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RADIOLOGICAL AND CHEMICAL BASELINE RISK ASSESSMENT OPERABLE UNIT 4 APRIL 2, 1990 PRELIMINARY DRAFT

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PRELIMINARY

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Radiological and Chemical Baseline Risk Assessment Operable Unit 4

FEED MATERIALS PRODUCTION CENTER (FMPC)
Fernald, Ohio

Prepared By:

IT CORPORATION
Knoxville, Tennessee

April 2, 1990

U.S. DEPARTMENT OF ENERGY
OAK RIDGE OPERATIONS OFFICE

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LIST OF ACRONYMS AND ABBREVIATIONS

ADI	Acceptable Daily Intake
AEC	U.S. Atomic Energy Commission
AMS	Air Monitoring Station
ASI	Advanced Sciences Incorporated
ARARs	Applicable or Relevant and Appropriate Requirements
BEIR	Biological Effects of Ionizing Radiation
CEDE	Committed Effective Dose Equivalent
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIS	Characterization Investigation Study
DOE	U.S. Department of Energy
EDI	Estimated Daily Intake
EIS	Environmental Impact Statement
EP	Extraction Procedure
EPA	U.S. Environmental Protection Agency
FFCA	Federal Facilities Compliance Agreement
FMPC	Feed Materials Production Center
FS	Feasibility study
HI	Hazard Index
HSL	Hazardous Substance List
ISP	Interim stabilization project
IT	International Technology Corporation
LET	Linear Energy Transfer
LOAEL	Lowest Observed Adverse Effect Level
msl	Mean sea level
NAS	National Academy of Sciences
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection and Measurements
NLO	National Lead (Company) of Ohio
O&M	Operations and Maintenance
ODH	Ohio Department of Health
OU4	Operable Unit 4
OU5	Operable Unit 5
PCBs	Polychlorinated biphenyls

LIST OF ACRONYMS
(Continued)

RA	Risk Assessment
RfD	Reference dose
RGTS	Radon gas treatment system
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable Maximum Exposure
SARA	Superfund Amendments and Reauthorization Act
SSOD	Storm sewer outfall ditch
TLDs	Thermoluminescent dosimeters
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WL	Working Level
WLM	Working Level Month
WMCO	Westinghouse Materials Company of Ohio
WM	Working Month

LIST OF DEFINITIONS

Absorbed Dose - The quantity of energy deposited in matter (usually the human body) by ionizing radiation per unit mass of irradiated matter at the location of interest. The common unit for absorbed dose is the rad.

Action Level - A dose level below a dose limit that indicates a need to take further action to decrease the dose level to ensure that limits are not exceeded.

Baseline Risk Assessment - An assessment of potential risks to public health and the environment from current site conditions and in the future in the absence of remediation.

Berm - Earthen embankment surrounding the K-65 waste storage silos.

Committed Effective Dose Equivalent (CEDE) - The sum, over specified tissues, of the products of the committed dose equivalent in a tissue and the weighting factor for the tissue.

Committed Dose Equivalent - The total dose equivalent averaged throughout a tissue in a specified time period after intake of a radionuclide into the body. For this assessment, a 50-year time period after intake is specified.

Dose Equivalent - The quantity used to express the amount of effective absorbed dose caused by ionizing radiation. It is obtained by multiplying the absorbed dose by the quality factor and other modifying factors. The common unit for dose equivalent is the rem.

Dose Limits - Maximum dose rates permitted by regulations. Dose limits do not define a boundary between safe and hazardous conditions but rather they are conservatively established for regulatory purposes at levels that are not known to induce observable health effects in humans.

Exposure Pathway - A transport route and mechanism for human exposure to materials that have migrated from a source. An exposure pathway consists of a point of exposure in the environment, a receptor, a migration pathway, and a mechanism of entering the body (e.g, inhalation).

Hydraulic Conductivity - Indicates the ease with which water will flow through geologic media, such as soils. It is dependent upon a variety of characteristics and is expressed in terms of distance per unit of time.

Indicator Chemicals - Those site-specific chemicals identified as contributing the greatest portion of the health risk associated with an operable unit.

K-65 Raffinates - The less soluble residues that remained after extraction of uranyl nitrate during the processing of pitchblende ore. These residues ultimately were transferred to the K-65 silos for storage.

LIST OF DEFINITIONS
(Continued)

Reasonable Maximum Exposure - The highest exposure that is reasonably expected to occur at a site.

Migration Pathway - Mechanism for the transport of radioactive or hazardous materials through environmental media.

Mixed Waste - Waste materials containing a mixture of hazardous chemicals and radioactive materials.

Pitchblende - A primary mineral-ore source of natural uranium.

Radon Progeny - The series of radionuclides that result from the radiological decay of radon-222.

Receptor - A person in the environment who may be exposed to radioactive or hazardous materials.

Reference Dose (RfD) - An estimate of the daily chemical exposure of humans that is unlikely to result in deleterious effects during a lifetime of exposure, based on the assumption that a threshold exists for certain toxic effects of chemical substances. The RfD is derived from pertinent human or animal toxicity data.

Pharmacokinetic Model - A mathematical model that describes how a substance moves through the human body.

Working Level (WL) - Any combination of short-lived radon progeny in 1 liter of air that will result in the ultimate emission of 1.3×10^5 million electron volts (MeV) of alpha particle energy.

Working Level Month (WLM) - Cumulative exposure to radon progeny is expressed in WLMs. One WLM is equal to exposure to a combination of radon progeny equal to one working level times an exposure duration of a 170-hour occupational month.

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EXECUTIVE SUMMARY

This draft document presents the baseline risk assessment for Operable Unit 4 (OU4) at the Feed Materials Production Center (FMPC), Fernald, Ohio. This risk assessment is mandated under the Federal Facilities Compliance Agreement signed in 1986 by the U.S. Department of Energy and the U.S. Environmental Protection Agency. It complies with provisions of both the 1986 Superfund Amendments and Reauthorization Act and the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) that require the completion of an assessment of risks to public health and the environment during the Remedial Investigation (RI) of a CERCLA site. OU4 includes the waste storage silos (two K-65 silos and two metal oxide silos). The soils directly beneath the silos and the berm soils surrounding the K-65 silos are also considered within OU4 under the pretext that any contamination originated from the silo wastes and could be most cost-effectively remedied as an integral part of the remedial action program for the silos.

Data collected during the RI and the results of other studies suggest that two radiological exposure pathways from OU4 currently contribute nontrivial amounts of above-background radiation exposure to the public. These pathways are:

- Exposure to penetrating radiation emitted from the residues in the silos
- Exposure to airborne radon and radon progeny emitted from the K-65 silos.

Data also suggest that ground water and surface water runoff to stream sediments could be potential pathways of migration for radionuclides or chemicals released from the silos; however, no data directly link contamination measured in these media with releases from OU4. Supplemental sampling and analyses of the soils directly beneath the silos and the berm soils surrounding the K-65 silos is scheduled. The analytical results of this sampling will be used to better determine whether the waste storage silos are releasing contaminants to ground water and to stream sediments via surface water runoff.

Three current exposure pathways are quantitatively evaluated in this risk assessment:

- Exposure to penetrating radiation emitted from the residues in the silos
- Exposure to airborne radon and radon progeny emitted from the K-65 silos
- Exposure to uranium and Ra-226 eroded into stream sediments and ingested by children

Potential future exposure to uranium in ground water via ingestion is qualitatively addressed. The risk associated with contamination that has been measured in the ground water will be addressed in the risk assessment for OU5. However, estimates of exposure and risk associated with modeled future releases from the silos will be included in subsequent drafts of the OU4 risk assessment.

The above-background calculated radiation dose equivalent associated with direct exposure to penetrating whole body radiation is 2,500 mrem over a 70-year lifetime (36 mrem/year) at the location of a hypothetical reasonable maximally exposed (RME) individual. The RME is located at the point of highest average measured off-site exposure, which is the site boundary approximately 340 meters west of OU4. This lifetime radiation dose equivalent corresponds to an incremental lifetime fatal cancer risk of 3×10^{-4}.

The above-background calculated exposure to radon progeny is 25 working level months (WLM) over a 70-year lifetime at the location of a hypothetical RME individual. The RME is located at the point of highest average measured off-site exposure, which is the site boundary approximately 340 meters west of OU4. This lifetime radon progeny exposure corresponds to an incremental lifetime fatal lung cancer risk of 9×10^{-3}.

The calculated RME committed effective dose equivalent associated with exposure to uranium and Ra-226 eroded into stream sediments and ingested by children is approximately 8 mrem over a 6-year exposure duration. This exposure corresponds to a lifetime fatal cancer risk of 1×10^{-6}. The calculated nonradiological RME exposure to uranium eroded into stream sediments and ingested by

children is 0.13 μg/kg/day. The nonradiological hazard index ratio associated with a child exposed to this intake of uranium in stream sediment is 0.043, when the intake is compared to the reference dose (RfD) of 3 μg/kg/day, and 0.17 when the intake is compared to the site-specific action level of 0.75 μg/kg/day. Thus, children could receive a calculated intake of uranium that is 17 percent of the allowable limit. The nonradiological intake estimate and the radiological dose and risk estimate for the sediment ingestion pathway both incorporate very conservative assumptions. These assumptions render them upper bound estimates with low probabilities of occurrence.

This risk assessment has determined that the potential public exposure to baseline conditions attributable to OU4 exceeds the Applicable or Relevant and Appropriate Requirement (ARAR) action level of 25 mrem/year previously established for an individual operable unit at the FMPC. Assuming that a single individual could reasonably be exposed to the RME exposure from both penetrating radiation and airborne radon, the combined lifetime risk from lifetime exposure to these two pathways is 9.3×10^{-3}. The chemical exposure ARAR of 25 percent of the acceptable daily intake is not exceeded under existing conditions in OU4.

1.0 INTRODUCTION

The Feed Materials Production Center (FMPC) is a contractor-operated federal facility for the production of pure uranium metals for the U.S. Department of Energy (DOE). The FMPC site is located near the unincorporated village of Fernald, Ohio on a 1,050-acre (4.2×10^6 m^2) site in a rural area about 20 miles (32 k) northwest of downtown Cincinnati, Ohio. About 850 acres (3.4×10^6 m^2) of the FMPC site are in northern Hamilton County, and the remaining 200 acres (0.8×10^6 m^2) are in southern Butler County. The villages of Ross, New Haven, and Shandon are also within a few miles of the FMPC (Figure 1-1). The site is on a relatively level plain approximately 580 feet (177 m) above mean sea level (msl). The production area is limited to an approximate 136-acre (5.50×10^5 m^2) tract near the center of the FMPC site.

On March 9, 1985, the U.S. Environmental Protection Agency (EPA) issued a Notice of Noncompliance letter to DOE identifying EPA's major concerns over potential environmental impacts associated with the FMPC's past and present operations. Between April 1985 and July 1986, conferences were held between DOE and EPA representatives to discuss the issues and to identify the steps DOE proposed to take to achieve and maintain environmental compliance.

On July 18, 1986, a Federal Facilities Compliance Agreement (FFCA) was jointly signed by DOE and EPA pertaining to environmental impacts associated with the FMPC. The FFCA was entered into pursuant to Executive Order 12088 (42 CFR 47707) to ensure compliance with existing environmental statutes and implementing regulations. The FFCA is intended to ensure that human health and environmental impacts associated with past and present activities at the FMPC are thoroughly investigated so that appropriate remedial response actions can be formulated, assessed, and implemented.

In response to the FFCA, a Remedial Investigation and Feasibility Study (RI/FS) was initiated pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. All RI/FS activities are being

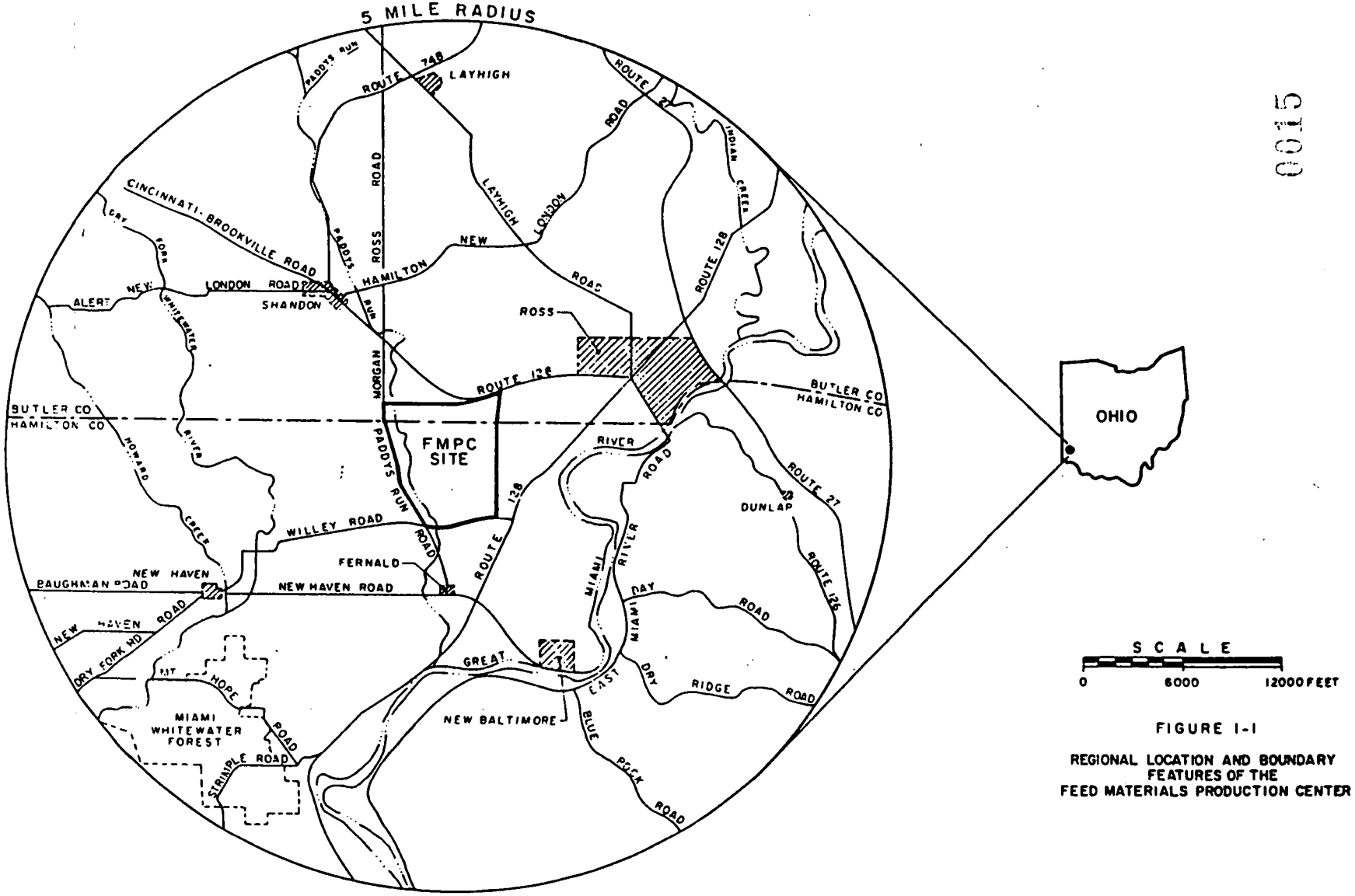

FIGURE I-I

REGIONAL LOCATION AND BOUNDARY FEATURES OF THE FEED MATERIALS PRODUCTION CENTER

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conducted in conformance with EPA's Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (EPA, 1988a). The performance of the RI/FS conforms with current EPA guidance and guidelines, criteria, and the considerations set forth in the National Contingency Plan (NCP).

CERCLA requires that actions selected to remedy hazardous waste sites be protective of human health and the environment. Compliance with this objective under the RI/FS is determined by the risk assessment process. The ultimate goal of the risk assessment is to provide information which serves as a basis for appropriate consideration of risk management in the decision-making process. The baseline risk assessment, which provides an analysis of the baseline risks and helps to determine the need for remedial action, is an integral part of the decision-making process.

1.1 OVERVIEW

The RI/FS for the FMPC was initially designed to address the entire site and to focus on various environmental media that could potentially be impacted by past and present operations at the FMPC. In the course of the investigation, it became apparent that, for technical and program management purposes, the site should be divided into operable units. Five operable units identified for the FMPC are:

- Operable Unit 1 - Waste Storage Area
- Operable Unit 2 - Solid Waste Units
- Operable Unit 3 - Production Area and Suspect Areas
- Operable Unit 4 - K-65 Silos and Metal Oxide Silos
- Operable Unit 5 - Environmental Media.

Operable Unit (OU4) encompasses four storage silos that contain elevated levels of hazardous and radiological materials (chemical and radioactive contaminants) resulting from activities at the FMPC. Due to the presence of mixed waste at the FMPC, the risk assessment will be conducted for both the radiological components and hazardous chemical components of the wastes.

The baseline risk assessment has two major objectives. The first is to determine whether no further action is an acceptable alternative from a public health perspective. The second objective is to provide the baseline conditions for comparison with the public health impacts of alternative remedial actions in the FS.

To fulfill these objectives, a systematic evaluation was conducted to estimate the potential risks to human health from the radiological and hazardous chemical components of the wastes. Existing site information on the waste quantities and sources, potential transport and exposure pathways, and potential receptors at the FMPC site were used in the baseline risk assessment. Environmental impacts associated with OU4 are being studied in detail under the Environmental Impact Statement (EIS) for Fernald. Results of this evaluation will be incorporated into a later draft of the baseline risk assessment.

The baseline risk assessment for OU4 was conducted in accordance with EPA's Baseline Risk Assessment Guidance for Superfund--Human Health Evaluation Manual, Part A -- Interim Final (EPA, 1989a) and the interim final document, Guidance for Conducting Remedial Investigation and Feasibility Studies Under CERCLA (EPA, 1988a). Methods used to assess the risk from human exposure to radiological and chemical contaminants originating from OU4 are described in Section 1.3.

1.2 SITE BACKGROUND

This section provides background information on the FMPC and the surrounding area. It includes a brief description of the FMPC and a site history. More information is available in the RI report for OU4.

1.2.1 Site Description and History

The U.S. Atomic Energy Commission (AEC), predecessor to DOE, established the FMPC for processing uranium and its compounds from natural uranium ore concentrates for U.S. government needs. This integrated production complex began operations in conformance with AEC Orders in the early 1950s. In 1951, NLO Inc. (formerly National Lead Company of Ohio) entered into contract with AEC as Operations and Maintenance (O&M) Contractor. This contractual relationship

lasted with AEC, and eventually with DOE, until January 1, 1986. Westinghouse Materials Company of Ohio (WMCO), a wholly owned subsidiary of Westinghouse Electric Corporation, then assumed management responsibilities of the site operations and facilities for a minimum of 5 years.

A pilot plant was completed in 1951 and was the first operational facility at the FMPC. A diagram of the existing FMPC layout is provided in Figure 1-2. The production area is the original source of wastes included in the RI/FS and provides a convenient reference point within the site. The FMPC wastes include:

- Production area process wastes
- General scrap and refuse
- Contaminated and noncontaminated metal scrap
- Waste oils
- Low-level radioactive waste
- Mixed wastes
- Toxic waste
- Sewage treatment plant sludge
- Fly ash
- Stored radium- and thorium-bearing residues.

OU4 is located inside a fenced, limited-access area approximately 1,300 feet (320 meters) west of the main production area fence (Figure 1-3). OU4 consists of the two K-65 silos (Silos 1 and 2) and the metal oxide silo (Silo 3). The berm soils surrounding the K-65 silos and the soils directly beneath the silos are also considered within OU4 under the pretext that any contamination originated from the silo wastes and could be most cost-effectively remedied as an integral part of the remedial action program for the silos. A fourth silo (Silo 4) is also present within the OU4 study area, but this silo has remained empty and is not addressed in the risk assessment.

A number of documents describe the structural characteristics of the K-65 silos (Grumski, 1987a; Shanks and Vogel, 1988). Each of the concrete silos is 80 feet in diameter with an overall height of 36 feet (27-foot-high walls and a 9-foot-high dome). The walls are constructed of 8-inch-thick, post-tensioned, reinforced concrete. The domes are constructed of concrete reinforced by wire mesh and they taper from a thickness of 8 inches at the

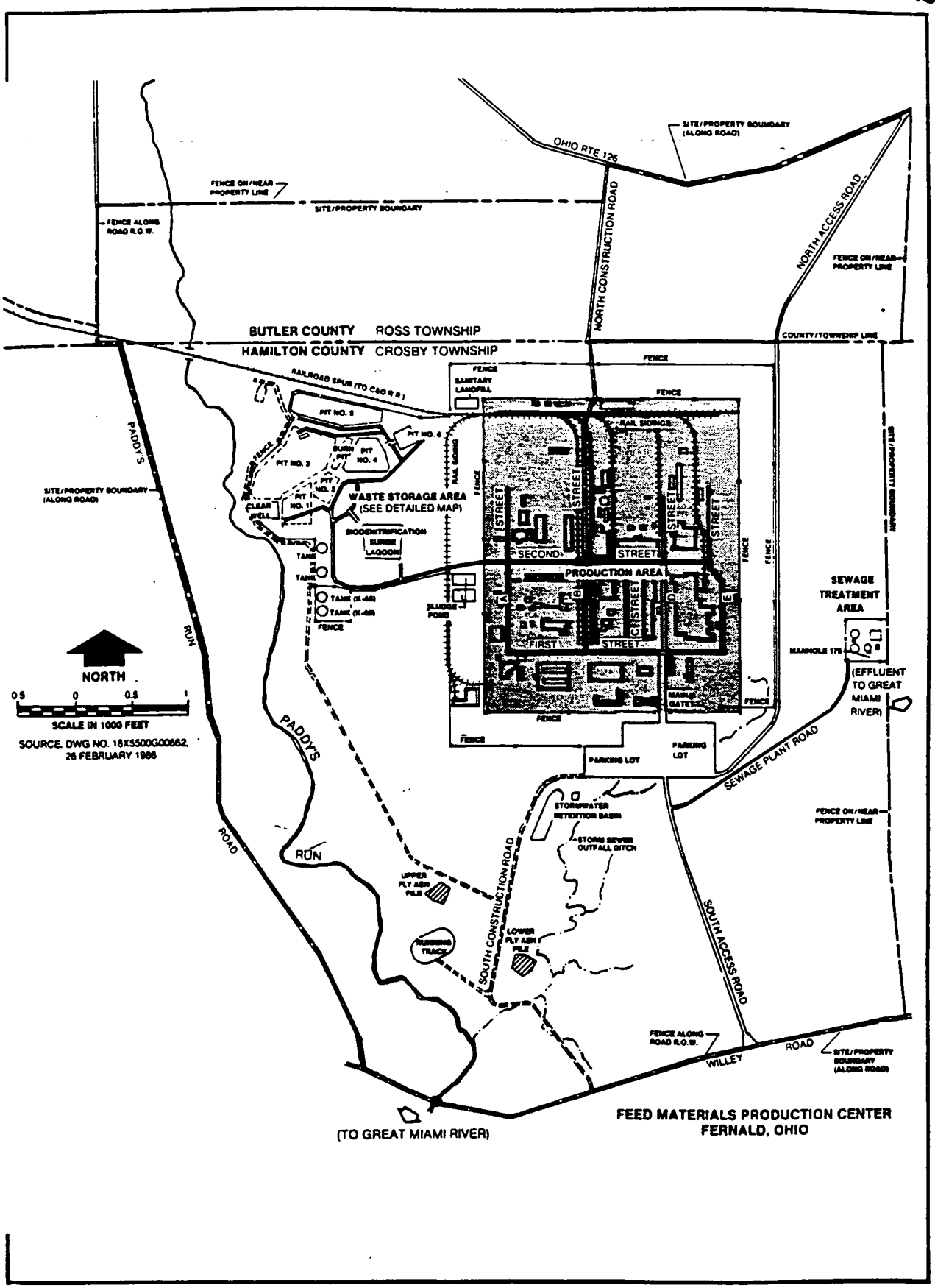


FIGURE 1-2 EXISTING PLANT LAYOUT

Source: Adapted from Weston, 1987

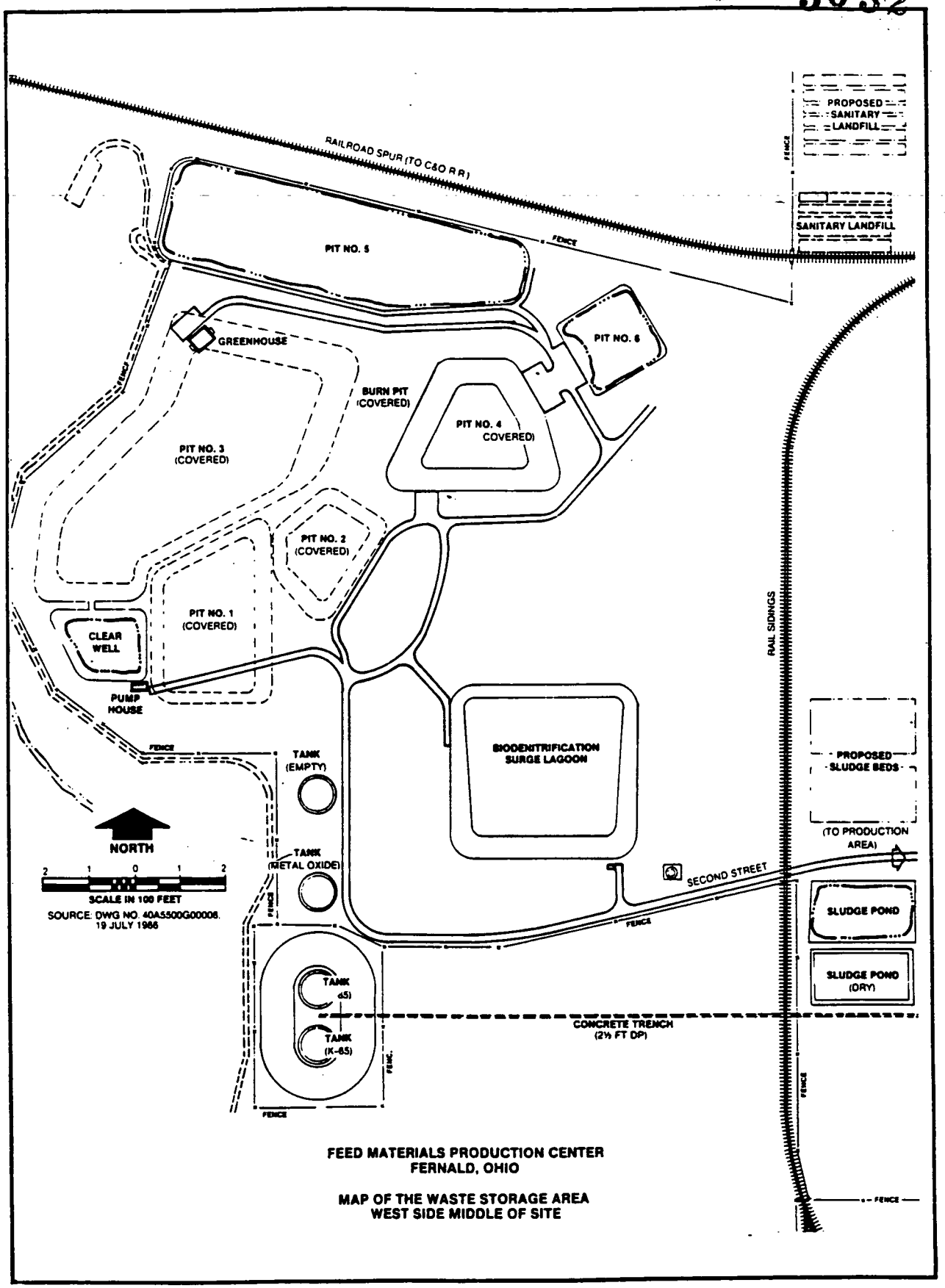


FIGURE 1-3 THE WASTE STORAGE AREA INCLUDING OPERABLE UNIT 4

Source: Adapted from Weston, 1987

silo walls to a thickness of 4 inches at their apex. The 4-inch concrete floors were constructed over an 8-inch layer of gravel. This gravel layer contains a system of 2-inch-diameter slotted piping that drains to a collection tank. Below the gravel is a 2-inch layer of asphalt and concrete underlain by 17 inches of compacted clay. A leachate collection system, including drain sampling tanks, is buried underneath the silos. Silos 1 and 2 are surrounded by an earthen embankment (berm).

Silos 1 and 2 were built in 1951 and 1952, respectively, to store radium-bearing residues from the processing of pitchblende ore mined in what was then the Belgian Congo. The radium-bearing residues from aqueous slurries were collected in these silos from 1953 to 1955 (Boback et al., 1987). The radioactive residues in the slurry were allowed to settle and the free liquid was decanted through a series of valves placed at various levels along the silo wall. The decanted liquid was recycled. As the depth of solids approached the level of a given valve, the valve was sealed and the next higher valve was used to decant the liquids. The K-65 silos were filled to approximately 4 feet below the top of their vertical walls (DOE, 1988a). The current combined volume of residues in the K-65 silos is estimated to be 195,000 ft^3 (approximately 8,800 metric tons) (ASI/IT, 1988; Dettorre et al., 1981; Grumski, 1987a).

The residues currently stored in the K-65 silos came from the FMPC, from a plant in St. Louis, Missouri, and from a storage facility in Niagara Falls, New York. Shipments from the latter two facilities totaled 25,000 drums and 6,000 drums, respectively (DOE, 1988a).

Silos 1 and 2 contain an air space above the pitchblende residues where radon gas accumulates. Current estimates of the void volumes above the residues are 38,000 cubic feet (ft^3) in Silo 1 and 48,000 ft^3 in Silo 2 (Grumski and Shanks, 1988). The K-65 silos exchange air with the outside environment. The estimated historical rate of exchange of gas from the silos to the outside atmosphere is 1,650 ft^3 per day from each silo (IT Corporation, 1989a). Since the installation of a foam covering over the silos in 1987, the rate of gas exchange should be significantly reduced because the foam is an effective thermal insulator that reduces daily temperature variations inside the silo dome.

After the FMPC discontinued transfer of pitchblende residue slurries to the K-65 silos, the slurry system piping was removed (Boback et al., 1987). All openings to the K-65 silos were sealed, except for one small gooseneck pipe on each silo. These two remaining openings were permanently sealed in 1979 (Boback et al., 1987).

In 1953, NLO personnel detected a leak in Silo 1 (Heatherton, 1953). NLO correspondence dating from early years of plant operation also suggest that a decant liquor tank buried beneath the silo overflowed on occasion (Karl, 1953). This information suggests that leakage from Silo 1 and from the buried collection system beneath the silos has occurred in the past. However, the magnitude of the releases was not extensively quantified.

By 1963, the exterior surfaces of the K-65 silos were showing signs of deterioration, necessitating repairs in 1964. At that time, an earthen embankment was built to the top of the vertical walls of Silos 1 and 2 to provide relief from tensile stress that had developed within the walls. This embankment also provides weather protection, a reduction of radon emissions, and increased shielding from penetrating radiation. The embankment originally had a slope of 1.5:1 (horizontal:vertical), which was subsequently modified in 1983 to a slope of 3:1 to reduce erosion (Grumski, 1987b; Boback et al., 1987). This embankment is commonly referred to as the site berm.

In 1985, Camargo Associates began a structural analysis of the K-65 silos (Camargo, 1986). Grumski (1987a) has summarized the Camargo recommendations and conclusions which include, but are not limited to, the following:

- The base slab and walls were structurally stable at the time of the analysis and should remain stable for approximately 5 to 10 years.
- The contents of the silos and the silo berm must be removed simultaneously rather than separately or failure of the walls or base slab could result.

- The center 20-foot-diameter portion of each dome is structurally unsound for a load greater than the existing static dead load.
- The weight of a structure chosen to cover the center portion of each silo should be as light as possible.

In January 1986, construction and installation of temporary dome covers over the center portions of the K-65 silos were completed (Grumski, 1987a). The 30-foot-diameter steel and plywood covers were installed to contain the contents of the silos in the event of a dome center collapse (Grumski, 1987a).

In 1987, an interim stabilization project (ISP) was implemented at the K-65 site in response to the FFCA between DOE and EPA (Grumski, 1987b). Compliance with the FFCA required that DOE take immediate action to control radioactive emissions from the FMPC. Work performed as part of the ISP included:

- Installation of a radon gas treatment system (RGTS)
- Application of a layer of rigid polyurethane foam insulation to the exterior of the dome surfaces.

The RGTS consists of a calcium sulfate bed to remove moisture, followed by charcoal beds to adsorb the radon. It is a closed system in which the cleaned air is recirculated back to the silos. The RGTS is designed to be operated on an interim basis, such as when the dome is to be opened, and therefore does not provide permanent reduction of external radiation exposure levels or radon levels. This system was operated before and during application of the exterior foam layer. Operation of this system immediately before the installation of the polyurethane foam reduced penetrating radiation levels at the exterior surfaces of the K-65 silo domes by 60 to 70 percent without increasing the ambient radon levels outside the silos (Grumski and Shanks, 1988).

In the fall of 1987, the exterior surfaces of the domes were covered with a 3-inch layer of polyurethane foam, the dome caps were covered with a 1.5-inch layer of foam, and the entire exterior surface of the domes was waterproofed with an ultraviolet-resistant, urethane-finish coating 0.045 inches thick

(Grumski and Shanks, 1988). The polyurethane foam is an effective thermal insulator that reduces daily temperature fluctuations inside the domes. The foam layer reduces daily gas releases caused by the expansion of heated gas inside the K-65 silos. The polyurethane foam is also a very effective barrier to radon diffusion. No diffusion of radon occurred through an average foam thickness of 2.2 inches in laboratory tests of the attenuating ability of the polyurethane foam (Grumski, 1987b).

Silo 3 was constructed in mid-1952 and was designed to receive dry materials only. Waste raffinate slurries from the FMPC refinery operations were dewatered in a raffinate evaporator and spray calcined to produce a dry waste form. This waste was blown under pressure into Silo 3 (DOE, 1988a). An estimated volume of 138,000 ft^3 of material is contained in Silo 3 (DOE, 1988a). There is no soil embankment around this silo.

Surrounding lands support several residences, small industries, and farms. Several industries are located south of the FMPC. These include Rutgers-Nease Chemical Company, Albright and Wilson Chemical Co., and Delta Steel. Population density in the immediate area is low, with approximately 160 persons within a 1-mile radius of the plant boundary (SAIC, 1987).

1.3 SCOPE OF THE BASELINE RISK ASSESSMENT

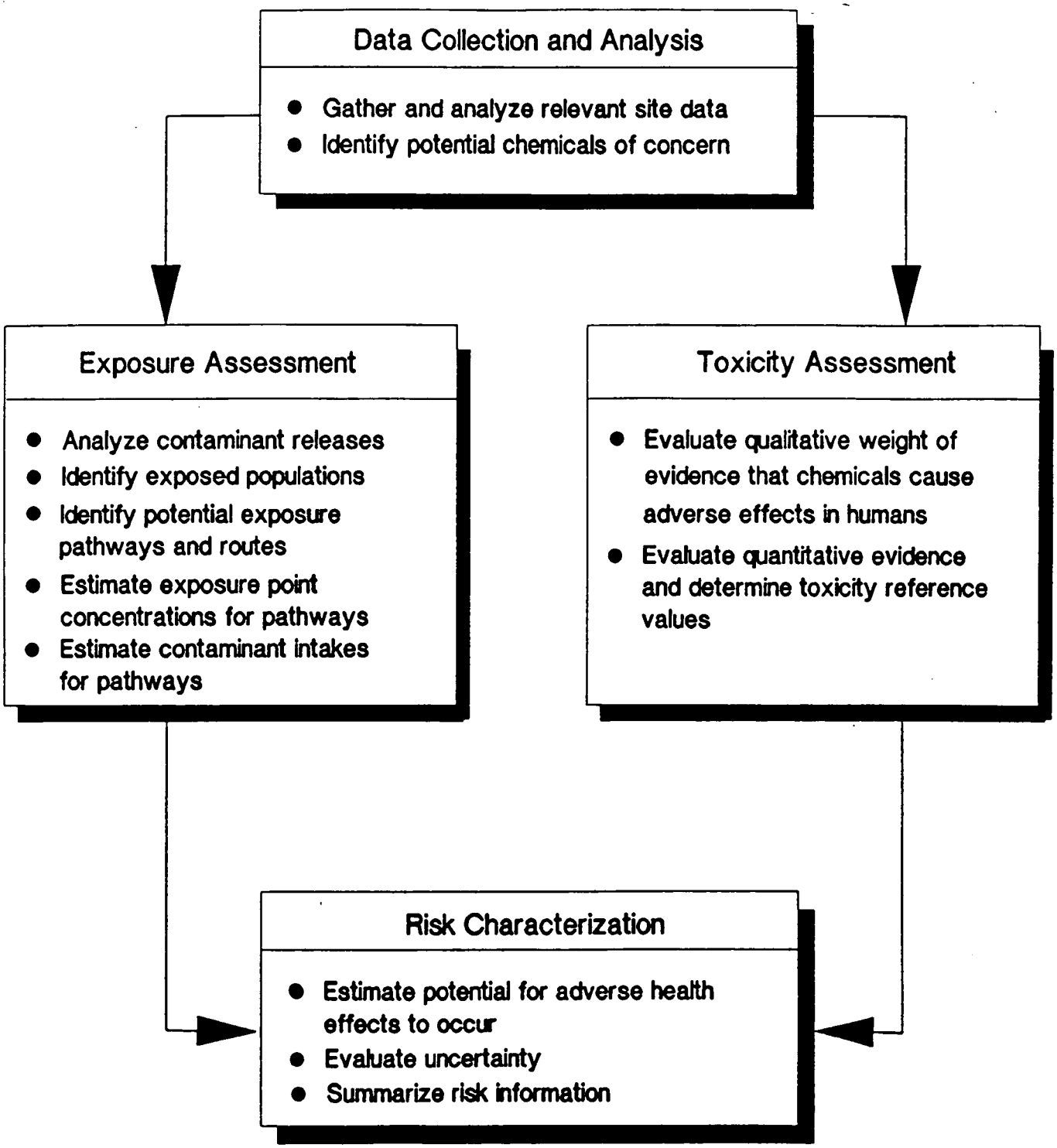
The process used in the baseline risk assessment for OU4 is shown in Figure 1-4 (EPA, 1989a).

The first step in completing the baseline risk assessment involves data collection and analysis, and identification of all contaminants (radionuclides and hazardous chemicals) of potential concern. These contaminants are identified by examination of existing site information, including:

- Descriptions of the processes used at the FMPC
- Radionuclides and chemicals known to have been used in these processes
- Present and historical site environmental monitoring data

FIGURE 1-4

Baseline Risk Assessment Process



Source: Adapted from EPA, 1989a

- Results of special investigations conducted in the past.

Following the examination of this information, a list of tentatively identified radionuclides and chemicals of concern is produced. This list is evaluated to ensure identification of contaminants that are likely to be related to the activities at the FMPC and to determine the quality of the data to be used in the baseline risk assessment. Throughout this process, existing information is supplemented by data collected through the RI field investigation.

Once chemicals and radionuclides of potential concern have been identified, the process is directed toward characterizing the exposure setting and identifying exposure pathways. An exposure pathway is defined by describing the mechanism by which humans may be exposed to contaminants originating from the site. Each pathway must consist of:

- A source of a contaminant
- A mechanism for transporting the contaminant to a point of exposure (e.g., ground water, air, surface water)
- A potential receptor at the location of exposure
- A route of exposure (e.g., inhalation, ingestion, dermal absorption).

The concentration of each contaminant is quantified at the exposure point for the present and at appropriate times in the future. Direct measurements may be used to determine current exposure point concentrations, or mathematical models can be used to predict current and future concentrations.

Intakes of the contaminants are then estimated on the basis of the reasonable maximum exposure (RME) scenarios for both present and future land-use conditions. The RME is defined by EPA (EPA, 1989a) as "the highest exposure that is reasonably expected to occur at the site." This concept is discussed further in Chapter 3.0 of this report.

The process continues with an evaluation of the adverse effects each contaminant has on human health. These effects include impacts on the function of body organs and the induction of cancer. When possible, an estimate is made of the relationship between the extent of exposure to the contaminant and the probability and/or severity of identified adverse effects.

The final step in the baseline risk assessment process is risk characterization. In this step, comparisons are made between estimated contaminant intakes and the toxicity threshold values for noncarcinogenic effects identified in the toxicity assessment. The probability that an individual will develop cancer over a lifetime of exposure is estimated from projected intakes and contaminant-specific dose-response relationships.

Before initiating the baseline risk assessment process for individual operable units, potential applicable or relevant and appropriate requirements (ARARs) for radiological and chemical contaminants were identified. ARARs have been established for OU4 and the FMPC site as a whole. The ARARs for the FMPC RI/FS baseline risk assessment process are documented in a work plan for ARARs and the baseline risk assessment (IT Corporation, 1989b).

Radiation dose limits apply to the collective impact from all operable units at the FMPC. Because each operable unit may affect different receptors, the estimated doses from individual operable units are not necessarily additive for computing total doses to individual members of the public. To ensure that the combined impact on human health from all RI/FS operable units does not inadvertently exceed established dose limits, a system of action levels is being maintained throughout the baseline risk assessment for each operable unit (IT Corporation, 1989b). Action levels are not regulatory limits, but rather administrative guidelines that trigger additional evaluation and site-wide comparison of exposures from all operable units to ensure that site limits are not exceeded.

Chemical ARARs will be identified on a site-specific basis for each operable unit, depending on the environmental media evaluated (IT Corporation, 1989b).

A risk-based chemical action level for an individual operable unit of 25 percent of the reference dose (RfD) for each identified chemical has been adopted for the FMPC.

1.4 ORGANIZATION OF BASELINE RISK ASSESSMENT REPORT

This baseline risk assessment report provides a baseline (or no-action) risk assessment under the RI for OU4 at the FMPC. In general, it follows the "Suggested Outline for a Baseline Risk Assessment Report" set forth in Exhibit 9-1 of the Interim Final version of Baseline Risk Assessment Guidance for Superfund--Human Health Evaluation Manual, Part A (EPA, 1989a). This report is modified as required to address an operable unit rather than the entire site.

Chapter 1.0 has provided an introduction and overview of the FMPC and the waste units covered under OU4 of the RI/FS. Chapter 2.0 describes the evaluation of general site-specific data and the identification of contaminants of potential concern. Chapter 3.0 details the process used in formulating pathways of exposure, the selection of the most significant of these pathways, and the quantitation of the exposure point concentrations, radiation doses, and chemical intakes. Chapter 4.0 presents specific toxicity information for chemicals and radionuclides of concern. Chapter 5.0 characterizes the risks associated with the radiological doses and chemical intakes calculated in Chapter 3.0. Chapter 6.0 summarizes the results of the baseline risk assessment. Throughout the baseline risk assessment report, appropriate discussion is presented on the uncertainties involved in the available data, in the assumptions made, and in the dose-response relationships. Additional analytical information will be forthcoming from the ongoing RI; appropriate revisions to the baseline risk assessment will be made at that time.

2.0 IDENTIFICATION OF CHEMICALS AND RADIONUCLIDES OF POTENTIAL CONCERN

This chapter of the OU4 RI baseline risk assessment report identifies the chemicals and radionuclides of potential concern for OU4. The first section of this chapter describes general site-specific data collection and evaluation considerations for the risk assessment. The second section presents the site-specific data collected, evaluated, and used in the OU4 risk assessment. A summary at the end of the chapter identifies the chemicals and radionuclides of potential concern in the OU4 baseline risk assessment.

2.1 GENERAL SITE-SPECIFIC DATA COLLECTION AND EVALUATION CONSIDERATIONS

The following general data collection and evaluation considerations are of importance to the baseline risk assessment:

- Identification of chemical and radiological contaminants in the silos
- Quantification of chemical and radiological contaminant concentrations in the silos and adjacent soils
- Determination of the characteristics of contaminated source materials
- Determination of the characteristics of environmental media that may affect the migration of contaminants from OU4
- Evaluation of data that have been collected.

The first consideration is to identify contaminants that are present in the K-65 silos and the metal oxide silo. This provides a starting point for the development of exposure pathways by identifying potential contaminant source terms in the silos.

The second consideration is to quantify contaminant concentrations in the silos, the berm soils, the soils directly beneath the silos, and in any other media of concern. Quantification of potential source terms furthers the

development of potential exposure pathways and is necessary to quantify the health hazard associated with potential exposure pathways.

The third consideration is to determine the characteristics of the contaminated source materials of concern. These characteristics are important because they affect the potential for release of contaminants into the environment. Characteristics of source materials include chemical forms of contaminants, solubilities of contaminants, porosities or permeabilities of the waste materials, and potential water flow rates through the waste materials.

The fourth consideration is to determine the characteristics of environmental media that may potentially become contaminated by releases from the waste storage silos and which may affect the migration of contaminants. This type of information is critical to any exposure pathway modeling to be performed. Characteristics of environmental media include surface and subsurface geological and hydrological properties that affect contaminant retention and transport.

The fifth consideration is to evaluate the available data before it is used in the risk assessment. This is necessary because some of the data collected are not representative or are otherwise unsuitable for use in the risk assessment. For example, data may not be pertinent to the baseline risk assessment process because they do not reflect baseline conditions; data may not meet quality assurance/quality control requirements of the risk assessment; or a set of data may be too qualitative for the purpose of quantitative risk assessment.

2.2 DATA COLLECTED AND EVALUATED FOR OPERABLE UNIT 4

Numerous sources of information were examined during the course of the OU4 baseline risk assessment. Specific sources examined and a description of the type of useful information obtained from each source are tabulated in Table 2-1.

TABLE 2-1

SOURCES OF INFORMATION EXAMINED IN THE
OU4 BASELINE RISK ASSESSMENT

SOURCE OF INFORMATION	TYPE OF INFORMATION OBTAINED
WMCO, 1988a, 1989a	Concentrations of contaminants in environmental samples.
Boback,1987	Source term estimates for silo residues
Dames and Moore, 1985	Ground water modeling parameters/characteristics
ASI, 1989	Concentrations of contaminants in environmental samples
Dettorre, 1981	Processing and purification information
Grumski, 1987a	Engineering information on silos, ISP information
Grumski, 1987b	Engineering information on silos, ISP information
Grumski and Shanks, 1988	Engineering information on silos, ISP information
Heatherton, 1953	Qualitative indication of silo leakage
Weston, 1987	Concentrations of contaminants in environmental samples
ODH, 1988	Radon concentration data
Karl, 1953	Qualitative indication of silo leakage
Litz, 1974	Source term information, K-65 residues
Camargo, 1986	Silo engineering information and source term characteristics
Frazier, 1989	Concentrations of contaminants in environmental samples
Gill, 1988	Analyses of K-65 residues

The analytical methods, sample quantitation limits, and data qualifiers were evaluated for all environmental data used in the quantitative risk assessment to the extent that such information was available. The measurement data used in the assessment of the exposure and risk from penetrating radiation and airborne radon were not collected as part of the field investigation activities of the RI. These data were obtained from the FMPC environmental monitoring program. Pertinent sample data were compared to measured background data collected off-site in the vicinity of the FMPC to assess the magnitude of the incremental exposure to radionuclides and chemicals.

A list of radiological contaminants identified in the waste storage silos is presented in Table 2-2. Two of these contaminants (uranium and radium) are considered of concern as a consequence of their radiological properties and the large activities present. Uranium is also considered a chemical hazard because of its chemical toxicity.

Nonradioactive inorganic constituents are also present in the waste storage silo residues. Table 2-3 presents elemental, nonradiological constituents of Silos 1 and 2 (Dettorre et al., 1981). Approximately 40 percent (by weight) of the waste in Silos 1 and 2 is accounted for by silicates (SiO_2). Other elements contributing at least 1 percent to the total mass of waste material include calcium, iron, magnesium, and lead. No sample analyses for organic compounds are yet available; however, based on plant processing and waste disposal information, no organics are expected to be present (ASI, 1987).

Constituents in Silo 3 are residues from waste raffinate slurries that were dewatered in an evaporator, spray calcined, and pneumatically transferred to the silos (DOE, 1988b). The waste is in a dry, powder-like form. Principal constituents of Silo 3 include aluminum, calcium, iron, magnesium, sodium, phosphate, and sulfate. Sample analyses for organic compounds have not yet been performed, but no organics are expected to be present in the residues. Most of the chemicals in the silo residues are physiologically essential elements and naturally-occurring ions, most of which are not listed as hazardous materials.

TABLE 2-2

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ESTIMATED QUANTITIES OF RADIONUCLIDES
IN SILOS 1, 2, AND 3

MATERIAL	QUANTITY	REFERENCE
Silos 1 and 2		
Total uranium	11,200 kg (0.71% U-235)	Grumski, 1987a
	1400 ppm to 1800 ppm	Gill, 1988
Radium	1672 g[a] to 3164 g[b]	Grumski, 1987a Litz, 1974
Ra-226	0.13 ppm to 0.21 ppm	Gill, 1988
Ra-228	0.18 ppt to 0.22 ppt	Gill, 1988
Total thorium	301 ppm to 322 ppm	Gill, 1988
Th-228	0.77 ppt to 0.85 ppt	Gill, 1988
Th-230	1.5 ppm to 2.1 ppm	Gill, 1988
Silo 3		
Uranium	18,000 kg	DOE, 1988a
Radium	15.2 g[a]	DOE, 1988a

[a]Assumes all radium in K-65 residues is radium-226 with a specific activity of 0.988 Ci/g.

[b]Assumes the total mass of K-65 residues is 8.79×10^6 kg.

TABLE 2-3

ESTIMATED QUANTITIES OF NONRADIOLOGICAL CONSTITUENTS
IN SILOS 1, 2, AND 3
OPERABLE UNIT 4[a]
SILOS 1 AND 2

CONSTITUENT	(Metric ton)	(PPM[b])	SILO 3 (metric ton)
Ag	0.176	18	<0.07
Al	77.0		98.67
As	<2.64		
Au	0.44	<40 - 78	<0.14
B	1.32		0.70
Ba	6.16	45,300 - 50,000	0.70
Ca	342.0		144.48
Cd	<0.008	NA	
Cl	0.19	NA	
Co	15.4	1,500 - 2000	8.81
Cr	1.06		1.76
Cu	4.4	400 - 800	8.81
F	0.33		NA
Fe	105.6	13,000 - 18,000	225.52
La	7.83		NA
Mg	110		229.52
Mn	1.76		17.27
Mo	1.76		2.11
Na	61.6		133.0
Ni	19.8	2,000 - 3,700	22.9
Pb	448.8		8.81
PO_4	NA		683.62
Sb	NA		<0.53
SiO_2	3,587.0		461.62
Sn	0.7		1.4
SO_4	NA		692.08
Ti	6.16		2.11
V	1.85		3.52
Zn	<0.060		NA
Zr	1.76		NA

[a]Source: DOE, 1988b.

[b]Source: Gill, 1988.

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The area proximal to OU4 has been monitored for direct exposure to penetrating radiation (gamma radiation). These measurements are collected at periodic intervals from fixed air monitoring stations along the FMPC site boundary to provide a composite annual measurement. The monitoring stations employ thermoluminescent dosimeters (TLDs) to measure the annual external exposure rate from penetrating radiation. A summary of measured penetrating radiation data from WMCO's environmental monitoring program (WMCO, 1989a) is included in Table 2-4. Because this risk assessment describes and quantifies the existing conditions, only direct radiation and airborne radon measurement data collected after recent modifications to OU4 facilities (Grumski and Shanks, 1988) were considered. The addition of the polyurethane foam layer during the K-65 silo ISP altered the direct radiation and radon emanation characteristics of the K-65 silos. Therefore, only environmental monitoring results for airborne radon concentrations and ambient external exposure rates measured after implementation of the ISP are used in the risk assessment. During 1988, the boundary air monitoring station exhibiting the highest average radiation exposure rate was air monitoring station No. 6 located along the western FMPC site boundary directly west of OU4, at a distance of about 340 meters (Figure 2-1).

Airborne radon concentrations at various locations on and off the FMPC site are measured throughout each year as part of the FMPC environmental monitoring program (WMCO, 1989a). Locations of air monitoring stations used in the FMPC environmental monitoring program are shown in Figure 2-1. Monitoring stations employ commercially available radon detectors. These devices are exposed to the ambient air and, after processing, indicate the radon concentrations at each location. A summary of measured airborne radon concentration data collected since completion of the forming project is included in Table 2-4.

The Ohio Department of Health (ODH) performed independent indoor and outdoor radon concentration measurements in the vicinity of the FMPC (ODH, 1988). The ODH established 16 outdoor radon monitoring stations around the FMPC, including 12 locations along the FMPC site boundary (samples) and 4 locations distant from the FMPC (controls). Analyses of the detectors located at the site boundary closest to the K-65 silos and at background locations do not reveal consistent significant differences in measured radon concentrations (ODH, 1988). The ODH study also concluded that environmental measurements of radon

TABLE 2-4

SUMMARY OF CHEMICALS AND RADIONUCLIDES
SAMPLED IN AIR IN THE VICINITY OF OU4[a]

CHEMICAL OR RADIONUCLIDE	FREQUENCY OF DETECTION	RANGE OF DETECTED CONCENTRATIONS	BACKGROUND LEVELS
Penetrating radiation[b]	13/13	5.16 - 23.53 μrem/hr	7.62 - 15.07 μrem/hr
Radon-222	19/19	0.70 - 1.85 pCi/l	0.30 - 0.95 pCi/l

[a]Data from WMCO, 1989a.
[b]Penetrating radiation is defined as energetic electromagnetic emissions from radionuclides.

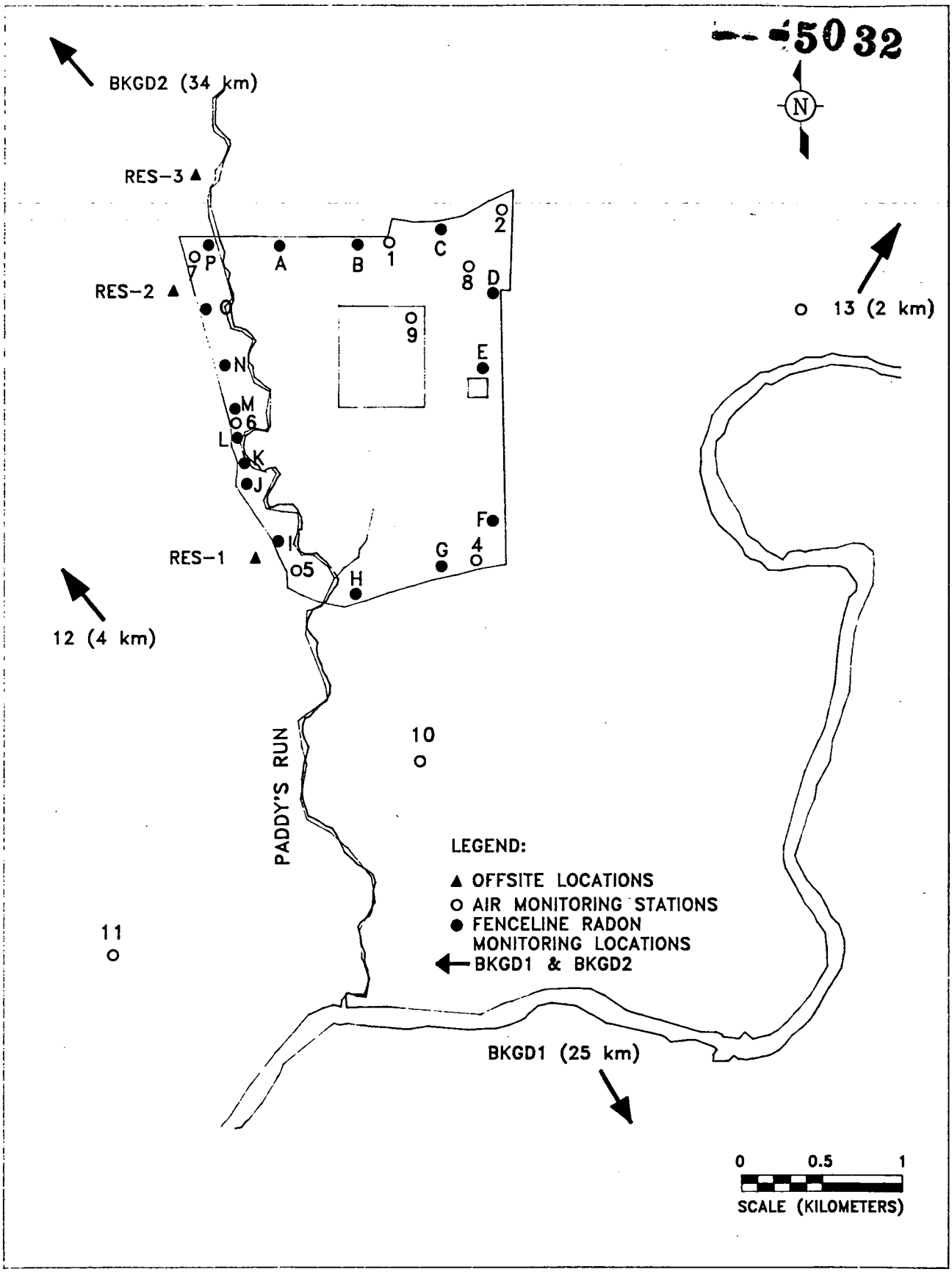

FIGURE 2-1. AIR MONITORING STATION AND FENCELINE RADON MONITORING LOCATIONS

and radon progeny concentrations at the FMPC boundary are sufficiently low that they often cannot be distinguished from variations in natural background concentrations. Measured concentrations do not appear to correlate with distance or prevailing wind direction from the K-65 silos (ODH, 1988). The data collected in the ODH study are not utilized in the quantitative risk assessment because the data were collected prior to the completion of the K-65 ISP and are not representative of the current exposure conditions.

Surface soil samples collected in the area proximal to OU4 have been analyzed for radionuclides. To date, no Hazardous Substance List (HSL) analyses have been performed on soil samples from areas surrounding the silos. Locations of RI surface soil samples are shown in Figure 2-2. Radiological characterization of surface soils surrounding the OU4 silos reveals elevated levels of uranium in the vicinity of the silos (Table 2-5). Table 2-5 presents measured concentrations of uranium in surface soils as high as 37.4 pCi/g U-238 and 11.0 pCi/g U-234 within the vicinity of OU4 (Weston, 1987; ASI, 1989). For purposes of comparison, background concentrations of U-238 in Ohio surface soils average 1.4 pCi/g (Myrick, 1983). In natural soils, a similar background activity concentration of U-234 may be expected. Details of RI sampling and analysis procedures are presented in the RI/FS project plans (IT Corporation, 1988).

Radiological assessment of surface soils surrounding the OU4 silos also reveals elevated concentrations of Ra-226 in the vicinity of OU4 (Table 2-5) (Weston, 1987; ASI, 1989). The highest concentration of Ra-226 in surface soil is 35.8 pCi/g. For purposes of comparison, background concentrations of Ra-226 in Ohio surface soils average 1.5 pCi/g (Myrick, 1983).

In addition, soil samples were collected in 1983 from two diagonal slant boreholes drilled beneath the silo berms. Radiological analyses of these samples reveal elevated concentrations of uranium in soil (Table 2-6) (Vogel, 1989). A similar sampling program that will include analyses for HSL inorganics, volatiles, semivolatiles, pesticides, polychlorinated biphenyls (PCBs), and Extraction Procedure (EP) toxicity metals has been requested (Harmer, 1989) and is scheduled for completion by the spring of 1990.

TABLE 2-5

SUMMARY OF CHEMICALS AND RADIONUCLIDES
SAMPLED IN SURFACE SOILS
IN THE VICINITY OF OU4

CHEMICAL OR RADIONUCLIDE	FREQUENCY OF DETECTION	RANGE OF SAMPLE QUANTITATION LIMITS	RANGE OF DETECTED CONCENTRATION[a]	BACKGROUND LEVELS
Ra-226	31/38	0.3 - 0.5 pCi/g	0.5 - 35.8 pCi/g	1.5 pCi/g[b]
U-238	28/38	3.3 - 19.4 pCi/g	2.4 - 37.4 pCi/g	1.4 pCi/g[b]
U-234	7/38	e	2.4 - 11.0 pCi/g	1.4 pCi/g[c]
U-235	0/38	0.4 - 0.6 pCi/g	None	0.06 pCi/g[d]
Th-232	8/38	0.3 - 6.5 pCi/g	0.6 - 1.7 pCi/g	1.0 pCi/g[b]
Th-230	4/38	e	2.2 - 226 pCi/g	1.4 pCi/g[c]

[a]Data from FMPC CIS Gamma Spectrometry Analysis (Weston, 1987) and FMPC RI/FS Soil Sampling Program.
[b]Myrick, 1983.
[c]Assuming secular equilibrium for U-238, U-234, and Th-230 under natural background conditions.
[d]Assuming natural isotopic ratios of U-235 to U-238.
[e]Data not available.

TABLE 2-6

SUMMARY OF CHEMICALS AND RADIONUCLIDES SAMPLED
IN SLANT BORINGS BENEATH THE K-65 SILOS

CHEMICAL OR RADIONUCLIDE	FREQUENCY OF DETECTION	RANGE OF SAMPLE QUANTITATION LIMITS	RANGE OF DETECTED CONCENTRATION	BACKGROUND LEVELS
Natural (total) uranium	8/8	a	0.77 - 9.66 pCi/g	2.9 pCi/g[b]
Ra-226	8/8	a	0.68 - 1.2 pCi/g	1.5 pCi/g[b]

[a]Data not available.

[b]Assumed to be the same as for surface soils.

FIGURE 2-2 SURFACE SOIL SAMPLING LOCATIONS

An additional transport pathway identified during the risk assessment concerns radon diffusion through the K-65 silo walls and into the silo berms. This pathway is considered a potential release mechanism. Diffusion through the domes is reported to release approximately 60 curies of radon per year (Grumski, 1987a; Borak, 1985). If radon diffuses through the silo walls into the soil, it will decay to nongaseous progeny which will be deposited in the soil. Two of these progeny, Pb-210 and Po-210, have sufficiently long half-lives to accumulate in the berm soil. The radiological characterization of the K-65 silo berm soils has been requested but has not yet been performed; therefore, the significance of this potential accumulation of radiological contaminants and future transport to off-site areas cannot be fully assessed at this time.

Ground water in the area proximal to and downgradient from OU4 has been sampled for radionuclides and chemicals as part of the RI/FS (Figure 2-3) (ASI, 1989). Elevated concentrations of uranium have been measured in water from all wells in the vicinity of OU4. Well 1032 to the west of the K-65 silos (Figure 2-3) revealed a maximum total uranium concentration of 0.276 mg/l (184 pCi/l) (Table 2-7). Measured concentrations of total uranium in background wells are below the analytical lower limit of detection of 1 pCi/l. The background total uranium concentration for the region is reported to be 1.5 µg/l (1 pCi/l) (Hem, 1982). The source of the uranium in well 1032 has not been confirmed. If the source of the measured uranium in these wells had been OU4, one would also expect to detect Ra-226 in above-background concentrations because Ra-226 is a unique indicator of waste material from OU4 (and the K-65 silos in particular). No wells in the vicinity of OU4 reveal concentrations of Ra-226 above the analytical lower limit of detection of 1 pCi/l (Table 2-7). However, the absence of Ra-226 in ground water samples collected does not preclude the possibility that uranium, in a more soluble form than radium, could have been or could continue to be released from the silos.

Table 2-7 also presents results of analyses for metals in ground water samples (ASI, 1989; WMCO, 1989a). Selected ground water samples were also analyzed for semivolatile organics, volatile organics, pesticides and PCBs. No organics or PCBs were found in concentrations above detection limits.

TABLE 2-7

SUMMARY OF CHEMICALS AND RADIONUCLIDES
SAMPLED IN GROUND WATER
IN THE VICINITY OF OU4

CHEMICAL OR RADIONUCLIDE	FREQUENCY OF DETECTION	RANGE OF SAMPLE QUANTITATION LIMITS	RANGE OF DETECTED CONCENTRATION	BACKGROUND LEVELS
Natural (total) uranium	46/49	0.0015 mg/l	0.001 - 0.276 mg/l	0.0001 - 0.0027 mg/l
Ra-226	1/56	1.0 pCi/l	1.0 pCi/l	1.0 - 2.0 pCi/l
Arsenic	0/51	0.0019 - 0.2 mg/l	None	0.002 - 0.55 mg/l
Cadmium	12/50	0.0007 - 0.005 mg/l	0.002 - 0.032 mg/l	0.002 - 0.01 mg/l
Lead	8/50	0.002 - 0.2 mg/l	0.002 - 0.015 mg/l	0.002 - 0.08 mg/l
Manganese	43/50	0.01 - 0.08 mg/l	0.002 - 0.572 mg/l	0.001 - 0.48 mg/l
Nickel	6/50	0.012 - 0.04 mg/l	0.02 - 0.034 mg/l	0.02 - 0.026 mg/l
Silver	2/50	0.0005 - 0.02 mg/l	0.024 - 0.03 mg/l	0.01 - 0.11 mg/l
Zinc	2/2	None given	0.0119 - 0.042 mg/l	a

[a]Data not available.

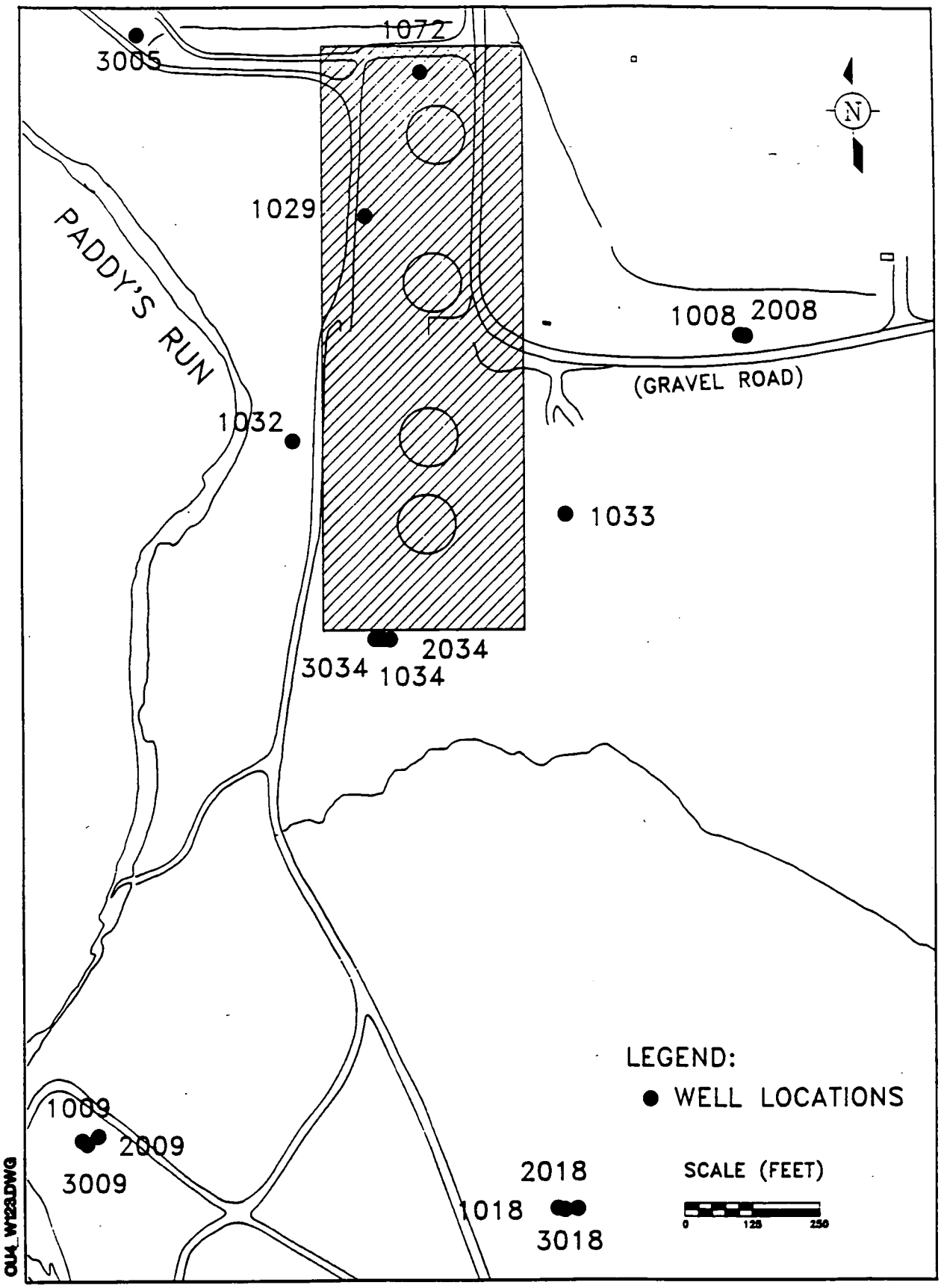

FIGURE 2-3
GROUND WATER SAMPLING LOCATIONS

Surface water in Paddy's Run has been sampled as part of the WMCO annual environmental monitoring program and the RI/FS. Surface water sampling locations are shown in Figure 2-4. Measured concentrations of chemicals and radionuclides in surface water are presented in Table 2-8. Above-background concentrations of uranium have been found at sampling locations in Paddy's Run that are downstream from the silos but upstream from the confluence of Paddy's Run and the storm sewer outfall ditch (SSOD). The maximum measured total uranium concentration is 1,480 pCi/l (2,219 µg/l) from a sample collected at location ASIT-10 (Table 2-8). The average background total uranium concentration in surface water in the vicinity of the FMPC is approximately 1.4 pCi/l (2.1 µg/l) (WMCO, 1989a). This average background was derived by averaging data from three sampling locations along the Great Miami River upstream of the FMPC.

The source of above-background concentrations of uranium in Paddy's Run is not confirmed, but it is noteworthy that drainage ditches from the waste storage area enter Paddy's Run in this general area. Concentrations of Ra-226 in surface water did not exceed background concentrations at any location along Paddy's Run.

Analyses of sediment samples from Paddy's Run collected as part of the WMCO environmental monitoring program and the RI/FS provide a description of the radiological concentrations in stream sediments (WMCO, 1989a; ASI, 1989). Figure 2-4 presents sediment sample locations. At each sediment sample location, a sample was collected from the eastern and western sides of the stream bed and from the middle of the stream bed. Concentrations of chemicals and radionuclides measured in sediment samples are presented in Table 2-9. The maximum total uranium concentration in the sediment samples collected is 30.3 µg/g.

Review of documentation concerning uranium purification processes (Dettorre et al., 1981) reveals the potential for the presence of Th-230 in the storage silo wastes. Wastes produced from the extraction and purification of uranium from uranium ores contain Th-230 because natural uranium ores contain equilibrated activities of all decay products of U-238, including Th-230. The disposition of the Th-230 removed from natural uranium ores at the FMPC has

TABLE 2-8

SUMMARY OF CHEMICALS AND RADIONUCLIDES
SAMPLED IN SURFACE WATER
IN THE VICINITY OF OU4

CHEMICAL OR RADIONUCLIDE	FREQUENCY OF DETECTION	RANGE OF SAMPLE QUANTITATION LIMITS	RANGE OF DETECTED CONCENTRATION	BACKGROUND LEVELS
Natural (total) uranium	6/6	1 µg/l	0.005 - 2.2 mg/l	1.4 pCi/l[b]
U-234	6/6	1.0 pCi/l	1.3 - 85.6 pCi/l	1.0 pCi/l
U-235/236	2/6	1.0 pCi/l	6.0 - 6.7 pCi/l	0.2 pCi/l
U-238	6/6	1.0 pCi/l	2.0 - 196 pCi/l	1.0 pCi/l
Ra-226	0/6	1.0 pCi/l	None	1.0 pCi/l
Tc-99	1/6	30 pCi/l	36.9 pCi/l	a

[a]Data not available.

[b]WMCO, 1989a.

TABLE 2-9

SUMMARY OF CHEMICALS AND RADIONUCLIDES
SAMPLED IN SEDIMENT FROM PADDY'S RUN

CHEMICAL OR RADIONUCLIDE	FREQUENCY OF DETECTION	RANGE OF SAMPLE QUANTITATION LIMITS	RANGE OF DETECTED CONCENTRATION	BACKGROUND LEVELS
Natural (total) uranium	6/7	1.0 pCi/g	1.0 - 30.3 µg/g	1.0 pCi/g[a]
Ra-226	7/7	b	0.4 - 1.0 pCi/g	1.5 pCi/g

[a]WMCO, 1989a.

[b]Data not available.

[c]Assumed to be the same as for surface soil.

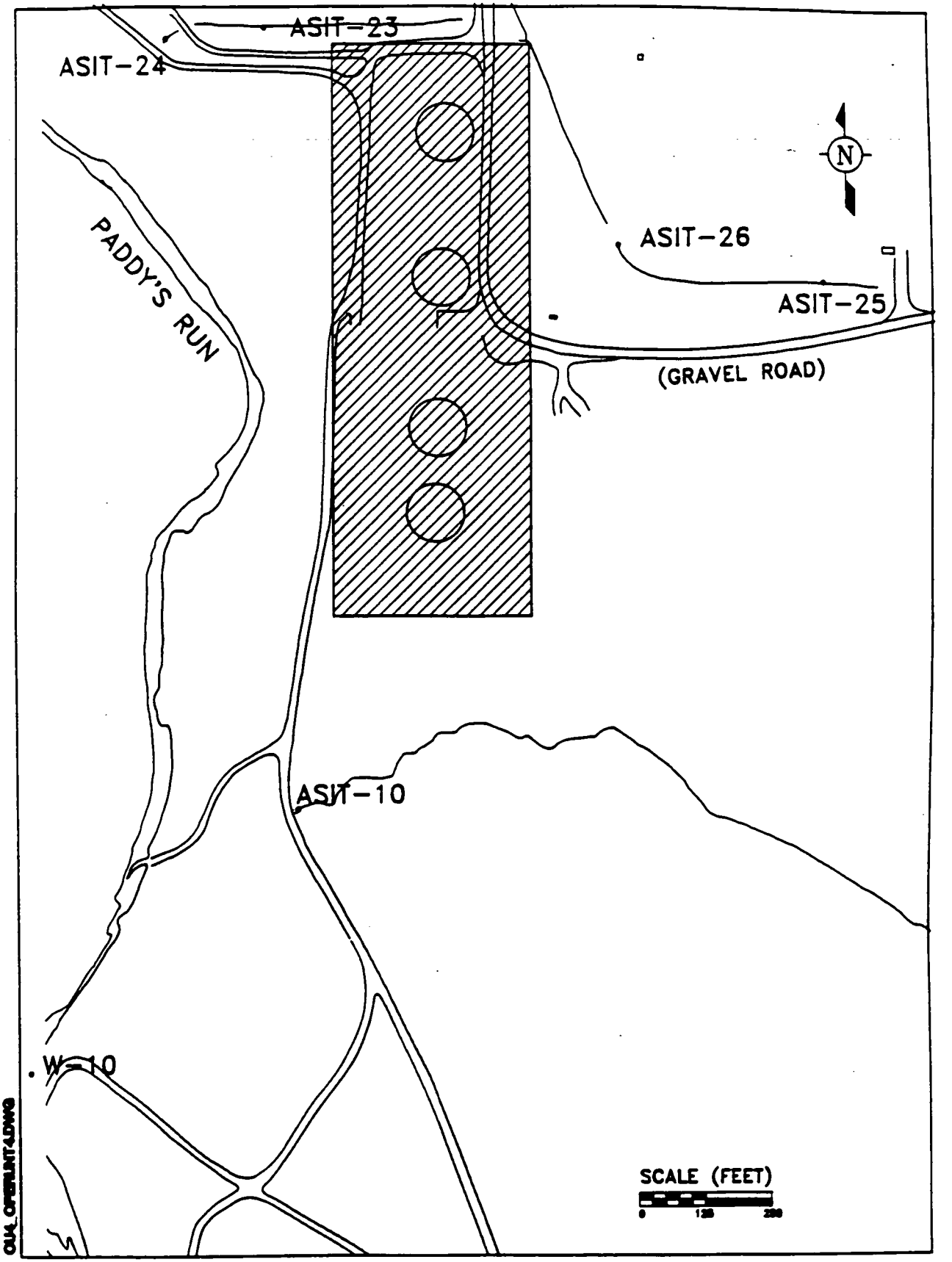

FIGURE 2-4

SURFACE WATER AND SEDIMENTS SAMPLING LOCATIONS

not yet been confirmed. Therefore, it is not known whether quantities of Th-230 activity are present in one or more silos. It is also possible that soluble Th-230 was discharged with the decant water from silos 1 and 2 and then concentrated during the drying process before disposal in silo 3. Nevertheless, Th-230 is necessarily retained as a site-related radionuclide of concern for the OU4 risk assessment pending the completion of ongoing sampling and analyses of the silo wastes. The reason is that Th-230 is an alpha-particle emitting radionuclide which presents a significant internal radiation dose hazard if ingested or inhaled.

2.3 UNCERTAINTIES, LIMITATIONS, AND GAPS IN DATA

EPA risk assessment guidance (EPA, 1989a) emphasizes the importance of identifying the variables and assumptions that contribute the greatest uncertainty to the risk assessment rather than collecting sufficient data to conduct a highly quantitative uncertainty analysis. Therefore, discussions of uncertainty in this chapter address sources of uncertainty only in a qualitative manner.

The data used in the OU4 quantitative risk assessment incorporate uncertainty from radiation exposure rate data and airborne radon concentration data because of the natural variations in these quantities in the environment. Stations monitoring external radiation exposure and airborne radon concentrations are located at points in the environment on-site and off-site. Few of the average external radiation exposure rate measurements and average airborne radon concentrations exceed average annual background levels by more than a factor of two. For example, the average background airborne radon concentration is 0.6 pCi/l with a standard deviation of 0.5 pCi/l, and the average background external radiation exposure rate is 9.9 μrem/hr with a minimum measurement of 7.6 μrem/hr and a maximum measurement of 15.1 μrem/hr (WMCO, 1989a). The calculated average airborne radon concentration is 1.19 pCi/l with a sample standard deviation of 0.36 pCi/l (WMCO, 1989a). The calculated average external radiation exposure rate is 10.21 μrem/hr with a sample standard deviation of 1.95 μrem/hr (WMCO, 1989a). This makes it difficult to differentiate between natural variations in background levels and levels of radon and external radiation exposure attributable to OU4.

Uncertainty also exists in the data used to conduct the quantitative risk assessment as a result of systematic biases. Examples include biased selection of sampling locations, numbers of samples collected, media sampled, and types of analyses performed on samples. For example, analytical data are needed that quantify Th-230 in the waste storage silos. These data are not available at this time. Th-230 is an important potential contaminant from the perspective of ingestion pathways because it is an alpha-particle emitter and, therefore, an internal exposure hazard. Data identifying and quantifying additional chemical and radiological contaminants (e.g., Th-230) are expected to be available as a result of the scheduled waste storage silo sampling and analysis plan.

There are insufficient measurement data to fully identify and quantify the radiological and nonradiological components of the residues and their physical and chemical states. In the absence of measurement data, the risk assessment must rely on previous reports and facility records to quantify potential source terms. Additional analyses are needed to narrow the range on estimated source terms, such as the quantity of Ra-226 in Silos 1 and 2. Current estimates range from 1,672 to 3,164 grams Ra-226, contributing an uncertainty factor of nearly two. For exposure pathways for which there are additional data needs, a reasonable upper bound for each parameter is used whenever possible.

Sampling and analyses data for environmental media immediately adjacent to the silos are currently limited. The effect of the current paucity of data applicable to OU4 is that two important questions cannot yet be definitively answered:

- Are above-background concentrations of radionuclides and chemicals in surface soils, subsurface soils, ground water, and surface water within and adjacent to OU4 attributable to releases from OU4?
- If so, to what extent are these conditions attributable to OU4 rather than other source terms?

Sampling and analyses have been scheduled for the berm soil and the soil beneath the waste storage silos to determine whether the silos could be releasing contaminants to surface soil, surface water, subsurface soil, and ground water. Until the results of these analyses are available, the quantitative exposure assessment will rely on best estimates of source terms and transport parameters.

2.4 SUMMARY OF RADIONUCLIDES AND CHEMICALS OF POTENTIAL CONCERN

Based on available measurement data concerning the constituents of the OU4 waste storage silos, measurement data from environmental monitoring, and information concerning uranium purification processes at the FMPC, the site-related radionuclides of concern for OU4 are: U-234, U-235, U-238; Th-230; Ra-226; Rn-222, and the radon progeny Po-210 and Pb-210. Uranium is the only site-related chemical constituent of concern for OU4.

The K-65 waste storage silos are a relatively unique source of large quantities of Ra-226 activity at the FMPC. In contrast, uranium contamination at the FMPC most likely originates from many areas of the site. Measured above-background quantities of Ra-226 in environmental media in the vicinity of OU4 could indicate releases from the K-65 silos or contamination from past practices associated with silo filling. However, the relative absence of Ra-226 contamination in environmental samples does not entirely preclude the possible release of uranium from the K-65 silos because radium in the silos, in its insoluble radium sulfate form (Dettorre et al., 1981), would be expected to be less mobile than uranium in its soluble uranyl carbonate form (Dettorre et al., 1981). Under such circumstances and assuming that materials are being released from the silos, uranium could be released at a faster rate than radium such that the radium has not yet appeared in environmental samples that have been collected. The scheduled sampling and analyses of the soils directly beneath the silos is expected to resolve the issue as to whether OU4 presents any exposure pathways other than direct radiation exposure and exposure to airborne radon from the K-65 silos.

The ARARs associated with OU4 radionuclides and chemicals of potential concern are listed in Table 2-10. Action levels applicable to OU4 have been determined to be 25 percent of identified ARARs. The primary radiological action

TABLE 2-10

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS
FOR PUBLIC EXPOSURE TO CONTAMINANTS
ASSOCIATED WITH OPERABLE UNIT 4

CONSTITUENT	EXPOSURE LIMIT
Annual radiological exposure limit	100 mrem/yr CEDE[a,b]
Air pathways limits	25 mrem/yr[b] whole body
	75 mrem/yr[b] any organ
Drinking water limit (beta/gamma emitters)	4 mrem/yr CEDE[b]
Radioactivity concentration limits	As set forth in DOE[b] Order 5400.xx
Airborne radon	0.5 pCi/l above-background[c]
Elemental uranium RfD	3 µg/kg/day[d]
	ACTION LEVELS
Operable unit radiation action level	25 mrem/yr CEDE
Pathway/media specific radiation action level	5 mrem/yr CEDE
Chemical toxicity risk based uranium intake action level	0.75 µg/kg/day

[a]CEDE = Committed effective dose equivalent.
[b]See IT Corporation, 1989b.
[c]DOE, 1988c.
[d]EPA, 1989b.

level for OU4 will be a total committed effective dose equivalent of 25 mrem/yr, or 25 percent of the DOE dose limit (100 mrem/yr) for the public (DOE, 1988c). The chemical action level for uranium intake is 25 percent of the RfD which is 3 µg/kg/day.

3.0 EXPOSURE ASSESSMENT

This section presents the estimation of contact, or exposure, between a human receptor and chemicals from OU4. The general procedure for conducting an exposure assessment is (EPA, 1989a):

- Characterization of exposure setting
- Identification of exposure pathways
- Quantification of exposures.

This section covers each step of the exposure assessment.

3.1 CHARACTERIZATION OF EXPOSURE SETTING

3.1.1 Physical Setting

OU4 lies west of the FMPC production area in the waste storage area. To the north of OU4 lies the waste pit area, which historically has contributed relatively large quantities of uranium to the environment (WMCO, 1989b). Due west of the silos lies a creek, Paddy's Run, which flows south before feeding into the Great Miami River. Paddy's Run is dry at times throughout the year. West of the creek lies the FMPC site boundary, which is marked by a fence. The land between Paddy's Run and the west site boundary is leased to local dairy farmers for grazing cattle. This area is upgradient of the silos. An on-site wooded area is found to the south of OU4.

The average rainfall for the area for the years 1985 through 1988 was 102 centimeters (40.0 inches) (WMCO, 1989a). For 1988, the wettest month was July (17.4 centimeters), and the driest month was June (3.02 centimeters) (WMCO, 1989a). The average annual rainfall recorded is 99.2 centimeters (IT Corporation, 1989a). Prevailing winds at the site are from the south-southwest at approximately 10 miles per hour (U.S. Department of Commerce, 1985).

Review of aerial photographs taken from 1950 through 1988 show that, over time, Paddy's Run creek has rerouted itself to the east of its original course, moving closer to the silos. Historically, the east bank of the creek has experienced significant soil erosion (Grumski, 1987b; Boback et al.,

1987). The silos lie at an elevation approximately 15 to 20 feet above Paddy's Run. The east bank of Paddy's Run is covered with thick vegetation. Areas of water seepage from the east bank of Paddy's Run below the silos have been noted. Surface waters generally run off the OU4 area to the west and southwest towards Paddy's Run. The estimated flow rate into Paddy's Run is 1.2×10^7 gallons/year from the waste storage area (WMCO, 1987).

A grass-covered soil berm surrounds the K-65 silos; however, no berm surrounds the metal oxide silo. The original berm eroded and has been regraded to reduce the erosion. The current slope of the berm soils is 3:1 (horizontal:vertical). The bulk density of the soils is approximately 2.6 g/cm^3 (ASI, IT, 1989). A fence surrounds the K-65 silos at the bottom of the berm.

A review of soil characteristics beneath the silos from well boring data logs suggests the following:

- The existence of a saturated zone of perched water approximately 10 feet below land surface. During wet months water levels in surrounding monitoring wells reach close to ground surface. The perched water would tend to flow west toward Paddy's Run.
- Soils are heterogeneous in nature but, for the most part, contain clays. They can generally be described as silty clay loams (ASI, 1989; WMCO, 1989a).
- Soil types approximately 20 feet below ground surface range from silts to sands, indicating a transition into the underlying sands of the regional aquifer.

The regional aquifer lies approximately 45 feet below ground surface and flows generally east with a southeastern branch. However, water from Paddy's Run may also enter the aquifer downstream of the silos near the confluence of Paddy's Run and the FMPC SSOD flow in a southerly direction from that point.

3.1.2 Potentially Exposed Populations

Population centers in the area surrounding the FMPC include the town of

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Fernald, 2.8 kilometers (km) directly south of the plant site with an estimated population of 30; and New Baltimore, 4.4 kilometers southeast of the plant with an estimated population of 200 (SAIC, 1987). The villages of Ross, New Haven, and Shandon are also located near the FMPC. Within an 80-kilometer radius of the plant, there is a population of approximately 2,577,000 in Hamilton and Butler counties (SAIC, 1987). Cincinnati, the largest metropolitan area, is approximately 32 kilometers southeast.

OU4 is completely located within the FMPC boundaries. Human receptors are not expected to have direct contact with OU4 or its constituents of potential concern. It is assumed that strong institutional and governmental controls will persist indefinitely to prevent development of the land within the plant boundaries. However, current contact with constituents may occur via radionuclide and chemical migration from the site. Potentially exposed populations off site include persons living near the western site boundary. An additional potentially-exposed population includes persons living downstream along Paddy's Run who have contact with sediments in Paddy's Run. It is assumed that mainly children will be exposed to creek sediments. A potential, future-exposed population includes well-water users in the area downgradient from the plant site.

For the purpose of this risk assessment, it is assumed that land use within the plant boundaries and adjacent to the plant site will not change appreciably in the future. Aside from the introduction of the FMPC in early 1950s, local land-use has always been primarily agrarian. The assumption that land use in the area will remain unchanged is supported by several studies performed to evaluate future potential economic growth and development of the area (OKI, 1989; CDM, 1989). These population and economic forecasts prepared for the Hamilton County Metropolitan Sewer District (CDM, 1989) and the Ohio, Kentucky, Indiana (OKI) Regional Council of Governments (OKI, 1989) conservatively estimate a population growth of less than 1 percent for Hamilton County by the year 2010. More detailed population trends in the area immediately adjacent to the site show population decreases of up to 25 percent (OKI, 1989). The area will continue to exhibit low-density residential levels and is not expected to be officially classified as "residential." Northwest

Hamilton County has the potential to grow economically by a factor of 7.78 percent due to the fact that 24.7 percent of the land is considered "potentially" developable as residential and 1.1 percent as industrial (CDM, 1989).

Ground water south of the FMPC could be impacted by future potential releases from OU4. The ODH (ODH, 1988) received requests to sample 264 private wells in the vicinity of the FMPC; however, not all of these wells are downgradient from OU4. Wells for three industries are located directly south of the site; however, the ground water is not used in commercial products without treatment. In 1988, a single ground water well was drilled for irrigation purposes southeast of the plant site.

The FMPC lies in the Oak-Hickory Forest Section of the Eastern Deciduous Forest, as described by Bailey (1978). Ecological communities at the FMPC consist of grazed and ungrazed pastures, two pine plantations, deciduous woodlands, riparian woodlands, and a reclaimed fly ash pile area. These habitats are estimated to contain 47 species of trees and shrubs, 190 species of herbaceous plants, 8 mammal species, 98 bird species, 10 species of amphibians and reptiles, 21 species of fish, 47 families of benthic macroinvertebrates, and 132 families of terrestrial invertebrates.

Typical grasses found on the FMPC are red fescue, Kentucky bluegrass, timothy, and red top. Herbs include teasel, red and white clovers, and goldenrod. The dominant tree species in the pine plantations is white pine, with Norway spruce occurring occasionally. Common trees in the deciduous woodlands are white ash, American elm, shellbark hickory, and slippery elm. Dominant tree species in the riparian woodlands are eastern cottonwood, hackberry, American elm, and box elder. The reclaimed fly ash pile is dominated by American elm, eastern cottonwood, and black locust.

Mammal species observed at the FMPC include white-tailed deer, coyote, red fox, opossum, raccoon, groundhog, eastern cottontail, and fox squirrel. Common small mammals are the white-footed mouse, short-tailed shrew, meadow vole, meadow jumping mouse, and eastern chipmunk.

The most common birds breeding on site include the mourning dove, American robin, blue jay, American crow, American goldfinch, northern bobwhite, and common grackle. Species occurring in the greatest density are the goldfinch, song sparrow, and robin. Raptor species observed on-site are the northern harrier, red-shouldered hawk, Cooper's hawk, red-tailed hawk, and American kestrel. The eastern screech owl and great horned owl are also common.

Amphibians and reptiles that occur at the FMPC include the American toad, spring peeper, eastern box turtle, and snapping turtle. Several species of snakes also occur on site, including the eastern garter snake, Butler's garter snake, black rat snake, northern water snake, and the queen snake.

Approximately 130 insect families from 15 orders are represented in FMPC habitats. Leaf hoppers are abundant in all habitats, while less abundant groups include short-horned grasshoppers, leaf beetles, springtails, fruit flies, dark-winged fungus gnats, ants, bees, and wasps.

Potential jurisdictional wetlands occupy areas along the railroad on the north side of the FMPC, along Paddy's Run, and in several drainageways. These habitats harbor small fish, amphibians, and a variety of benthic macroinvertebrates. The most common fish are the bluntnose minnow, creek chub, and stoneroller minnow. The most common benthic macroinvertebrates are nonbiting midges, riffle beetles, mayflies, and stoneflies.

No federally-listed threatened or endangered species have been observed at the FMPC or in its immediate vicinity. Suitable habitat for one species of mammal listed as federally endangered, the Indiana bat, occurs along Paddy's Run. The Indiana bat was not found on site, however.

3.2 IDENTIFICATION OF EXPOSURE PATHWAYS

This section summarizes the potential routes of migration and exposure applicable to the OU4 risk assessment. Potential pathways from OU4 to human receptors are summarized in Table 3-1. These include:

- Direct exposure to gamma radiation from emissions of gamma rays from the contents of the K-65 silos

TABLE 3-1

POTENTIAL EXPOSURE PATHWAYS FROM OPERABLE UNIT 4

Exposed Population	Pathway	Probability of Exposure/ Inclusion in Risk Assessment	Reason for Inclusion or Exclusion
Nearby residents	Direct Radiation	High/Yes	Current and future exposure may exist
Nearby residents	Airborne Radon	High/Yes	Current and future exposures may exist
Children	Ingestion of creek sediments eroded from soils surrounding OU4	Medium/Yes	OU4 could be contributing to elevated levels of uranium and radium in creek sediments, currently and in the future. However, this pathway assumes the silos are leaking. Radon progeny could be a soil contaminant.
Residents south of Operable Unit 4	Ingestion of contaminated ground water	Low/Yes	Current conditions in ground water south of site are addressed in detail in the RI and RA for OU5. Future potential exposures via this pathway from OU4 will be addressed qualitatively.

- Inhalation of radon gas and radon progeny emitted and dispersed through the air from the K-65 silos
- Ingestion of contaminated soils that have eroded into Paddy's Run from the soils surrounding the silos.

Ingestion of ground water containing contaminants that may migrate from OU4 in the future will be considered as a potential future pathway. The nonradiological constituents of the silos are not volatile; thus, it is not likely that any residues will partition into the air.

3.2.1 Direct Radiation

Penetrating radiation propagates in the form of electromagnetic waves; therefore, no transport media are involved. The primary source of penetrating radiation from OU4 is the K-65 residue. This residue contains large quantities of Ra-226 activity from the processing and purification of uranium ores. The energy of penetrating radiation is reduced through scattering processes as it travels from the source and interacts with materials (including air) in its path. The intensity of penetrating radiation decreases with increasing distance from the source. As a result, direct exposure to penetrating radiation exceeding background levels is confined to areas a short distance from OU4. Only a small segment of the general public is subject to any potential above-background exposure to penetrating radiation from OU4.

3.2.2 Airborne Radon

Radioactive decay of Ra-226 in the K-65 residues produces radon-222 (hereafter referred to as radon). Because Ra-226 has a very long radioactive half-life (1,600 years), the rate of generation of radon inside the K-65 silos is nearly constant. Radon accumulates in the airspace inside the K-65 silos between the surface of the residues and the silo domes. Radon in this airspace either decays to its progeny or escapes from the K-65 silos. The emission of radon from the K-65 silos is affected by several parameters including:

- The short half-life of radon (3.82 days)
- Local meteorological conditions establishing pressure gradients between the outside air and the silo airspaces

- The porosity of the residues, the silo domes, and the silo walls.

The exposure concentration of radon is best determined from airborne concentration measurements taken at the FMPC site boundary and off-site air monitoring stations.

3.2.3 Erosion of Soils

Above-background concentrations of uranium and Ra-226 have been detected in surface soil samples in the vicinity of OU4 (Table 2-5; Figure 2.2). The source of the uranium and radium is uncertain; it could be from leakage from the silos, from deposition of airborne emissions from other areas of the FMPC, from historical spills and leaks in the K-65 area, or from other areas at the site such as the waste pits. Because established institutional controls at the FMPC site boundary and around OU4 prevent unintentional access to the operable unit, potential receptors are not expected to be directly exposed to soils in or immediately surrounding OU4. However, the potential exists for constituents from OU4 surface soils to migrate to Paddy's Run, especially in the event of heavy rainfall.

In addition to uranium and radium, Pb-210 and Po-210 may be of concern in the berm soil. Because radon is a gas, it is capable of diffusing through the K-65 silo walls. In the silo walls and in the soil berms outside the silos, the radon may decay into its progeny (e.g. Pb-210 and Po-210). Radon progeny readily attach to particulates, and in this way are deposited in the silo walls and berm soils. The radon progeny, Pb-210 and Po-210, have sufficiently long half-lives to allow Pb-210 and Po-210 activity to accumulate in the berm soils. Stable lead, Pb-206, could also accumulate in the soils. Sampling to quantify these radionuclides in the berm soils is planned.

Simplified modeling of this migration pathway suggests that radon may be diffusing through the K-65 silo walls into the berm soils. Preliminary estimates suggest that up to 1×10^7 pCi/g (approximately 0.2 μg/g) Pb-210 may be present in the silo berms as a result of radon diffusion through the silo walls. The background concentration for elemental lead in southwest Ohio is approximately 15 μg/g (USGS, 1984). This suggests that the total mass of lead

contributed to the environment via this pathway may not be a significant increase above background; however, the elevated Pb-210 activity would be of potential concern if the calculated concentrations are present. The assumptions used to estimate the amount of radon that has decayed to lead and deposited in the berm soil are presented in Attachment A. If soil samples collected from the berms around the K-65 silos reveal elevated concentrations of Pb-210 or Po-210 activity, erosion of these radionuclides into Paddy's Run will be evaluated as a potential migration pathway. However, it is believed that if present, the lead in the soils is likely to be deep in the berm soils and not available for erosion in surface water runoff.

The Universal Soil Loss Equation (USLE) (Williams, 1975; EPA, 1988b) has been used to estimate the amount of soils eroding annually from the silo area. Additional equations have been used to estimate the amount of material that will erode from the silo berm into the surface water of Paddy's Run and the amount that will remain in the sediments along Paddy's Run (Haith, 1980; Mills et al., 1982). These equations are based on the ability of the material to partition between soil and water. Application of these models is difficult without results of berm soil samples. Preliminary calculations have been performed using the average measured uranium and radium concentrations in surface soil samples from the RI field investigation (ASI, 1989) and three samples taken at the base of the berms during the CIS study (Weston, 1987). The model assumes that constituents in the upper 1 centimeter of soil are available for erosion. Results of the modeling are presented in Table 3-2. Results indicate that a greater portion of each selected material will remain in the sediments than will dissolve in the water. The portion entering the water will be diluted upon entering Paddy's Run. A complete explanation of the model and modeling parameters is provided in Attachment B. Modeling results compare well with sediment samples collected along the banks of Paddy's Run directly downgradient from OU4 (Table 2-9).

3.2.4 Ground Water

The presence of above-background concentrations of uranium in ground water and surface water within the FMPC site boundaries has been confirmed by environmental sampling. Limited ground water and surface water sample data are available for the immediate vicinity of OU4 (see Tables 2-7 and 2-8; Figures

TABLE 3-2

ESTIMATED CONTAMINANT RUNOFF FROM OPERABLE UNIT 4 BERM SOILS USING THE UNIVERSAL SOIL LOSS EQUATION[a]

Constituent	Average Concentration in soils (pCi/g)/ (ug/g)	Modeled Concentration migrating to sediments (pCi/g)/ (ug/g)	Modeled Concentration migrating to surface water (pCi/l)/ (ug/g)
Total Uranium	9.8[b]/ 15	6.9/ 10	2.1×10^{-5}/ 3.2×10^{-5}
Ra-226	10[c]/ 1.1×10^{-5}	11/ 1.1×10^{-5}	2.3×10^{-13} 2.3×10^{-7}

[a]See Attachment B for complete modeling results.

[b]Average of four RI samples taken at the base of the berm soils (5650, 5644, 5647, 5884), and three CIS samples (320, 322, 324) taken at the northern base of the berm surrounding Silo 2.

[c]Average of 1 RI sample taken at the base of the berm (5884) and three CIS samples (320, 322, 324) taken at the northern base of the berm surrounding Silo 2.

2-3 and 2-4). Free water found in Silo 2 during recent core sampling of K-65 silo residues suggests that leaking through the bottom of the K-65 silos could occur; however, neither the K-65 silos nor the other areas of OU4 have been established as the source of uranium contamination in environmental media within or outside the immediate area of OU4. No above-background concentrations of Ra-226 have been measured in ground water samples.

Samples are scheduled to be collected that will alleviate some of the assumptions that must be made to model the groundwater exposure pathway. In addition, a study is currently being conducted to evaluate the probability that the silos could fail and lead to a release of constituents. This information will be factored into the analysis of the groundwater exposure pathway in subsequent drafts of this risk assessment.

Contamination in the regional aquifer is being considered under OU5. Consequently, the evaluation of the ground water pathway under OU4 will be confined to the potential for OU4 to contribute to future ground water contamination.

3.3 QUANTIFICATION OF EXPOSURE

3.3.1 Exposure to Human Receptors

Measured values from environmental sampling were used to estimate exposures at receptor locations for the quantification of direct exposure to penetrating radiation and exposure to airborne radon from OU4. Modeling results were used to estimate potential current exposure to OU4 constituents in sediments.

An RME, defined as the highest exposure that is reasonably expected to occur at the site (EPA, 1989a), was identified for each potential current or future exposure to constituents of OU4. In addition, an OU4 RME will be identified to account for an individual that may be subject to one or more identified exposure pathways.

3.3.1.1 Direct Radiation

Environmental measurements of radiation dose equivalent at monitoring stations along the FMPC site boundary are used to quantify direct exposure to penetrating radiation from OU4 (see Table 2-4). For exposure to direct radiation, the

RME individual (located a15 the FMPC boundary due west of the silos) is assumed to be exposed to an average above-background dose equivalent rate of 5.4 μrem/hr. The RME individual is assumed to spend 24 hours/day at home for 365 days/year. The time spent at home is divided into:

- Waking hours spent outdoors
- Waking hours spent indoors
- Sleeping hours spent indoors.

A shielding factor is applied to the time spent indoors to account for the reduction in dose equivalent rate provided by typical dwellings. The following expression is used to calculate the dose equivalent rate for each of the three daily time periods:

$$DE = (DE_{gross} - DE_{bkg})(CF)FI)(EF)(MF)(SF)$$

where

DE	=	annual dose equivalent, (mrem/yr),
DE_{gross}	=	gross RME dose equivalent rate, (μrem/hr),
DE_{bkg}	=	background dose equivalent rate, (μrem/hr),
CF	=	conversion factor, (mrem/μrem),
FI	=	time spent as waking hours, (hr/day); time spent as sleeping hours, (hr/day),
EF	=	exposure frequency, (days/yr),
MF	=	modifying factor for waking hours spent outdoors; modifying factor for waking hours spent indoors; modifying factor for sleeping hours spent indoors (unitless), and
SF	=	shielding factor for dose rate reduction indoors (unitless).

The dose equivalent rates for each of the three daily time periods are summed to obtain a total annual RME dose equivalent rate from penetrating radiation exposure from OU4 of 36 mrem/year. The total annual RME dose equivalent rate is converted to total RME lifetime dose equivalent by multiplying by 70 years, resulting in a dose of 2,500 mrem over a lifetime. The parameter values used to calculate these results are defined in Table 3-3.

TABLE 3-3

PARAMETERS USED TO DESCRIBE EXPOSURE TO
SITE-RELATED CHEMICALS AND RADIONUCLIDES OF POTENTIAL CONCERN

Exposure Pathway	Measured Quantity of Constituent in Medium	Exposure Assumptions	Source
Direct Radiation	Highest average value measured along western fenceline	DE_{bkg} = 9.9 µrem/hr	WMCO, 1989a
		DE_{gross} = 15.3 µrem/hr	WMCO, 1989a
		CF = 10^{-3} µrem/mrem conversion	
		FI = 16 hr/day awake	Assumption
		= 8 hr/day asleep	Assumption
		EF = 365 days/year	EPA, 1989a
		MF = 0.75 awake outdoors	NCRP, 1984a
		= 0.25 awake indoor	
		= 1.0 asleep indoor	
		SF = 0.5	NRC, 1977
Airborne Radon	Highest average value measured along western fenceline	pCi/l_{bkg} = 0.63 pCi/l	WMCO, 1989a
		pCi/l_{gross} = 1.85 pCi/l	WMCO, 1989a
		CF = 10^{-2} WL/pCi/l	Assumption
		DF = 0.6 outdoor daughter equilibrium;	UNSCEAR, 1982
		0.5 indoor daughter equilibrium	UNSCEAR, 1977; 1982
		EF = 50 WM/yr	NCRP, 1984b
		FI = 0.67, awake	Assumption
		= 0.33, asleep	Assumption
		MF = 0.75, awake, outdoor	NCRP, 1984a
		= 0.25 awake, indoor	
		= 1.0 asleep, indoor	
Sediment Ingestion			
Radiological	Average value modeled in Paddy's Run upstream of storm sewer outfall ditch	DCF = radionuclide specific	NRPB, 1987
		IR = 0.2 g/day	EPA, 1989c
		ER = 365 days/yr	EPA, 1989a
		FI = 1	Site-specific
Chemical	Average value modeled in Paddy's Run upstream of storm sewer outfall ditch	IR = 200 mg/day	EPA, 1989c
		CF = 1E-6	
		FI = 1	Site-specific
		EF = 365 days/yr	EPA, 1989a
		ED = 6 years	EPA, 1989c
		BW = 16 kg	EPA, 1989b
		AT = ED x 365 days/yr	EPA, 1989a

3.3.1.2 Airborne Radon

Environmental measurements of airborne radon concentrations collected at air monitoring stations along the FMPC site boundary are used to quantify the RME exposure concentration to airborne radon and radon progeny from OU4. For exposure to airborne radon and radon progeny, the RME individual is assumed to be exposed to an average above-background airborne radon concentration of 1.22 pCi/l (Table 2-4). The RME individual is assumed to spend 24 hours/day at home for 365 days/year. The time spent at home is divided into:

- Waking hours spent outdoors
- Waking hours spent indoors
- Sleeping hours spent indoors.

No shielding factor is applied to the time spent indoors. It is assumed that the outdoor above-background airborne radon concentration attributed to releases from OU4 is also present indoors (NRC, 1980). The following expression is used to calculate the radon exposures during each of the three daily time periods:

$$WLM = (pCi/l_{gross} - pCi/l_{bkg})(CF)(DF)(EF)(FI)(MF)$$

where

WLM	=	cumulative working level month radon progeny exposure, (WLM/yr),
pCi/l_{gross}	=	gross RME radon concentration, (pCi/l),
pCi/l_{bkg}	=	background radon concentration, (pCi/l),
CF	=	conversion factor, (WL/pCi/l),
DF	=	radon daughter equilibrium factor outdoors, indoors (unitless),
EF	=	exposure frequency, (WM/year),
FI	=	fraction of time spent as waking time; fraction spent as sleeping time (unitless), and
MF	=	modifying factor for waking time spent outdoors; for waking time spent indoors, and for sleeping time spent indoors (unitless).

The above equation was used to determine the airborne radon progeny exposure for each of the daily time periods. These three exposures were then summed to obtain a total annual RME radon progeny exposure from OU4 of 0.35 WLM/year.

The total annual RME exposure is converted to total lifetime RME radon progeny exposure by multiplying by 70 years, resulting in a lifetime exposure of 25 WLM. The parameter values used to calculate these results are defined in Table 3-3.

3.3.1.3 Sediment Ingestion

Calculations of both radiation dose and chemical intake were performed for the hypothetical scenario of children ingesting sediments in Paddy's Run. For purposes of this risk assessment, it is assumed that the RME concentration in the sediment is the average concentration of total uranium and the average concentration of Ra-226 modeled using the USLE. Modeled sediment concentrations are used instead of concentrations measured in sediment because the modeled results are based on measured surface soil concentrations from the silo area. The concentrations measured in sediment from Paddy's Run are likely to be partially attributable to erosion from areas other than OU4. The modeled concentration of uranium in sediment is 6.9 pCi/g (approximately 10 µg/g assuming naturally occurring isotopic percent abundance) and the calculated concentration of Ra-226 in sediment is 11 pCi/g (1.1×10^{-5} µg/g). It is assumed that this is the concentration of uranium and radium from OU4 that could be carried downstream and deposited off site in Paddy's Run. Because sediments deposit along the banks of the creek and the creek is often dry, sediments are frequently exposed.

For the calculation of radiological dose, it was assumed that a child consumes 0.2 grams of sediment/day, 365 days/year. This is conservative because it is likely that, during the winter months, exposure to creek sediments would be reduced. Approximately one-half of the total uranium activity (3.5 pCi/g) is contributed by U-234 and one-half (3.5 pCi/g) by U-238, assuming the uranium isotopes are present in their natural percent abundance. The equation for describing the 50-year committed effective dose equivalent (CEDE) for ingestion of uranium or radium is:

$$CEDE = (Cs)(DCF)(IR)(EF)(ED)$$

where

CEDE	=	50-year committed effective dose equivalent, (mrem)
Cs	=	concentration of contaminant in sediment, (pCi/g),
DCF	=	dose conversion factor, (mrem CEDE/pCi),
IR	=	sediment ingestion rate, (g/day),
EF	=	exposure frequency, (days/year), and
ED	=	exposure duration, (years).

Using a U-234 sediment concentration of 3.5 pCi/g with a dose conversion factor of 4.1×10^{-4} mrem/pCi; a U-238 concentration of 3.5 pCi/g with a dose conversion factor of 3.7×10^{-4} mrem/pCi, the resultant CEDE for total uranium is 0.2 mrem per year of ingestion. Using a Ra-226 soil concentration of 11 pCi/g with a dose conversion factor of 1.5×10^{-3} mrem/pCi, the resultant CEDE from ingestion of Ra-226 is 1.2 mrem per year of ingestion. It is assumed that children ingest sediment for 6 years, resulting in a total radiological dose of 8.4 mrem for ingestion of contaminated sediments. Table 3-3 presents a summary of the parameters used for the sediment ingestion pathway.

For the calculation of chemical intake, it was assumed that a 16-kilogram child would ingest sediments at a rate of 0.2 g/day, 365 days/year for 6 years (EPA, 1989b). The child is exposed to 10 µg/g of uranium in the sediments. The model describing intake is (EPA, 1989a):

$$Isi = (Cs)(IR)(CF)(FI)(EF)(ED)/(BW)(AT)$$

where

Isi	=	Intake from sediment ingestion, (mg/kg/day),
Cs	=	concentration in the sediment, (mg/kg),
IR	=	sediment ingestion rate, (mg/day),
CF	=	conversion factor,
FI	=	fraction of ingested soils from contaminated source, (unitless),
EF	=	exposure frequency, (days/yr),
ED	=	exposure duration, (yrs),
BW	=	body weight, (kg), and
AT	=	averaging time (equal to exposure duration * days/yr), (days).

The resultant chemical intake from ingestion of uranium from Paddy's Run sediment is 0.13 µg/kg/day.

3.3.1.4 Ingestion of Drinking Water

Once information becomes available on slant boring samples and estimated probabilistic silo failure scenarios, ground water modeling will be performed. These results will be available in subsequent drafts of the OU4 risk assessment

3.3.1.5 Summary of Intakes

Table 3-4 presents the estimated radiological doses and chemical intake for each pathway quantified under OU4. It has been determined that the OU4 site RME may be exposed to both direct radiation and airborne radon throughout a lifetime. The combined health effect for the RME individual from these two pathways is addressed in the risk characterization in Chapter 5.0.

3.3.2 Exposure to Environmental Receptors

Exposure to environmental receptors is being addressed under the National Environmental Policy Act (NEPA) EIS being performed at the site. These results will be included in subsequent drafts of the OU4 risk assessment.

3.4 UNCERTAINTIES

A major source of uncertainty associated with modeling transport of constituents from OU4 arises from predicting migration through environmental media. Data that are needed but were unavailable to model migration of constituents include:

- Characterization of the chemical species of the constituents in OU4 to determine solubility and soil sorption properties
- Determination of the extent of potential leakage from OU4 waste storage silos
- Characterization of radioactive and chemical materials in the berm soils and the soil beneath the operable unit.

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TABLE 3-4

POTENTIAL EXPOSURE ESTIMATE RESULTS

Exposed Population	Exposure Pathway	Constituent	Concentration at Receptor Location	RME Dose/ Intake	Site-specific Action level[A]
Nearby residents	Direct radiation	Gamma radiation	5.4 μrem/hr above-background	36 mrem/yr	25 mrem/yr
Nearby residents	Inhalation of airborne radon progeny	Radon	1.2 pCi/l above-background	0.35 WLM/yr	0.5 pCi/l above-background
Children playing in Paddy's Run	Ingestion of creek sediments				
Radiological		Uranium	6.9 pCi/g	1.2 mrem/6 yrs	
		Radium	11 pCi/g	7.2 mrem/6 yrs	
		Total		8.4 mrem/6 yrs	150 mrem/6 yrs
Chemical		Uranium	10 μg/g	0.13 μg/kg/day	0.75 μg/kg/day

[a]See Table 2-11 for list of site-specific action levels.

Several uncertainties are associated with receptor exposure estimates. The use of environmental measurement data to estimate radiological dose, assuming OU4 as the singular source term, tends to overestimate the risk associated with that particular operable unit. Sample measurement data might be used to attribute Ra-226 measured in the environment to releases from OU4. Above-background concentrations of Ra-226 may have originated from the K-65 silos in particular because the K-65 residues are a unique source of large quantities of Ra-226 activity at the FMPC site. However, above-background concentrations of uranium may be attributed to releases from a variety of sources.

Receptors for this risk assessment are RME individuals. In the case of exposure to direct radiation and radon, the RME is hypothetical because no resident currently lives along the western fenceline, due west of the silos. These scenarios assume that an individual is exposed continuously 24 hours/day, 365 days/year. The receptors for the sediment ingestion pathway are assumed to ingest sediment for 365 days/year. These scenarios err on the side of health protectiveness.

3.5 SUMMARY OF EXPOSURE ASSESSMENT

Three potential pathways of exposure leading from OU4 to human and environmental receptors have been identified as potential current exposure pathways; a fourth pathway, movement through the ground water, is being evaluated as a potential future pathway of concern, assuming that the silos eventually leak. The risk associated with exposures from potential current pathways will be addressed quantitatively in the risk characterization presented in Chapter 5.0. The risk associated with potential future exposures to OU4 constituents that may migrate to the ground water will be addressed qualitatively in the risk characterization.

4.0 TOXICITY ASSESSMENT

Four potential health hazards are reviewed in this section: direct exposure to penetrating radiation, exposure to airborne radon gas, exposure to Ra-226, and exposure to uranium. Direct exposure to penetrating radiation and exposure to airborne radon are considered potential health hazards in the OU4 risk assessment since above-background levels of these constituents have been measured at the site boundary. Exposure to penetrating radiation or airborne radon poses a radiocarcinogenic health hazard.

Ra-226 is included in the OU4 risk assessment as a radionuclide of potential concern because it has been measured above-background in soils surrounding the silos. If ingested, Ra-226 presents a radiocarcinogenic hazard.

Uranium is a heavy metal found in several iostopic states, all of which are radioactive. Uranium presents both radiocarcinogenic and chemical toxicity health hazards. The primary target organs for the radiocarcinogenic effects are the lung and bone; the target organ for uranium chemical toxicity is the kidney.

4.1 NONCARCINOGENIC EFFECTS

The chemical toxicity of uranium is the only noncarcinogenic health effect associated with OU4 chemicals of concern. Pharmacokinetic and pharmacodynamic studies used to understand the toxicity of this compound and to develop a threshold effect dose limit are summarized below.

4.1.1 Pharmacokinetics

The primary chemically-induced health effect of uranium is nephritis, or kidney damage. Symptoms of this include albuminuria (elevated protein in the urine) and glycosuria (elevated sugar in the urine). In general, uranium compounds are not well absorbed over the human gastrointestinal tract. Soluble uranium compounds demonstrate the best absorption, but in a study where patients drank a solution of uranyl nitrate hexahydrate, a water soluble compound, only 0.5 to 5 percent of the dose was found to be absorbed (Hursh et al., 1969). Most recently, uranium metabolic models have estimated the fractional gastrointestinal (GI) absorption from the GI tract to the blood to be

0.6 percent (Wrenn et al., 1987). Although human data for dermal exposure are minimal, water-insoluble uranium compounds are not absorbed in significant amounts across the skin and are not believed to pose a risk to humans under this exposure route (Yuile, 1973).

Once absorbed into the circulation, uranium compounds are metabolically converted to uranyl ions. The uranyl ion acts as a ligand in the systemic circulation, binding to the plasma proteins and bicarbonate present in the circulation. While this uranyl-bicarbonate complex is stable at the pH of the plasma, the pH change that occurs at the kidney as the urine is acidified favors dissociation of the complex. This leaves the uranyl ion free to bind to the tissues in the proximal tubule wall, resulting in cellular necrosis (Leggett, 1989).

As well as being the only soft tissue that stores uranium in any appreciable amount, the kidney is also the main organ of excretion (Hursh and Spoor, 1973). Approximately 70 percent of a dose of uranium has been estimated to be excreted by the kidney within 24 hours (Berlin and Rudell, 1979). What is not excreted is stored in both the kidney and the bone. While uranium has an affinity for kidney tissue, it also has an affinity for the phosphate groups in the bone structure. Based on studies using laboratory animals, it was concluded that the white rat most closely resembles man in the metabolic handling of uranium compounds (Luessenhop et al., 1958).

4.1.2 Human Studies

Human data on exposure to uranium compounds comes mainly from acute studies on terminal and/or volunteer patients in the years 1940 to 1960. Single injections of 70 to 100 μg/kg of uranium nitrate to terminally ill patients resulted in proteinuria and increased levels of catalase in the urine (Berlin and Rudell, 1979; Luessenhop et al., 1958). In another study, patients were given uranyl nitrate injections ranging from 6.3 to 71 μg U/kg. One of the early signs of renal damage, the appearance of the enzyme catalase in the urine, occurred in patients receiving 55 or 71 μg U/kg (Hursh and Spoor, 1973; Leggett, 1989).

4.1.3 Animal Studies

Laboratory animals demonstrate a great deal of variation in their responses to acute intravenous toxicity studies, with rabbits and guinea pigs appearing to be the most sensitive. The acute intravenous toxicity of soluble uranium compounds like uranyl nitrate is very high: the approximate dose at which 50 percent of the test organisms did not survive (LD_50) for rabbits is 0.1 mg/kg; for guinea pigs, 0.3 mg/kg; for rats, 1 mg/kg; and for mice, 10-20 mg/kg (Stokinger, 1982).

In chronic animal experiments, sublethal threshold doses of uranium have been demonstrated (Leggett, 1989). Though the exact mechanism of tolerance is not known, it is believed that regenerated kidney tissue is associated with tolerance. When uranium exposure ceases, the regenerated epithelium will be transformed into normal renal tubular tissue (Yuile, 1973).

An extensive chronic feeding study was performed on rabbits, rats, and dogs for periods of 30 days, 1 year, and 2 years (Maynard and Hodge, 1949). These animals received uranium doses of 2.8, 14, and 71 mg kg/day in the diet. Rabbits were maintained for 30 days, with rats and dogs maintained for 1 year, and rats maintained for 1 and 2 years. For all species, water soluble compounds were more toxic than insoluble compounds, and lowest observed adverse effect levels (LOAELs) were established for all compounds and each species (Maynard and Hodge, 1949). In all cases, the LOAEL could be established within the first 30 days (EPA, 1989b). Of the three species, rabbits appeared to be the most sensitive, with renal damage exhibited at all administered dose levels. The renal damage was judged to be only moderate at the lower doses, but moderately severe at the highest dose. Based on this, the lowest uranium dose of 2.8 mg kg/day was established as the LOAEL by EPA (Maynard and Hodge, 1949; EPA, 1989b).

4.1.4 Regulatory Guidance

The EPA (1989b) has recently established a reference dose for uranium of 3 µg/kg/day. This reference dose is based on the LOAEL of 2.8 mg/kg/day from the Maynard and Hodge (1949) bioassay and an uncertainty factor of 1,000. The uncertainty factor accounts for intra- and interspecies variability to toxicity and for the use of the LOAEL. No factor of 10 has been included to

account for the short duration of the exposure (30 days) because it has been shown that chronic nephrotoxic effects can be adequately characterized with experiments of acute/subacute duration (EPA, 1989b).

Because of the numerous uncertainties associated with the determination of an acceptable intake, a pharmacokinetic model and the suggested acceptable threshold dose for uranium levels in the kidney are used to calculate an acceptable uranium intake. The National Council on Radiation Protection and Measurements (NCRP) (Wrenn et al., 1985) proposed a single compartment model with long-term retention in the kidney. The International Commission on Radiological Protection (ICRP) (1979) developed a two-compartment model which also assumes long-term retention in the kidney (e.g. a 1,500-day half-time). The NCRP model is considered to be more appropriate for the evaluation of chronic ingestion of uranium at low levels found in the environment. The reason is that the ICRP model was developed for application to inhalation of insoluble forms by radiation workers (Kocher, 1989), and because the fraction transferred to the kidney is so small (Kathren et al., 1989). The NCRP model is:

$$\frac{Ao}{Im} = \frac{f_1}{m(\ln 2)} \left(f_2 T_1\right)$$

where

- Ao = amount of U in the kidney at equilibrium,
- m = kidney mass (310 g),
- f_1 = fractional GI absorption from GI tract to blood (0.014),
- f_2 = fractional transfer from blood to kidney (0.11),
- T_1 = half time in kidney (15 days), and
- I = daily intake (µg).

then

$$\frac{Co}{I} = \frac{Ao}{Im}$$

where

- C = concentration of uranium in µg/g kidney per µg/day intake, or the amount of ingested U that deposited in the kidney at equilibrium.

An acceptable daily intake (I_L) can then be calculated by:

$$I_L = \left(\frac{Cl/S}{A\infty/m}\right)$$

where

C_L = limiting concentration in the kidney (1 µg/g), and
S = safety factor (50).

The limiting concentration of 1 µg/g suggested by the NCRP is below the generally acceptable concentration of 3 µg/g kidney (Spoor and Hursh, 1973) based on dog data that suggests 0.6 may be below the threshold for man (Wrenn et al., 1985). The safety factor of 50 is higher than recently suggested by Kocher (1989).

Based on this model, the I_L for uranium is 186 µg/day. In terms of intake by a 70-kilogram adult, the acceptable intake is 2.7 µg/kg/day, or approximately 3 ug/kg/day, completely agreeing with the RfD determined using animal data.

4.2 CARCINOGENIC EFFECTS

This section of the chapter presents a compilation of radiocarcinogenic risk coefficients for use in radiological risk assessments for OU4. These risk coefficients have been obtained from two radiation protection publications. Radiocarcinogenic risk coefficients are generally expressed as a function of exposure to radiation or exposure to quantities of radionuclides; therefore, they may be multiplied by either the estimated radiation dose received or the estimated exposure to radioactive material.

4.2.1 Radiocarcinogenic Risk from Exposure to Penetrating Radiation and Ingested Radioactive Material

Assessment of the lifetime radiocarcinogenic risk of fatal cancer from exposure to radiation is performed using a somatic whole body risk coefficient of 125×10^{-6} rem^{-1} published by the NCRP (NCRP, 1987). The NCRP presents a tabulation of risk coefficients associated with various body tissues (Table 4-1).

The sum of the tissue-specific risk coefficients equals the NCRP's total whole body risk coefficient of 165 x 10^{-6} rem^{-1}. The total whole body risk coefficient of 165 x 10^{-6} rem^{-1} includes the somatic whole body risk of 125 x 10^{-6} rem^{-1} and the genetic risk of 40 x 10^{-6} rem^{-1}. The somatic whole body risk is used in the risk characterization in Chapter 5.0 to quantify the risk of fatal cancers in individuals exposed to ionizing radiation. The risks of health effects in offspring of individuals exposed to ionizing radiation have not yet been demonstrated.

All of these risk coefficients quantify risk as deaths per unit dose equivalent received (rem^{-1}). The risk coefficients presented by the NCRP are consistent with the recommendations of the ICRP in Publication 26 (ICRP, 1977).

The somatic whole body risk coefficient may be used whether the dose equivalents received are delivered by external penetrating whole body radiation exposure or by radiation exposure of specific tissues from internally deposited radionuclides (as long as the tissue dose equivalents are expressed as risk-weighted dose equivalents). Risk-weighted tissue dose equivalents are tissue dose equivalents that have been multiplied by the appropriate tissue risk-weighting factor (Table 4-1).

4.2.2 Radiocarcinogenic Risk from Exposure to Radon-222 Progeny

Assessment of the radiocarcinogenic risk from exposure to airborne radon and its short-lived progeny is performed using risk coefficients published by the BEIR IV Committee (NAS, 1988), the ICRP (ICRP, 1987), and adopted by the EPA (EPA, 1989d) for use in risk assessments. The BEIR IV and ICRP risk coefficients are selected by the EPA (EPA, 1989d) because they represent the most recent comprehensive examinations of estimated health risks associated with exposure to radon and radon progeny. The risk estimation approach employed by the BEIR IV Committee and the ICRP involves the evaluation of epidemiological data collected on underground miners. The BEIR IV Committee and the ICRP developed relative risk models based on estimated radon progeny exposures of the miners and the incidence of lung cancer mortality in the miners. The

TABLE 4-1

RISK COEFFICIENTS
AND RECOMMENDED WEIGHTING FACTORS

Tissue	Risk Coefficient	Weighting Factor
Breast	25×10^{-6} rem^{-1}	0.15
Red Bone Marrow	20×10^{-6} rem^{-1}	0.12
Lung	20×10^{-6} rem^{-1}	0.12
Thyroid	5×10^{-6} rem^{-1}	0.03
Bone Surfaces	5×10^{-6} rem^{-1}	0.03
Remainder[a]	50×10^{-6} rem^{-1}	0.30
Somatic (whole body)[b]	125×10^{-6} rem^{-1}	0.75
Gonads	40×10^{-6} rem^{-1}	0.25
Total (whole body)[b]	165×10^{-6} rem^{-1}	1.00

[a]A weighting factor of 0.06 is assigned to each of the five remainder tissues receiving the highest dose equivalents under the particular exposure conditions of concern. Dose equivalents to any other tissues beyond the five remainder tissues are neglected.

[b]The somatic whole body risk alone is 125×10^{-6} rem^{-1}. The genetic risk alone is 40×10^{-6} rem^{-1}.

Source: NCRP, 1987

EPA selected an average of the risk coefficients obtained using the BEIR IV and ICRP models, consistent with the recommendation of the EPA's Radiation Advisory Committee (EPA, 1989d).

A fatal lung cancer risk coefficient for radon progeny exposure has been adopted by the EPA for use in assessing risk (EPA, 1989d). The nominal risk coefficient selected by EPA for assessing the risk from exposure to radon progeny is 360 excess lung cancer deaths per million persons per WLM due to lifetime exposure to radon progeny (360×10^{-6}/WLM).

4.3 UNCERTAINTIES RELATED TO TOXICITY INFORMATION

Toxicity information used in the human health assessment incorporates considerable uncertainty. This is because toxicity information is often based upon modeled projections that are themselves based upon empirical studies of animals or humans exposed to radiological or hazardous agents under circumstances that differ from the circumstances of exposure in a site-specific human health assessment. Four principal sources of uncertainty that are incorporated into the human health assessment for both chemical and radiological toxicity are listed below:

- The use of dose-response relationships (models) based on exposures at high doses to predict low dose effects
- The use of dose-response relationships based on acute exposures to predict effects from chronic exposures
- The use of dose-response relationships based on laboratory animal studies to predict effects on humans
- The use of dose-response relationships based on human study populations that may be significantly different from the populations of concern in the site-specific human health assessment.

The radiological risk coefficient and the uranium chemical toxicity reference dose presented in the toxicity assessment incorporate conservative assumptions that are considered to overestimate risk. This conservation is built into the

risk estimates because of the uncertainties that are associated with risk estimation.

The whole body risk coefficient selected by the NCRP incorporates a conservative assumption for radiation protection purposes. This assumption is that the dose-response relationship used to estimate risk is linear without threshold throughout the range of dose equivalent and dose equivalent rates of importance in routine radiation protection (NCRP, 1987).

The risk coefficients associated with exposure to radon progeny range from 140 x 10^{-6} to 720 x 10^{-6}/WLM. The magnitude of this range is a factor of approximately five. This risk range is presented by the ICRP to reflect its estimate of the uncertainty associated with their relative risk coefficient. The BEIR IV Committee did not place a range on its risk estimate.

The EPA uranium chemical toxicity reference dose of 3 μg/kg/day (EPA, 1989b) is based on a published LOAEL of 2.8 mg/kg/day (Maynard and Hodge, 1949) and an uncertainty factor of 1,000. The uncertainty factor is included to compensate for intraspecies and interspecies variability in toxicological response.

More detailed treatments of the uncertainties associated with the risk factors are presented in the referenced documents.

5.0 RISK CHARACTERIZATION

This section provides a characterization of the potential health effects associated with the intake of chemicals that currently, or have the potential to, migrate from OU4. Chapter 3.0 evaluated potential exposures and presents estimates of intake associated with these exposures. Chapter 4.0 presented the cancer potency factors and reference doses for uranium that will be used to characterize identified exposures. In accordance with methods described by EPA (1989a), a health protective approach that is likely to overestimate, rather than underestimate, risk is used. A quantitative evaluation of the risk associated with current exposure conditions, assuming a 70-year exposure period is presented. As necessary data becomes available from ongoing field investigations, a semiquantitative evaluation of the risks associated with potential future exposures to ground water will be presented. This evaluation will cover a 500-year period and is neither applicable nor appropriate to the evaluation of the current lifetime exposures.

5.1 CURRENT EXPOSURE CONDITIONS

This section addresses the concerns associated with currently identified exposures. As stated in Chapter 3.0, current and future land uses are assumed to be similar. Thus, assuming steady-state land use conditions, this section also applies to future land use conditions.

5.1.1 Carcinogenic Effects

Radiocarcinogenic risks from exposure to radiation and radionuclides are calculated using estimated radiation dose equivalents (rem), or cumulative exposure to radionuclides, and the appropriate risk coefficients presented in Chapter 4.0 of this report. Table 4-1 presents risk coefficients as a function of risk-weighted dose equivalent received (rem^{-1}). The toxicity assessment chapter also presents risk as a function of cumulative exposure to radon progeny (WLM^{-1}).

Radiocarcinogenic risks are characterized in this chapter for the following exposure pathways:

- Exposure to penetrating radiation
- Exposure to airborne radon and short-lived progeny
- Exposure to uranium and Ra-226 in stream sediments from Paddy's Run via ingestion.

Table 3-4 presents the estimated RME exposures to penetrating radiation, radiation from internally deposited radionuclides, and radon progeny.

The method for calculating the risk contributed by each of the exposure pathways is expressed by:

$$R_L = (E_L)\ (RC)$$

where

R_L = Lifetime risk of fatal cancer from lifetime exposure to the pathway of interest,

E_L = Lifetime exposure from the pathway of interest, and

RC = Lifetime risk coefficient per unit exposure from the pathway of interest.

Penetrating Radiation

The incremental RME exposure to penetrating radiation from the silos was estimated in the exposure assessment to be 36 mrem/year, or 2,500 mrem over a 70-year lifetime. The lifetime somatic risk per rem to the whole body presented in the toxicity assessment is 125×10^{-6} rem^{-1}. Thus, the incremental lifetime risk of fatal cancer from lifetime RME exposure to penetrating radiation from the silos is 3×10^{-4} for an individual at the FMPC boundary.

Airborne Radon

The incremental RME exposure to airborne radon and its short-lived progeny from the silos was estimated in the exposure assessment to be 0.35 WLM/year or 25 WLM over a 70-year lifetime. The lifetime risk per WLM presented in the toxicity assessment is 360×10^{-6} WLM^{-1}. Thus, the incremental lifetime risk of fatal lung cancer from lifetime RME exposure to airborne radon and radon progeny from the silos is 9×10^{-3} for an individual at the FMPC boundary.

Ingestion of Uranium and Radium-226 in Sediments

The incremental RME exposure to uranium in ingested sediments from Paddy's Run was estimated in the exposure assessment to be 1.2 mrem over a 6-year period (Table 3-4). Because this dose equivalent is a committed effective dose equivalent, it is already risk-weighted and is simply converted from mrem to rem and multiplied by the lifetime risk coefficient per rem. The lifetime risk per rem presented in the toxicity assessment is 125×10^{-6} rem^{-1}. Thus, the incremental lifetime risk of fatal cancer from the 6-year exposure to uranium in ingested sediment from Paddy's Run is 2×10^{-7}.

The incremental RME exposure to Ra-226 in ingested sediments from Paddy's Run was estimated in the exposure assessment to be 7.2 mrem over a 6-year period (Table 3-4). This exposure is used in the same manner as the uranium exposure because it is also a committed effective dose equivalent. The incremental lifetime risk of fatal cancer from the 6-year exposure to Ra-226 in ingested sediment from Paddy's Run is 9×10^{-7}.

Summation of Carcinogenic Risks

The lifetime risks from lifetime exposure to penetrating radiation and airborne radon are summed because it is reasonable to assume that the RME individual may be exposed to the RME exposure from both penetrating radiation and airborne radon released from the silos. This is a result of the fact that the gradients of the penetrating radiation fields and the airborne radon gas concentrations are similar. This results in an incremental lifetime risk of 9.3×10^{-3}.

The risks from exposure to uranium and Ra-226 in sediments are not summed with the risks from penetrating radiation and airborne radon because the sediment injestion pathway is considered a unique exposure pathway for children. However, the risks contributed by the uranium and the Ra-226 in the sediment can reasonably be summed. This results in an incremental lifetime risk of 1.1×10^{-6}.

5.1.2 Noncarcinogenic Effects

The potential health consequence of the noncarcinogenic effects of elemental uranium is evaluated by comparing estimated intakes (Chapter 3.0) with the RfD, which represents an estimate of the level of intake that would not result

in adverse health effects (i.e., a "threshold" effect). The parameter of interest is the hazard index (HI) defined as:

$$HI = I/RfD$$

where

HI = Hazard index (unitless),
I = Intake (µg/kg/day), and
RfD = Reference dose (µg/kg/day).

This approach is different from the probabilistic approach used to evaluate carcinogens. Note that an HI ratio of 0.01 does not imply a 1 in 100 chance of adverse effect, but indicates that the estimated intake is 100 times less than the acceptable intake limit.

The only potential exposure to elemental uranium from OU4 is from ingestion of creek sediments by children. The proper RfD to use in this evaluation may be a subchronic RfD because the exposure occurs over a small fraction (8.6 percent) of the total 70-year lifetime. However, the chronic RfD of 3 ug/kg/day is the only RfD currently exists for uranium. It is assumed that the chronic RfD is appropriate for use in this situation because the chronic effect of uranium toxicity, nephrotoxicity, is the same effect that would be seen during the 6-year exposure. The estimated HI for the child sediment ingestion pathway is 0.043. Using the site-specific action level of 25 percent of the RfD, or 0.75 ug/kg/day, the HI equals 0.17.

5.2 POTENTIAL FUTURE EXPOSURE

This section addresses the risk associated with potential future exposure to contaminated ground water. There is no evidence that confirms existence of a groundwater exposure pathway from OU4; however, the risk associated with potential future exposure to contaminated ground water is being considered (assuming the silos would begin to leak sometime in the future). Subsequent drafts of the risk assessment will incorporate additional information needed to complete an evaluation of this pathway. The University of Cincinnati, under contract to WMCO, is performing a probabilistic risk assessment to

determine the potential for silo failure. Additional RI data are being collected in the form of slant borings beneath the silos to determine if leakage from the silos may be occurring.

5.3 UNCERTAINTIES

The risk characterization integrates environmental sampling, fate and transport analysis, exposure analysis, and toxicological data. Uncertainties associated with each step of the risk assessment process impact the results of the risk characterization. The uncertainties associated with analysis of the environmental sampling data, fate and transport results, exposure estimates, and toxicological data have been presented in previous chapters. This risk characterization strives to minimize the probability that uncertainties may result in an underestimation of the actual health hazards associated with the site. Thus, each step of the process has incorporated bias intended to overestimate the potential hazards being addressed.

6.0 SUMMARY

6.1 CHEMICALS OF POTENTIAL CONCERN

Operable Unit 4 was used historically to store by-products of the uranium separation process. Consistent with process information, it was found that the silos contain high levels of uranium, radium, radon gas, and other inorganic materials found in the initial ores.

Review of environmental sampling data suggests that silo constituents may be contributing potential health hazards via three release mechanisms:

- High levels of uranium decay products emit gamma rays, or penetrating radiation
- Decay of Ra-226 produces radon gas which escapes from the silos and migrates to off-site receptor locations
- Uranium and Ra-226 detected in surface soils within the silo area may erode into environmental media.

Due to the complex nature of the waste problem at the FMPC and the availability of analytical sample data, it is not possible to determine what fractions of the contaminants in environmental media, if any, are attributable to releases from OU4. It is believed that uranium and Ra-226 may be in the soils as a result of historical spills and leaks around the silos. Uranium detected in ground water at above-background levels cannot be definitively attributed to releases from OU4 because, to date, there is no confirmation of significant silo leakage into the underlying soils. Additional sampling is required to resolve this issue. The necessary data will be obtained under the proposed sampling and analysis plan during the spring of 1990.

6.2 EXPOSURE ASSESSMENT

Three potential current migration pathways from OU4 have been identified: direct exposure to penetrating radiation, exposure to airborne radon and radon progeny, and ingestion of constituents eroded from the surrounding soils into stream sediment. Penetrating radiation presents direct radiation exposure. Airborne radon is transported by the prevailing winds. Constituents found in

the soils may erode into Paddy's Run during periods of rain. Soil transport to exposure areas has been modeled using the USLE.

Human exposure pathways have been identified for each chemical/hazard migrating from the OU4 site. The RME individual for direct exposure to penetrating radiation is a person living at the FMPC boundary west of the silos and receiving an incremental dose of approximately 36 mrem/year, or 2,500 mrem over a 70-year lifetime. The RME individual for exposure to airborne radon is also a person at the FMPC boundary west of the silos and receiving an incremental cumulative exposure of 25 WLM over a 70-year lifetime. The RME individual for exposure to eroded soils is a child that ingests sediments while playing in Paddy's Run. This individual may be exposed to modeled concentrations of 6.9 pCi/g of uranium (10 ug/g) and 11 pCi/g of Ra-226. This sediment exposure scenario results in a dose of approximately 8 mrem over a 6-year exposure period.

6.3 TOXICITY ASSESSMENT

The two major toxicological hazards associated with OU4 are the radiocarcinogenicity of the radionuclides and the chemical toxicity of uranium. The radiocarcinogenic hazard is quantified using established risk coefficients expressed as a function of radiation dose or exposure to radionuclides. A risk coefficient of 125×10^{-6} rem^{-1} (NCRP, 1987) is used to quantify the lifetime fatal cancer risk from exposure to ambient penetrating radiation fields. This risk coefficient is also used to quantify the lifetime fatal cancer risk from exposure to radiation emitted by internally deposited radionuclides (uranium and Ra-226). A risk coefficient of 360×10^{-5} WLM^{-1} (EPA, 1989d) is used to quantify the lifetime fatal lung cancer risk from exposure to airborne radon and ralon progeny.

Uranium is a potent chemical toxicant which acts as a nephrotoxicant. Kidney damage has been seen in rabbits at levels as low as 2.8 mg/kg/day. The RfD based on the rabbit data is 3 ug/kg/day, incorporating an uncertainty factor of 1,000.

6.4 RISK CHARACTERIZATION

The incremental lifetime risk of fatal cancer from lifetime exposure at the

RME level to penetrating radiation from OU4 is 3×10^{-4}. The incremental lifetime risk of fatal lung cancer from lifetime exposure at the RME level to airborne radon released from OU4 is 9×10^{-3}. Each of these risk estimates is based on annual averages of actual measurements collected at the FMPC boundary, which incorporates the assumption that all penetrating radiation fields and airborne radon concentrations measured at the boundary have their source in the silos. Assuming that a single individual could reasonably be exposed to both penetrating radiation and airborne radon, the combined incremental lifetime risk from lifetime exposure to these two exposure pathways is 9.3×10^{-3}.

A perspective can be placed on the incremental lifetime risks associated with RME exposures from the penetrating radiation and airborne radon pathways by considering the lifetime risks associated with background exposures from these pathways. Using the same calculational approach, the lifetime risks from lifetime exposures to background penetrating radiation and airborne radon levels are 6×10^{-4} and 4×10^{-3} respectively. This indicates that the incremental risks and background risks from these two pathways are in the same order of magnitude, which is consistent with the fact that the incremental RME exposures from these pathways are within a factor of approximately two of the background exposure levels.

Exposure of children to uranium and Ra-226 via ingestion of contaminated sediments eroded from soils in OU4 is considered separately because this exposure pathway is considered unique to children. The exposure duration is assumed to be 6 years rather than a lifetime. The risk of fatal cancer from this exposure pathway is 1.1×10^{-6}.

The chemical toxicity hazard associated with exposure to the elemental form of uranium does not appear to be of concern. The value of the HI ratio associated with a child ingesting 0.13 ug/kg/day of uranium in creek sediments is 0.043 using the RfD of 3 ug/kg/day in the denominator, and 0.17 using the site-specific action level of 0.75 ug/kg/day in the denominator. This suggests that children would receive an intake of uranium that is less than 20 percent of the allowable limit even under the conservative exposure scenario assumed.

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ATTACHMENTS

ATTACHMENT A

THE POTENTIAL PRESENCE OF LEAD-210, POLONIUM-210, AND STABLE LEAD IN K-65 BERM SOILS

Radium-226 present in K-65 residues decays to radon-222 (referred to here as radon). Radon is a dense noble gas and is free to diffuse in all directions. However, before radon can escape to the atmosphere, it must migrate through air spaces in surrounding materials. The half-life of radon is short, only 3.82 days; therefore, only a fraction of the radon gas inside the K-65 silos can migrate through the residues and possibly through cracks in the silo walls before decaying. In the case of radon released laterally through the silo walls, the material through which the radon must pass prior to emanating into the atmosphere includes not only silo residues and walls, but also the soils in the silo berms.

As radon decays in transit through the berm soils, radon progeny are deposited in these soils because they are capable of reacting physically and chemically with the soil matrix. Radon progeny include Pb-210 and Po-210, which have half-lives of 22.3 years and 138.4 days, respectively. The half-lives of Pb-210 and Po-210 are potentially long enough to allow accumulation in the berm soil surrounding the K-65 silos, assuming radon is being released laterally through the silo walls. All radon progeny will ultimately decay to stable Pb-206.

Radon progeny can pose a health risk if their activity concentrations reach significant levels and if a pathway to human receptors exists. The concentration of Pb-210 in the berm soil may be significant for occupational or public exposure during remediation of the site as a consequence of inhalation or ingestion, and subsequent internal radiation doses. This appendix presents calculated estimates of potential residual Pb-210 concentration within the soil berms of the K-65 silos.

Objective:

The objectives are to assess the potential for radon diffusion through the silo walls and berm soil, and to estimate the potential Pb-210 activity concentration in the berm soil resulting from radon decay. The computer code

RAECOM (NRC, 1988) is used to estimate radon fluence rates from the K-65 silo walls and the silo berms. Using the difference between these fluence rates and assuming that this difference represents radon retained in silo walls and berm soil, the concentration of Pb-210 in the berm soil is estimated. Lead-210 contamination in berm soil is calculated to be 1.4×10^{7} pCi/g soil or 1.83×10^{-1} µg/g soil.

RAECOM is a computer based program developed for the Nuclear Regulatory Commission to estimate radon fluence rates from uranium mill tailing piles. Source geometry restrictions of the RAECOM code require that the silo berms be considered as a series of concentric cylindrical layers of soil surrounding each of the K-65 silos. Each layer of the berm is assumed to be 2 meters thick for these calculations. The maximum berm thickness is 8 meters for the original berm slope, and 18 meters for the current berm slope. These thicknesses are based on the cylindrical approximation of the berms and are equivalent to the maximum thicknesses of the actual conical shape of the berms. Calculational results are approximate because the computer model approximates the conical berm shape with a cylindrical berm shape.

Assumptions:

1. The fluence rate entering the concrete silo wall from the residue is equal to 6.2×10^{4} pCi/m^{2}-s/silo.

   The rate is obtained from the estimated radon activity per year that is available to emanate from the residue surface into the adjacent silo walls and the estimated surface area of the residues. The available radon activity is approximated by the activity released annually from the silos by free air exchange (IT Corporation, 1989a) plus the activity that accumulates in the silo dome void volumes, based on measured void volume radon concentrations (Grumski and Shanks, 1988).

2. The concrete wall has a porosity of 0.01 and a diffusion coefficient of 1×10^{-2} cm^{2}/s.

3. The berm soil is mainly a sandy material with a porosity of 0.30, a diffusion coefficient of 5.4×10^{-2} cm^{2}/s, and a density of 1.6 g/cm^{3}.

4. The activity deposited in a berm soil layer (2 meters thick) is estimated from the difference between the fluence rate entering and the fluence rate exiting the layer.

5. The height of the residue has been reported as 20 ft and 22 ft for the south and north silos, respectively. An average of 21 ft (6.4 m) is used as the average berm height.

6. The maximum berm thickness is assumed to represent the total thickness of the concentric cylinders for use in calculations. The thickness of the original 1.5:1 slope berm is 8 meters and the thickness of the current 3:1 slope berm is 18 meters.

7. The original berm has been in place for 25 years. The current berm (3:1) has been in place for 5 years.

8. The specific activity of Pb-210 is equal to 76.4 Ci/g.

9. The berm surface area through which radon may migrate is approximated by a cylindrical surface area. This surface area is the area of the K-65 residues that is adjacent to the interior surface of the silo walls (approximately 490 m^2 per silo).

   Surface Area of Silo Walls = (2)(3.14)(12.2m)(6.4m) = 490 m^2

Results: Pb-210 Contamination in Berms

Concentrations of Pb-210 in berm soil calculated by RAECOM are presented below. The concentration in the existing berm summed over all layers of berm soil is approximately 1.4×10^7 pCi Pb-210/g soil which corresponds to 1.83×10^{-1} µg Pb-210/g soil.

Layer	Activity Deposition (pCi/m^2-s)	Concentration (pCi Pb-210/g soil)	Concentration (µg Pb-210/g soil)
Concrete 20cm			
Soil 1st 2m	4.2×10^4	1.0×10^7	1.3×10^{-1}
Soil 2nd 2m	1.2×10^4	3.0×10^6	3.9×10^{-2}
Soil 3rd 2m	3.5×10^3	8.6×10^5	1.1×10^{-2}
Soil 4th 2m	1.0×10^3	2.5×10^5	3.2×10^{-3}
Soil 5th 2m	2.9×10^2	1.4×10^4	1.8×10^{-4}
Soil 6th 2m	8.3×10^1	4.1×10^3	5.3×10^{-5}
Soil 7th 2m	2.4×10^1	1.2×10^3	1.6×10^{-5}
Soil 8th 2m	6.7×10^0	3.3×10^2	4.3×10^{-6}
Soil 9th 2m	1.4×10^0	6.9×10^1	8.7×10^{-7}
Sum	5.9×10^4	1.4×10^7	1.83×10^{-1}

The lead concentration in a 2 meter layer of the original berm soil, per pCi/m^2-s fluence rate is:

$(1\ pCi/m^2\text{-}s)(25\ y)(365\ d/y)(24\ h/d)(3600\ s/h)(1/2m)(m^3/10^6\ cm^3)(cm^3/1.6\ g) =$
$246\ pCi/g$

$(246\ pCi/g)(Ci/10^{12}\ pCi)(g/76.4\ Ci)(10^6\ \mu g/g) = 3.2 \times 10^{-6}\ \mu g/g$

The lead concentration in a 2 meter layer of the current berm soil, per pCi/m^2s fluence rate is:

$(1\ pCi/m^2s)(5\ y)(365\ d/y)(24\ h/d)(3600\ s/h)(1/2m)(m^3/10^6\ cm^3)(cm^3/1.6\ g)$
$= 49\ pCi/g$

$(49\ pCi/g)(Ci/10^{12}\ pCi)(g/76.4\ Ci)(10^6\ \mu g/g) = 6.4 \times 10^{-7}\ \mu g/g$

These calculated concentrations do not account for radiological decay of Pb-210 as it accumulates in the berm soil. The original 1.5:1 slope berm soil has been in place for 25 years. Approximately 45 percent of the Pb-210 deposited in the berm soil at the beginning of 25 years would remain at the end of 25 years. Similarly, the current 3:1 slope berm soil has been in place for about 5 years. Approximately 85 percent of the Pb-210 deposited in this berm soil at the beginning of 5 years would remain at the end of 5 years.

There are no known regulatory concentration limits for protection of human health and the environment for Pb-210 or stable lead in soil. However, the DOE does use a Ra-226 soil concentration limit of 5 pCi/g for its FUSRAP program (EPA, 1980). Since Pb-210 is a decay product of Ra-226, this limit could be used as a reference concentration until a more appropriate value can be selected. The estimated potential Pb-210 activity concentration in the berm soil is several orders of magnitude above the referenced level of 5 pCi/g. The best way to verify or refute these calculations is with soil sampling. Sampling and analysis of the berm soil is planned to determine whether the preliminary estimates presented in this attachment reveal a significant existing source of contamination.

ATTACHMENT B

MIGRATION OF CONTAMINANTS FROM SURFACE SOILS INTO RECEIVING WATER

Objective:

Surface soils taken around the berms of the K-65 and metal oxide silos show above-background concentrations of uranium and Ra-226. The potential exists for additional constituents to be present in the berm soils, such as Pb-206, and Po-210 (See Attachment A). The potential exists for these constituents to be resuspended and migrate towards Paddy's Run in the event of heavy rainfall. In this event, some of the constituents will sorb to the soils and deposit in the creek sediments; a portion will dissolve run off into the water and flow into the creek surface water. This attachment presents estimates of the potential for migration. It assumes steady state conditions for all environmental and physical influences.

Methodology:

Annual migration of contaminants in surface soils can be estimated with the Universal Soil Loss Equation (USLE) (Williams, 1975; EPA, 1988b) and models describing contaminant partitioning between soil and water (EPA, 1988b; Haith, 1980; Mills et al., 1982).

The first step in the process is to estimate soil loss (Ys) using USLE:

$$Ys = (Ac)(Rr)(K)(LS)(C)(P)(SD)$$

where

Ys	=	annual sediment yield (kg),
Ac	=	contaminated area (hectares),
Rr	=	rainfall and runoff erosion factor,
K	=	soil erodibility factor (metric ton/unit R),
LS	=	slope length and slope steepness factor,
C	=	cover factor,
P	=	correction for erosion control practice, and
SD	=	sediment delivery ratio, ($D^{-0.22}$)

D = overland distance between erosion site and receiving water (cm).

The second step is to estimate the portion of contaminant in the eroded soils that will remain in the sediment (Ss) and the portion that that will dissolve in the water (Ds):

$$Ss = [1/(1+Oc/(Kd*B))]*(Cad*Ys), \text{ and}$$

$$Ds = [(1/(1+(Kd*B)/Oc)](Cad*Ys)$$

where

Oc = available water capacity in the top cm of soil (unitless),
Kd = sorption partition coefficient (cm^3/g),
B = bulk soil density (g/cm^3),
Cad = contaminant in surface soil (mg/kg), and
Ys = annual sediment yield (kg).

The total contaminant concentration in the effluent (Ce) for the year is estimated by:

$$Ce = Ds/Vr$$

where

Ce = contaminant in effluent (mg/l),
Ds = dissolved substance in runoff (mg/yr),
Vr = site storm runoff (l/yr),

and

Vr = $100(Ac)(Qr)*1000\ m^3/l$, and
Ac = contaminated area (hectares)
Qr = depth of runoff (cm),
Qr = $(Rt - 0.2Sw)^2/(Rt + 0.8Sw)$,

Rt = annual rainfall (cm), and

Sw = water retention factor (cm).

The contaminant concentration in the receiving water body downstream (Cw) is estimated by:

$$Cw = (Ce*qp)/Qt,$$

where

Ce = contaminant in the effluent (mg/l),

qp = runoff peak flow rate (l/yr), and

Qt = Receiving water body flow rate (l/yr).

The contaminant concentration in the creek sediments (Cs) is estimated by:

$$Cs = Ss/Ys$$

where

Cs = contaminant in the creek sediment (mg/kg),

Ss = sorbed substance in runoff (mg/yr), and

Ys = annual sediment yield (kg/yr).

This approach was used to estimate contaminant runoff from the OU4 berms soils and soils immediately adjacent to the berms.

Assumptions:

Site-specific soil parameters were taken from ASI/IT (1989). Remaining assumptions were taken from GRI (1988). All assumptions are listed in Tables A-1 and A-2, along with modeling results.

TABLE A-1 CONTAMINANT MOVEMENT TO PADDY'S RUN FROM EROSION OF K-65 BERM - URANIUM

(references: Williams, 1975; Haith, 1980; Mills et al., 1982)

description	units	variable		value	References/ Assumptions
<<---------- Input Variables -->>					
contaminated area	hectares	Ac	=	0.485	1.5 acres * 0.8(portion sloped to creek/2.47 conversion to hectares)
soil erodibility factor	mtrc tons/unit R	K	=	0.26	GRI, 1988
slope length * slope steepness factor	-	LS	=	9	GRI, 1988
cover factor	-	C	=	0.003	GRI, 1988
erosion control practice factor	-	P	=	1	Assume no erosion control
rainfall and runoff erosion factor	-	Rr	=	200	GRI, 1988
overland distance between erosion site and receiving water	ft	D	=	100	From bottom of berm to Paddy's Run
annual rainfall	cm/yr	Rt	=	99.2	IT Corporation, 1989
SCS runoff curve number	unitless	Cn	=	71	GRI, 1988
available water capacity in top cm of soil	unitless	Oc	=	0.6	calculated
sorption partition coefficent	cm3/g	Kd	=	0.96	ASI/IT, 1989
bulk soil density	g/cm3	B	=	1.5	ASI/IT, 1989
contaminant activity	pci	pCi/g	=	9.76	Average U value surrounding silos
conversion to mass (*1.5)	sa	pCi/g	=	1.50E+00	
contaminant concentration	mg/kg	Cad	=	1.46E+01	Average value detected at base of berm
Paddy's Run flow rate	l/yr	Qt	=	4.50E+07	1.19E7 gallons/yr (WMCO, 1987)
Storm duration	yr	St	=	1	
<<---------- Intermediates (auto-calc) --->>					
sediment delivery ratio	-	Sd	=	0.36	Sd = D^-0.22
annual sediment yield	kg/yr	Ys	=	247.23	Ys = [(Ac)(Rr)(K)(L)(S)(C)(P)(Sd)]*1000
water retention factor	cm	Sw	=	-11.32	Sw = (1000/CN) - 10(2.45)
depth of runoff	cm	Qr	=	114.20	Qr = (Rt-0.2Sw)^2/(Rt+0.8Sw)
runoff peak flow rate	l/yr	qp	=	5415184.84	qp = [(((Ac)(2.471)(4047))(Rt*0.01)(Qr)*1000)/(St(Rt-0.2Sw)]**
sorbed substance quantity in runoff	mg/yr	Ss	=	2554.95	Ss = [1/(1+Oc/((Kd)(B)))]*(Cad*Ys)
dissolved substance quantity in runoff	mg/yr	Ds	=	1064.56	Ds = [1/(1+((Kd)(B))/Oc)]*(Cad*Ys)
total substance in runoff	mg/yr	TR	=	3619.51	TR = Ss + Ds
site storm runoff per year	yr/l	Vr	=	5538648.25	Vr = 100(Ac)(Qr)*1000 (m3 to liter)
Contaminant concentration in effluent	mg/l	Ce	=	1.92E-04	Ce = Ds/Vr
Contaminant concentration in receiving water body downstream	mg/l	Cw	=	2.31E-05	Cw = ((Ce)(qp)/Qt)
	pCi/l		=	1.54E-05	
Contaminant Concentration in creek sediments directly below Op. Unit 4	mg/kg	Cs	=	1.03E+01	Cs = Ss/Ys
	pCi/g		=	6.89	

K - silty clay loam, 4% organic matter
LS - See GRI, 1988 exhibit 7-10; L = slope length (80 feet) and S = slope steepness (3:1)
C - canopy of grass (50% - 6), 95 - 100% ground cover
** - Note: adjustments for hectares to acres to m2; cm to m; and m3 to liters

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TABLE A-2 CONTAMINANT MOVEMENT TO PADDY'S RUN FROM EROSION OF K-65 BERM - RADIUM-226

(references: Williams, 1975; Haith, 1980; Mills et al., 1982)

description	units	variable		value	References/ Assumptions
<<---------- Input Parameters -->>					
contaminated area	hectares	Ac	=	0.485	1.5 acres * 0.8 (portion sloped to creek)/2.47 (conversion to hectares)
soil erodibility factor	mtrc tons/unit R	K	=	0.26	GRI, 1988
slope length * slope steepness factor	-	LS	=	9	GRI, 1988
cover factor	-	C	=	0.003	GRI, 1988
erosion control practice factor	-	P	=	1	Assume no erosion control
rainfall and runoff erosion factor	-	Rr	=	200	GRI, 1988
overland distance between erosion site and receiving water	ft	D	=	100	From bottom of berm to Paddy's Run
annual rainfall	cm/yr	Rt	=	99.2	IT Corporation, 1989
SCS runoff curve number	unitless	Cn	=	71	GRI, 1988
available water capacity in top cm of soil	unitless	Oc	=	0.6	calculated
sorption partition coefficent	cm3/g	Kd	=	100	ASI/IT, 1989
bulk soil density	g/cm3	B	=	1.5	ASI/IT, 1989
contaminant activity	pci	pCi/g	=	10.7	Average Ra-226 value surrounding silos
specific activity of radionuclide	sa	pCi/g	=	9.88E+11	
contaminant concentration	mg/kg	Cad	=	1.08E-05	Average value detected at base of berm
Paddy's Run flow rate	l/yr	Qt	=	4.50E+07	1.19E7 gallons/yr (WMCO, 1987)
Storm duration	yr	St	=	1	
<<---------- Intermediates --->>					
sediment delivery ratio	-	Sd	=	0.36	Sd = D^-0.22
annual sediment yield	kg/yr	Ys	=	247.23	Ys = [(Ac)(Rr)(K)(L)(S)(C)(P)(Sd)]*1000
water retention factor	cm	Sw	=	-11.32	Sw = (1000/CN) - 10(2.45)
depth of runoff	cm	Qr	=	114.20	Qr = (Rt-0.2Sw)^2/(Rt+0.8Sw)
runoff peak flow rate	l/yr	qp	=	5415184.84	qp = [(((Ac)(2.471)(4047))(Rt*0.01)(Qr)*1000)/(St(Rt-0.2Sw)]**
sorbed substance quantity in runoff	mg/yr	Ss	=	0.00267	Ss = [1/(1+Oc/((Kd)(B)))]*(Cad*Ys)
dissolved substance quantity in runoff	mg/yr	Ds	=	0.00001	Ds = [1/(1+((Kd)(B))/Oc)]*(Cad*Ys)
total substance in runoff	mg/yr	TR	=	0.00268	TR = Ss + Ds
site storm runoff per year	yr/l	Vr	=	5538648.25	Vr = 100(Ac)(Qr)*1000 (m3 to liter)
Contaminant concentration in effluent	mg/l	Ce	=	1.93E-12	Ce = Ds/Vr
Contaminant concentration in receiving water body downstream	mg/l	Cw	=	2.33E-13	Cw = ((Ce)(qp)/Qt)
	pCi/l		=	2.30E-07	
Contaminant Concentration in creek sediments directly below Op. Unit 4	mg/kg	Cs	=	1.08E-05	Cs = Ss/Ys
	pCi/g		=	10.66	

K - silty clay loam, 4% organic matter
LS - See GRI, 1988 exhibit 7-10; L = slope length (80 feet) and S = slope steepness (3:1)
C - canopy of grass (50% - G), 95 - 100% ground cover
** - Note: adjustments for hectares to acres to m2; cm to m; and m3 to liters