migration of contaminants and provides estimates of the direction and rate of movement of contaminants in various environmental media. The assessment will include information on site-specific environmental factors that may significantly affect the environmental fate and transport of contaminants. Profiles of environmental fate and transport processes will be developed for each of the contaminants of concern.

Objective: Describe the fate and transport mechanisms that may affect the migration of contaminants from the installation/sites.

2.3.1. Description of Environmental Setting

A description of the environmental setting for the installation/sites, including important geologic, hydrologic, and atmospheric data will be presented. Potential migration pathways for the installation/sites will be discussed. These data will be thoroughly discussed and presented in a form that will facilitate evaluating remedial alternatives.

Technical Elements

- topography and surface water
- geology and groundwater
- meteorology/climatology
- biological regime
- migration pathways (listed below)

  - soil ---> groundwater (alluvium and valley fill materials, Arapahoe formation);

  - soil ---> groundwater (alluvium and valley fill) ---> surface waters (Woman Creek, Walnut Creek)

  - soil ---> groundwater ---> surface water ---> air

  - soil ---> surface water

  - soil ---> surface water ---> air

  - soil ---> air

2.3.2. Contaminant Release Analysis

Contaminant release analysis will involve the identification of potential and actual onsite sources of release for each of the contaminants of concern listed for the installation/sites. Estimates of the magnitude of potential release rates will be made.

Technical Elements

- Identify potential sources of release for each contaminant of concern.

  1) The contaminant concentrations in each of the affected media will be summarized.

  2) Actual/potential release pathways will be identified for each source. Releases to the following media through the listed mechanisms will be considered:

     - Air

       - generation of fugitive dusts (airborne wastes and contaminated soil particles)

       - volatilization

     - Surface water

       - groundwater discharge

       - runoff

     - Groundwater

       - leaching from contaminated soils

     - Soil

       - impoundment failure

       - runoff

       - spills

     - Biota

       - terrestrial/aquatic bioconcentration from direct uptake (ingestion) and from indirect uptake (absorption)

- Determine the likely contribution of each source of contaminant release to total contaminant release. Release to each medium will be evaluated and quantified to the greatest extent possible, based on the following:

  - contaminant concentrations
  - physical and chemical properties of the contaminants
  - climatological site parameters
  - hydrogeological site parameters

2.3.3. Environmental Fate and Transport Analysis

Technical Elements

(1) Determine the relative importance of environmental fate processes for each contaminant of concern in each potential migration medium.

(a) Inter-media physical fate processes to be considered include, but are not limited to,

- Sorption
  - soils
  - sediments
  - suspended particulates (surface water, groundwater)
- Volatilization
- Infiltration
- Bioaccumulation

(b) Inter-media chemical fate processes to be considered include, but are not limited to,

- Photolysis
- Hydrolysis
- Oxidation
- Biodegradation
- Rates of decay (radioactive substances)

(2) Quantify environmental fate and transport processes.

(a) Where possible use average release rate estimates derived during the contaminant release analysis to generate estimates of the direction of movement of contaminants and estimates of expected concentration of contaminants in various environmental media.

(b) Report any monitoring data to provide conservative estimates of final concentrations and the serial extent of contaminant migration.

(3) Determine if a need exists for "fate and effect" modeling (e.g., solute transport for groundwater and surface water; virtual point source for air).

(4) Results will be provided in a tabular as well as graphic format that will allow comparison to previously derived information.

2.4. EXPOSURE ASSESSMENT

The purpose of the exposure assessment is to identify the actual or potential routes of exposure, characterize the population exposed, and determine the extent of exposure. Information on expected doses received by a population will include a summary of the potential total dose received as a result of exposure.

Objective: Evaluate the actual and potential exposure levels to contaminants of concern from the installation/sites.

The following references will be used to derive estimates of exposure levels and dose.

a) *Short Course on Integration of Exposure and Risk Assessment*, Part 3. Exposure Assessment Methods (Schaum 1984).

b) *Development of Statistical Distributions or Ranges of Standard Factors used in Exposure Assessments* (Anderson et al. 1984).

The uncertainty associated with the exposure values is a function of the input parameters used throughout the exposure assessment process. As a result, all exposure calculations for the risk assessment will be adequately documented. Assumptions made in support of these calculations require justification, which will be included as part of the assessment document.

2.4.1. Identification of Exposed and Potentially Exposed Populations

Technical Elements

- Compare data on the distribution of environmental contamination with population data.

- Characterize the human, animal, and plant populations that may be exposed to the contaminants of concern for all potential migration pathways.

- Develop the most recent census tract information regarding population distibution.

- Obtain any available information regarding land development plans in the area from local agencies/developers to determine not only projected land and water use plans, but also future populations that may be at risk.

2.4.2. Characterization of Exposed Populations

Technical Elements

- Those groups within the exposed or potentially exposed populations that may experience a greater risk than the average populations will be identified.

2.4.3. Determination of Population Exposure Levels

Technical Elements

- Examine activities of potentially or actually exposed population to determine level of exposure in employment and recreation.

2.4.4. Development of Exposure Coefficients

Technical Elements

- Where possible, evaluate information on frequency and magnitude of contact with contaminants to yield a quantitative value of the amount of contaminated medium contacted per day for each exposure route.

A list of exposure coefficients is provided in *Superfund Exposure Assessment Manual* (Schultz et al. 1984).

2.4.5. Determination of Population Dosage Levels

Technical Elements

- The results of the Contaminant Release Analysis, Environmental Fate Analysis, and Exposed Population Analysis will be integrated to determine the cumulative dose of each contaminant incurred by the exposed population.

- For each target population "worst case" and "most probable case" estimates will be made of the total daily exposure/dosage to each contaminant of concern.

  1) Frequency and magnitude of contact with contaminants through each exposure route will be evaluated, e.g., average daily intake of drinking water, grams of fish consumed/day, volume of air inhaled/day.

  2) Rates of absorption will be characterized to the greatest extent possible for each contaminant of concern through each exposure route.

  3) Dosages will be determined for each exposure route on the basis of predicted exposure levels, frequency of contact, and absorption factors.

  4) Total dosages of each contaminant of concern will be calculated by adding dosages through all exposure routes.

2.5. TOXICITY ASSESSMENT

The toxicity assessment will present a characterization of the key toxicological properties of each of the contaminants of concern. The characterization will identify indices of toxicity, acceptable daily intakes, and estimates of unit cancer risk where this information is available.

Objective: Characterize the toxicities to human health and the environment associated with exposure to the contaminants of concern.

A toxicity profile for each contaminant of concern will be derived from current toxicological literature and will involve a critical evaluation and interpretation of all relevant data. The profile will include a consideration of doses used, routes of exposure, types of adverse effects manifested, and quantitative indices of toxicity.

Information concerning chemical, physical, and toxicological properties will be gathered from standard references and government documents. If necessary, a computer search will be performed to obtain additional information.

2.5.1. Literature Search

Technical Elements

- Potential sources of information include (but will not be limited to) the following EPA documents/references:

Criteria Document - Ambient Water Quality	Office of Water Regulations and Standards
Criteria Document - Air	Office of Air Quality Planning Standards (OAQPS)
Criteria Document - Drinking Water	Office of Drinking Water (ODM)
Chemical Hazard Information Profile (CHIP)	Office of Toxic Substances (OTS)
Chemical Profile	Office of Waste Programs Enforcement (OWPE)
Health Assessment Document	Office of Health and Environmental Assessment (OHEA)
Health Effects Assessments	Office of Emergency and Remedial Responses (OERR)
Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment	Office of Radiation Programs
Quality Criteria for Water 1986	Office of Water, Planning and Standards

- Non-EPA references that will be considered for review will include (but not be limited to):

  - American Conference of Government Industrial Hygienists (ACGIH), 1985.

  - Threshold Limit Values and Biological Exposure Indices for 1986-1987.

  - G. D. Clayton and F. E. Clayton, eds. *Patty's Industrial Hygiene and Toxicology* (John Wiley & Sons, New York, 1981).

  - I. N. Sax, *Dangerous Properties of Industrial Materials*, 6th ed. (Van Nostrand Reinhold Company, New York, 1984).

- United States Department of Health and Human Services. Registry of Toxic Effects of Chemical Substances. DHHS (NIOS) Publication No. 80-111 (1980).

- K. Verschueren, *Handbook of Environmental Data on Organic Chemicals*, 2nd ed. (Van Nostrand Reinhold Co, New York, 1983).

  - Computerized literature files that may prove valuable include

    CHEMLINE
    CHEMTREC
    MEDLINE
    OHM-TADS
    RTECS
    TOXLINE

2.5.2. Prepare a Health Toxicity Profile for Each Contaminant of Concern

Technical Elements

- Summarize data from animal studies, emphasizing dose-response relationships. Information will cover

  a) dose levels

    - acute, subchronic, chronic effects

    - no-observable adverse effect level or lowest observable adverse effect level

  b) routes of exposure

    - ingestion
    - inhalation
    - dermal absorption

  c) biological end points

    - carcinogenecity
    - mutagenicity
    - teratogenicity
    - neutrotoxicity
    - behavioral toxicity
    - immunosuppression

- Summarize data from human epidemiological studies or case histories (see above list).

- List quantitative indicators of toxicity, including regulatory standards:

1) Drinking water standards

2) Ambient air quality standards

3) Acceptable daily intakes (ingestion, inhalation, chronic, and subchronic)

2.5.3. Prepare an Environmental Toxicity Profile for Each Contaminant of Concern

Technical Elements

- Summarize toxic effects on terrestrial and aquatic animal/plant life, emphasizing dose-response relationships. Information will cover lethality, organotoxicity, behavioral effects, and reproductive effects.

- List applicable regulatory standards for ambient water quality criteria and irrigation criteria.

2.6. RISK CHARACTERIZATION

The purpose of this evaluation is to integrate the findings of the exposure and toxicity assessments to estimate site-specific risks. The characterization describes potential adverse effects and estimates risk to public health and the environment based on existing guidelines and standards (e.g., drinking water standards, water quality criteria, and ambient air quality standards).

The level of detail provided for each of the technical components depends on whether the available data are sufficient to perform individual assessments. All assumptions made in the performance of an assessment will be clearly defined.

Objective: Determine whether actual or potential health or environmental risks are posed by the exposure conditions described in the exposure assessment for the installation sites.

The risk characterization integrates the information developed during the environmental fate and transport, exposure, and toxicity assessments to determine whether unacceptable risks are posed by the contaminant of concern for each site. A four-task approach will be undertaken to achieve this goal:

1) Characterization of carcinogenic risk
2) Characterization of noncarcinogenic risk
3) Characterization of environmental risk
4) Characterization of public welfare risk

For each task, risk will be determined for both "worst case" and "most probable" situations. Current risk will be evaluated on the basis of recent sampling data collected at predicted exposure points. Potential future risk will be determined on the basis of projected exposure concentrations predicted by modeling.

2.6.1. Characterization of Carcinogenic Risk

Technical Elements

- Compare site-specific exposure levels to regulatory guidelines and standards.
- For each exposed human population, calculate (when possible) the carcinogenic risk posed by each known/suspect carcinogen.
- Calculate total carcinogenic risk for all carcinogens by adding individual risks.
- If no criterion is available for a contaminant, compare exposure concentrations to available dose-response information.
- Characterize uncertainties associated with risk estimates.

2.6.2. Characterization of Noncarcinogenic Risk

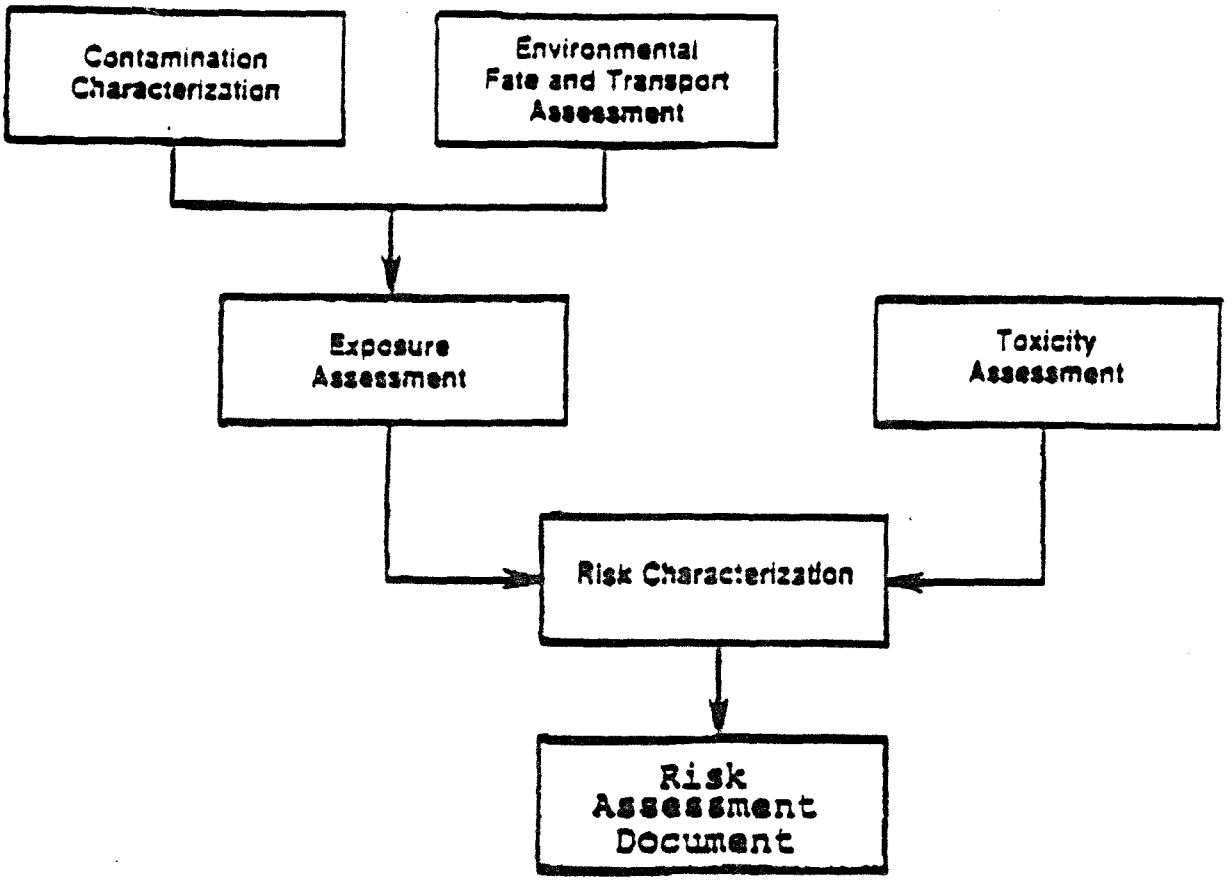
Technical Elements

- For each exposed human population, compare exposure/dosage levels of each contaminant of concern to acceptable levels (e.g., acceptable daily intakes), regulatory guidelines and standards and/or other health criteria.
- Calculate chronic/subchronic hazard index as described in the *Superfund Public Health Evaluation Manual* (U.S. EPA, 1986).
- If no criterion is available for a contaminant, compare exposure concentrations to available dose-response information.
- Characterize uncertainties associated with risk estimates.

2.6.3. Characterization of Environmental Risk

Technical Elements

- Compare estimated environmental concentrations of contaminants of concern to regulatory guidelines and standards.
- If regulatory guidelines are not available, evaluate potential risk to plants and animals on the basis of available ecotoxicity information.
- Evaluate risk to endangered or threatened species or critical habitats in direct or indirect contact with contaminants.
- Characterize uncertainties associated with risk estimates.



Source: U.S. EPA, 1985