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HAZARD ASSESSMENT FOR THE GENERAL MOTORS SITE

ADRIAN, MICHIGAN

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES v
ACRONYMS AND ABBREVIATIONS vii
EXECUTIVE SUMMARY ES-1

1. INTRODUCTION 1-1

2. BACKGROUND 2-1
   2.1 SITE HISTORY 2-1
   2.2 SUMMARY OF RECENT REMEDIAL ACTIONS 2-1
   2.3 HAZARD ASSESSMENT SCOPE 2-6

3. DATA EVALUATION 3-1
   3.1 BACKGROUND 3-1
   3.2 EXTRUSION PITS 3-1
   3.3 DRAIN LINES 3-2
   3.4 SUMPS, PITS, AND MANHOLES 3-7
   3.5 FLOOR DRAINS 3-9
   3.6 PIPE CHASE 3-9
   3.7 DATA EVALUATION SUMMARY 3-10

4. EXPOSURE ASSESSMENT 4-1
   4.1 INTRODUCTION 4-1
   4.2 IDENTIFICATION OF EXPOSURE PATHWAYS 4-2
      4.2.1 Non-Routine Maintenance Worker Scenario 4-2
      4.2.2 Future Renovation Worker Scenario 4-2
   4.3 EXPOSURE PARAMETERS 4-4
      4.3.1 Maintenance Worker Scenario 4-4
      4.3.2 Future Renovation Worker Scenario 4-5
   4.4 EXPOSURE POINT CONCENTRATIONS 4-6
      4.4.1 General Source Term and Exposure Point Concentration Calculations 4-6
      4.4.2 Exposure Point Concentrations for Filled Drain Lines, Manholes, and Sumps 4-7
      4.4.3 Exposure Point Concentrations for the Extrusion Pits 4-9
      4.4.4 Exposure Point Concentrations for the Former Floor Drains 4-9

5. DOSE CHARACTERIZATION 5-1
   5.1 DOSE CHARACTERIZATION METHODS 5-1
   5.2 DOSE CHARACTERIZATION RESULTS 5-2

TABLE OF CONTENTS (continued)

6. UNCERTAINTIES 6-1
6.1 DATA COLLECTION AND EVALUATION 6-1
6.2 SOURCE TERM CONCENTRATION CALCULATIONS 6-2
6.3 EXPOSURE POINT CONCENTRATION CALCULATIONS 6-3

7. SUMMARY AND CONCLUSIONS 7-1

8. REFERENCES 8-1

APPENDIX A: RESIDUAL ACTIVITY PLOTS
APPENDIX B: ACTIVITY CALCULATIONS
APPENDIX C: DOSE CALCULATIONS
APPENDIX C-1: DOSE CALCULATIONS WITH CONSIDERATION OF CONTAINMENT MEASURES
APPENDIX C-2: DOSE CALCULATIONS WITHOUT CONSIDERATION OF CONTAINMENT MEASURES

LIST OF FIGURES AND TABLES

Figure **Page**

2-1. Location of the General Motors Site 2-2
2-2. General Motors Site Layout 2-3
2-3. Areas included in 1995 Remedial Action 2-5

4-1. Conceptual Site Model for the General Motors Site Hazard Assessment 4-3

Table **Page**

2-1. Summary of Status of Areas of Concern at the General Motors Site 2-7

3-1. Results from Post-Remedial Action Surveys of the Oil Collection System and Pipe Chase 3-4

4-1. Critical Exposure and Intake Parameters 4-5
4-2. Exposure Point Concentrations 4-8

5-1. Estimated Doses from Residual Uranium for the Maintenance and Renovation Worker Scenarios (No Consideration of Containment Measures) 5-3
5-2. Estimated Doses from Residual Uranium for the Maintenance and Renovation Worker Scenarios (With Consideration of Containment Measures) 5-3

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ACRONYMS AND ABBREVIATIONS

AEC	Atomic Energy Commission
ANL	Argonne National Laboratory
BNI	Bechtel National, Incorporated
CERCLA	Comprehensive Environmental Response, Compensation, Liability Act
CLSM	controlled low-strength material
cm^2	square centimeter(s)
DCF	dose conversion factor
D&D	Decontamination and Decommissioning
DOE	Department of Energy
dpm	disintegrations per minute
EPA	Environmental Protection Agency
ft	foot/feet
FUSRAP	Formerly Utilized Sites Remedial Action Program
GM	General Motors
G-M	Geiger-Mueller
hr	hour(s)
in.	inch(es)
K_d	distribution coefficient
keV	kilo electron volt(s)
LLRW	low-level radioactive waste
m^2	square meter(s)
M1	manhole 1
MDA	minimum detectable activity
μCi	microcuries
mg	milligram(s)
ml	milliliter(s)
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
pCi/g	picoCuries per gram
PRAR	Post Remedial Action Report
psi	pounds per square inch
RAGS	Risk Assessment Guidance for Superfund
RESRAD	RESidual RADioactivity computer code
RME	reasonable maximum exposure
s	second
SAIC	Science Applications International Corporation
SEA	Science and Engineering Associates, Incorporated
U	uranium
UCL_{95}	95 percent upper confidence level
U.S.	United States
yr	year(s)

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EXECUTIVE SUMMARY

This hazard assessment report provides an assessment of potential current and future worker radiation doses associated with residual uranium at the General Motors (GM) site in Adrian, Michigan. The objectives of this report are to evaluate the potential health impacts (radiation doses) associated with the residual uranium at the site, and to provide documentation to support authorization of supplemental limits and release of the site without radiological restrictions.

The GM site was used during the 1950s by the former Bridgeport Brass Company to perform extrusion of uranium metal for the Atomic Energy Commission (AEC). After completion of the AEC work, uranium extrusion equipment was removed and the pits below the extrusion presses were filled with sand and covered with concrete. GM obtained the plant in 1974, and performed radiological surveys of the extrusion operations area in 1976. These surveys showed that radioactive material above current guidelines was still present in numerous places inside the facility. GM conducted decontamination efforts on interior portions of the building (including floors and overhead structural members) during 1976 and 1977. Followup surveys conducted by Oak Ridge National Laboratory (ORNL) in 1977 and 1979 showed that the decontamination efforts had removed radioactivity greater than the surface radioactivity criteria used by the Nuclear Regulatory Commission (NRC) for release of property, and that these interior areas could be used without radiological restrictions.

The GM decontamination efforts did not include areas below the floor slab, including drain lines, sumps, manholes, electrical conduit, and floor drains which had been impacted during the uranium extrusion operations. The 1979 survey results showed that some of these areas contain radioactivity greater than the NRC release criteria. In 1995, DOE conducted additional remedial actions in the below-slab areas to remove as much of this residual uranium as possible. In some areas, access restrictions and high estimated costs prohibited complete removal of the residual uranium. For those areas where residual uranium remains, potential doses under conservative worker scenarios were assessed to determine the possible health effects of leaving this material in place.

To perform the dose assessment, two worker scenarios were considered: a non-routine maintenance worker and a future renovation worker. The non-routine maintenance worker was assumed to work 10 hr/day, over a 10-day period, performing intrusive excavation work in an area where residual uranium was present. This scenario was intended to model possible exposures from future process modifications, such as installation of new assembly-line equipment. It was not intended to model current or routine maintenance worker conditions. The future renovation worker scenario was designed to provide conservative (upper-bound) estimates of potential future exposures. This scenario assumes extensive intrusive work including exposures to all areas of the sub-floor areas containing residual contamination.

The results from the dose assessment show that potential worker doses range from approximately 1 mrem/yr to approximately 3 mrem/yr for the non-routine maintenance worker and future renovation worker scenarios, respectively. These results show that potential future doses could be only a small fraction of the 100 mrem/yr public dose limit recommended by the International Commission on Radiological Protection, and the National Council on Radiation Protection and Measurements. In addition, the potential future doses are well below the proposed Nuclear Regulatory Commission (NRC) and the draft United States (U.S.) Environmental Protection Agency (EPA) site cleanup standard of 15 mrem/yr. These doses are based on the assumption that even though most areas with residual uranium were filled with grout or controlled low-strength material (CLSM), the residual uranium could eventually be released (although diluted by the fill material) through intrusive work activities such as pipe cutting and removal.

A separate assessment was conducted to evaluate potential doses if DOE had not used containment measures (grout or CLSM fill) in the areas with residual uranium. The purpose of this assessment was to provide an evaluation of assumptions used to account for the containment measures in the initial dose assessment discussed above. If DOE had not used containment measures, potential doses were estimated as 30 mrem/yr for the non-routine maintenance worker and 43 mrem/yr for the future renovation worker. Since containment measures were used, these doses do not represent an estimate of potential future conditions at the GM site.

The estimated cost associated with removal of only the drain line system is $1.2 million. This cost estimate does not include remediation of the extrusion pits, manholes, sumps, and floor drains. It also does not include the costs associated with lost productivity to GM of shutting down this plant for the major excavation work which would be required for complete removal of residual uranium exceeding surface activity guidelines. It is likely that the total costs associated with complete uranium removal would be in excess of $2 million.

The results from this hazard assessment show that supplemental limits, as described in DOE Order 5400.5, are warranted for the GM site. It is recommended that the existing residual uranium concentrations in the areas evaluated in this hazard assessment be approved as supplemental limits for the GM site. Leaving the residual uranium in place does not pose a significant potential future risk, and the cost of removal of uranium above current surface activity guidelines is very high relative to the long-term benefits that would result.

1. INTRODUCTION

This hazard assessment report provides an assessment of potential current and future worker radiation doses associated with residual uranium at the General Motors (GM) site in Adrian, Michigan. This site has been remediated under the United States (U.S.) Department of Energy's (DOE) Formerly Utilized Sites Remedial Action Program (FUSRAP). The objective of FUSRAP is to identify and clean up or otherwise control sites where residual radioactivity (exceeding current guidelines) remains from the early years of the nation's atomic energy program or from commercial operations causing conditions that Congress has authorized DOE to remedy. The residual radioactivity at the GM site resulted from activities conducted in support of the nation's early atomic energy and weapons programs.

During the 1950s, the former Bridgeport Brass Company used a portion of the Adrian, Michigan plant now operated by GM to produce material for uranium fuel elements for production reactors in Hanford, Washington and the Savannah River Plant in South Carolina. This work consisted of extrusion of uranium metal, using two large extrusion presses. After completion of the Atomic Energy Commission (AEC) work, the extrusion presses and associated equipment were removed, and the service pits below the extrusion presses were filled with sand (date unknown) (ORNL 1982). Most of the radioactivity at the GM site associated with the extrusion operations and subject to remedial action under FUSRAP, was removed during previous decontamination efforts. Decontamination of the interior portions of the building, including floors and overhead structural members, was completed in 1977 (ORNL 1982). These areas are not addressed in this report.

Remedial actions to reduce the amount of radioactivity in the areas not addressed during the 1977 remedial actions were completed in 1995. Because of the inaccessibility of some areas, and the high cost of complete remediation, residual concentrations of uranium above guidelines remain in the former uranium extrusion press pits, the oil collection system (including manholes, sumps, and drain lines), and the former floor drains in the area of the plant used for uranium extrusion operations. These locations are areas where the application of supplemental limits, based on assessment of potential current and future doses (hazard assessment) is appropriate because they present very low exposure risk to workers and members of the general public.

DOE protocol provides for the release of property without radiological restrictions in cases where residual radioactive material may exceed established guidelines but does not pose a significant present or future exposure risk, and where the cost of remedial action is unreasonably high relative to the long-term benefits (DOE 1986, Gilbert et al. 1989, DOE 1990). The objectives of this hazard assessment are to evaluate the potential radiation doses associated with residual uranium at the GM site, and to provide justification to support authorization of supplemental limits and release of this site for use without radiological restrictions. Site background and historical information related to the dose assessment are provided in Section 2 of the report. Section 3 summarizes and evaluates the radiological survey data used for dose calculations. Section 4 provides an assessment of the potential current and

future exposure pathways for workers at the plant, and Section 5 characterizes doses for each of these exposure pathways. The significance of uncertainties associated with the exposure assumptions is discussed in Section 6, and the results and conclusions are summarized in Section 7.

2. BACKGROUND

2.1 SITE HISTORY

The former Bridgeport Brass Company operated a special metals research extrusion plant in Adrian, Michigan during the 1950s under contract with the AEC. The location of the plant, now owned by GM, is shown in Figure 2-1. The operation produced material for uranium fuel elements for production reactors in Hanford, Washington and the Savannah River Plant in South Carolina. Uranium handled in this operation included depleted, natural, and up to 2.1 percent enriched. There are no descriptive records available which indicate the full nature of the operations at this plant. After completion of uranium extrusion work for the AEC, the extrusion presses were removed and service pits (extrusion pits) beneath the presses were cleaned out, filled with sand, and covered with concrete. Figure 2-2 shows the area of the plant used for uranium extrusion activities. The plant was sold to Martin Marietta in the early 1960s. Martin Marietta used the facility until 1974, when it was sold to the Chevrolet Manufacturing Division of GM. There are no records documenting radiological contamination levels for the period from about 1961 to 1976.

GM conducted radiological characterization surveys in 1976 which revealed radioactive material in numerous places inside the facility, including elevated horizontal surfaces, fixtures, and in floor cracks. These areas were decontaminated and a confirmatory radiological survey was conducted by Oak Ridge National Laboratory (ORNL). The results of the 1976 ORNL survey showed residual radioactive contamination greater than the limits for use without radiological restrictions on some floor areas and in off-gas ducts. The ducts were removed and additional decontamination efforts were completed in February 1977. A followup survey conducted by ORNL in 1977 verified that the interior building areas had been successfully decontaminated to levels less than the guidelines for use without radiological restrictions (ORNL 1982). This survey and an additional followup survey conducted in 1979, documented elevated concentrations of uranium-238 (U-238) in residue, scale, and other miscellaneous materials collected from the bottom of the extrusion press service pits, the electrical pipe chase, floor drains, and the oil collection system (including manholes, sumps, and drain lines) beneath the floor of the facility in the extrusion press operations area.

After removal of radioactive contamination from the interior building areas, the former extrusion press area was placed back into use for normal manufacturing operations. Because the remaining residual radioactive material was confined to areas not normally accessible to plant workers, automobile part manufacturing operations continued at the facility up to the most recent remedial actions.

2.2 SUMMARY OF RECENT REMEDIAL ACTIONS

Because of the potential for future exposures to radioactive material in the sub-floor areas, DOE conducted additional remedial actions at the GM site during April to July, 1995. For the electrical pipe chase area, the goal of the 1995 cleanup effort was to remove radioactive

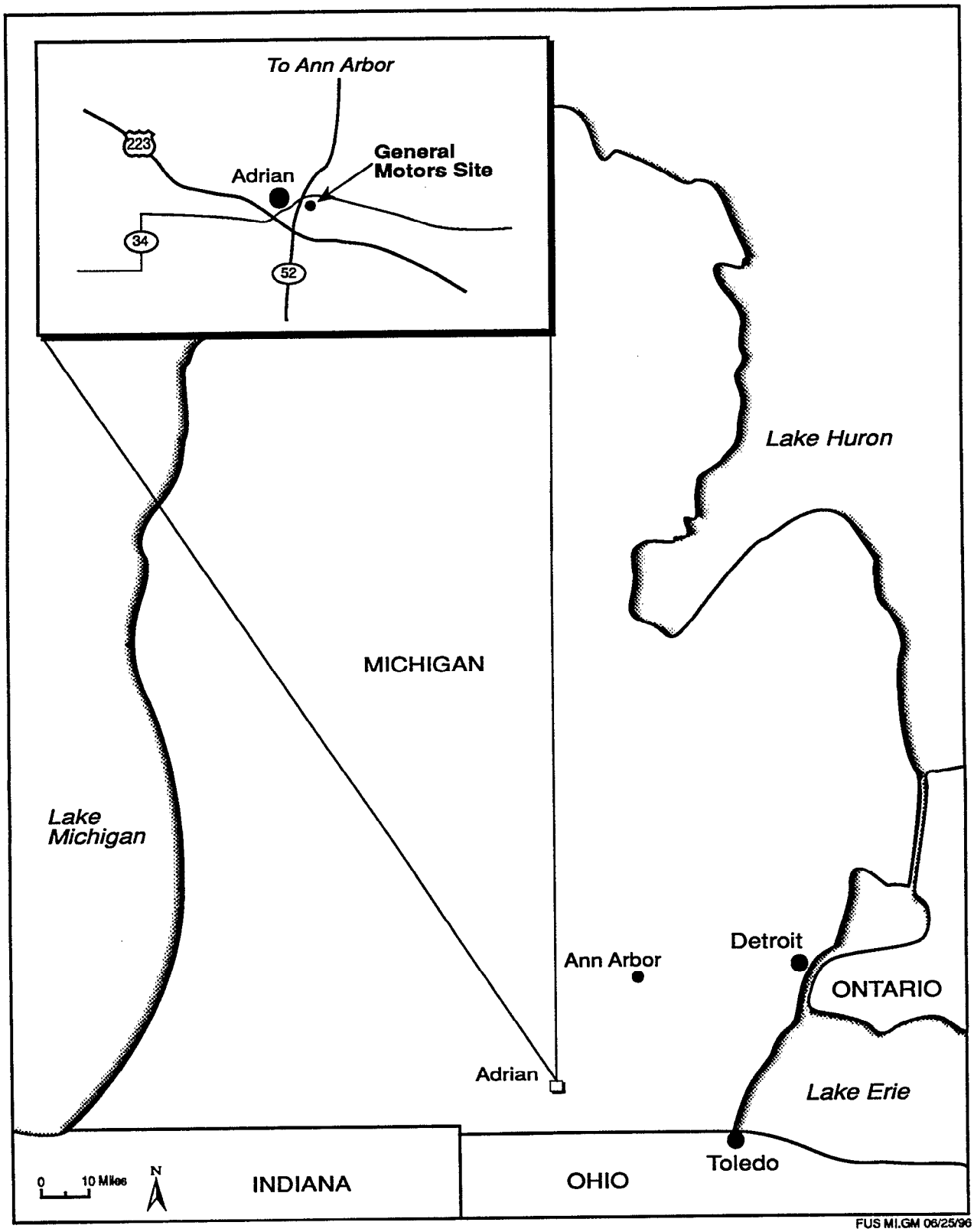

Figure 2–1. Location of the General Motors Site

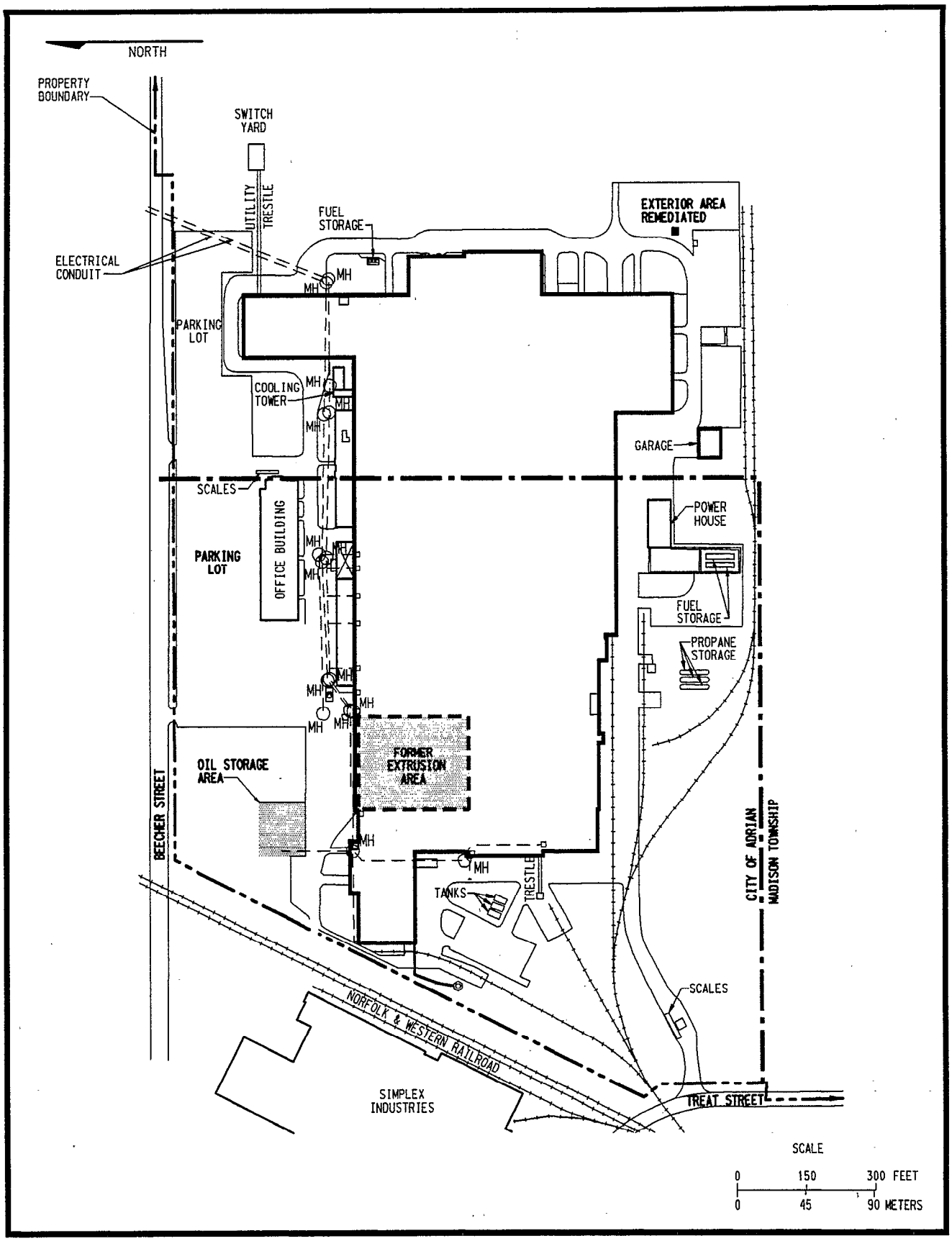

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Figure 2-2. GM Site Layout

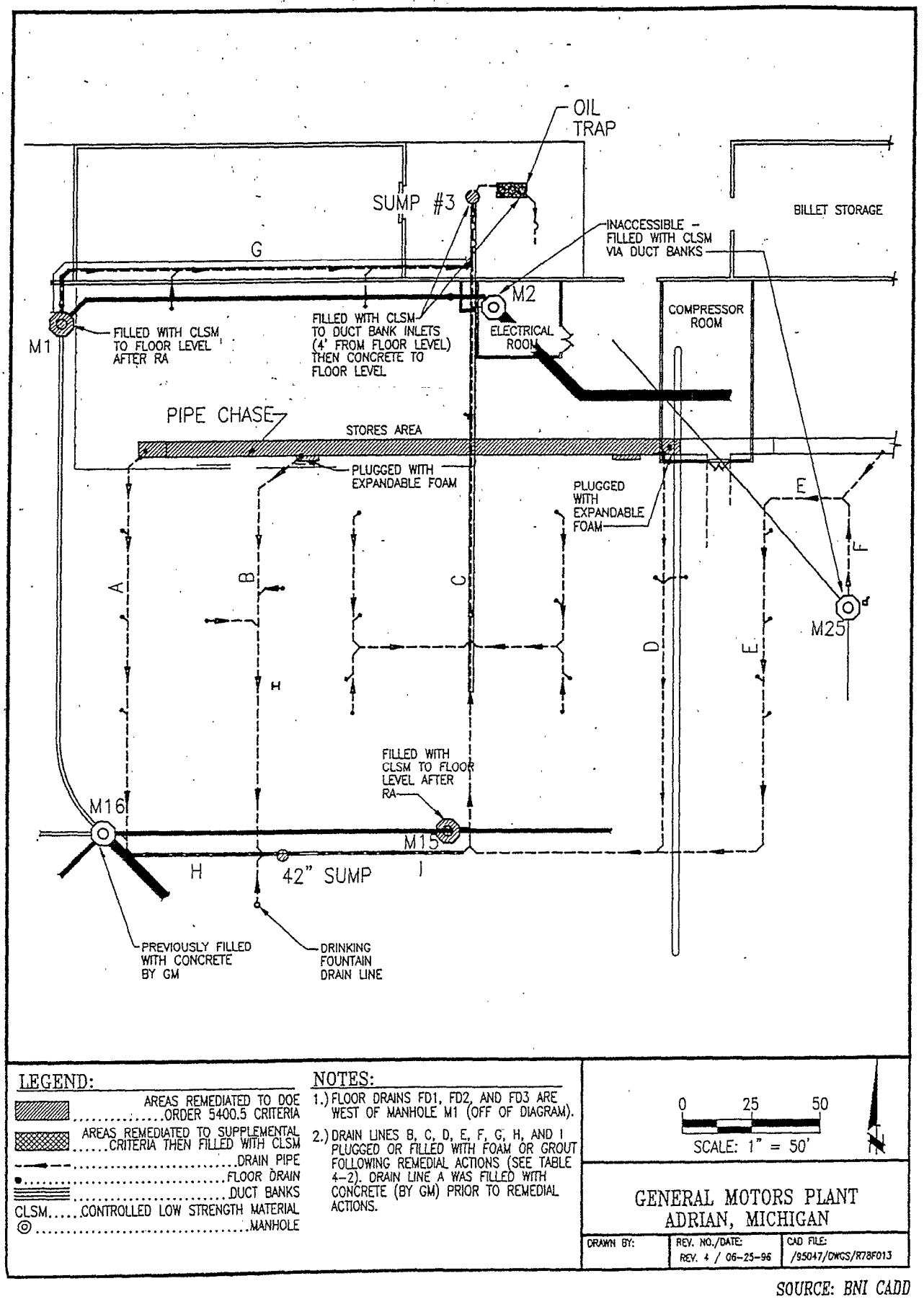
materials greater than the surface radioactivity cleanup criteria contained in DOE Order 5400.5. These criteria are functionally equivalent to the surface radioactivity limits established by the Nuclear Regulatory Commission (NRC) in Regulatory Guide (Reg. Guide) 1.86, which limit the amount of radioactivity in areas used without radiological restrictions. For the oil collection system, the goal was to remove as much radioactive material as feasible; ideally to levels less than those specified in DOE and NRC regulations. However, for areas where it was not possible to remove all radioactive material due to cost and accessibility constraints, as much uranium as feasible was removed, and the drain or sump was filled with flowable concrete (grout) or with controlled low-strength material (CLSM) to isolate the remaining residual radioactivity from current and future workers. CLSM is a mixture of sand, cement, and water. It is similar to concrete except that it contains no aggregate, and there is more sand in the mix. These features permit improved flow into inaccessive areas compared to concrete. In some areas, drain lines were plugged (but not filled) with foam due to access limitations. Because the extrusion press pits had been previously cleaned out and filled with sand, no additional remedial actions were conducted at these locations during the 1995 remedial actions.

The areas of the plant included in the 1995 remedial actions are shown in Figure 2-3. These areas include the electrical pipe chase and the oil collection system (including associated manholes, sumps, and drain lines). For purposes of the discussions in this assessment, the oil collection system includes the 42-inch (in.) sump, sump No. 3, and the oil trap pit; manholes M1, M2, M15, M16, and M25; and drain lines A, B, C, D, E, F, G, H and I as shown in Figure 2-3.

During the 1995 remedial actions, contaminated inactive lines within the pipe chase were cut, wiped to remove the oily film, and disposed as low-level radioactive waste (LLRW). Approximately 30 percent of the pipe hangers and brackets were clean and were left in place. Gang or multi-supports were decontaminated and abandoned in place. The walls and floors of the pipe chase were decontaminated using simple decontamination techniques. The decontamination effort successfully removed all uranium in the pipe chase greater than the surface radioactivity criteria.

Most of the oil collection system sumps, manholes, and drain lines contained an oil/water and sludge mixture that was removed during decontamination efforts. The liquid and sludge material was removed by pumping into drums. After removal of liquid and sludge, any remaining debris was removed to allow decontamination of the wall and floor surfaces of the sump or manhole. The walls and floors of each sump were decontaminated using a 3,000 pounds per square inch (psi) and a 10,000 psi Hydrolaser™ system, and wiping with soapy rags. The drain lines were decontaminated to the extent possible, surveyed, and then plugged or filled with foam, flowable concrete, or CLSM. Remedial actions successfully removed uranium to below the surface radioactivity criteria at the 42-in. sump, M1 and M15.

Manholes M2 and M25 were inaccessible, and were filled with flowable concrete via their duct banks from other manholes. M16 and the drain line associated with M16 (drain line A) were filled with concrete by GM during previous renovation activities (date unknown).



SOURCE: BNI CADD

Figure 2-3. Areas Included in 1995 Remedial Action

Floor drains in the area of the former extrusion operations (FD1, FD2, and FD3) were covered with a new floor slab by GM during previous construction work, and could not be located during investigation and remedial action activities.

While these locations were not specifically included in the 1995 remedial actions, they are included in this hazard assessment.

2.3 HAZARD ASSESSMENT SCOPE

The scope of this hazard assessment includes evaluation of potential doses from each area of the plant where residual uranium remains in concentrations greater than the surface radioactivity guidelines specified in DOE and NRC regulations. These areas include sump No. 3, the oil trap pit, manholes M2, M16, and M25, and drain lines A, B, C, D, E, F, G, H, and I. Because access to drain lines A and F was not possible, these lines were combined with manhole M16 and M25, respectively, for dose calculations. Three covered floor drains (FD1, FD2, and FD3) in the area of the former extrusion operation (which showed elevated uranium concentrations during the 1977 ORNL surveys) and the two extrusion press pits were also included in this hazard assessment. Doses were not assessed for the pipe chase, 42-in. sump, manholes M1 and M15 since these areas were decontaminated to the surface radioactivity criteria (supplemental limits are not required). However, summaries of the post- remedial action survey results for these areas are included in Section 3 to provide justification for not assessing potential doses associated with these locations. Table 2-1 provides a summary of the areas covered in previous and recent remedial actions, the current status of each area, and whether or not the area is included as part of this report. The most recent residual radioactivity concentration data from each of these areas was used as the source term for dose calculations. A detailed evaluation of the data from each of the potential hazard assessment areas is presented in Section 3.

Table 2-1. Summary of Status of Areas of Concern at the General Motors Site

Area	Remedial Action History	Current Status	Included in Hazard Assessment
Above-Floor Interior Building Surfaces	Decontaminated during 1977 remedial actions	Released for use without radiological restrictions	No
Pipe Chase	Decontaminated during 1995 remedial action	Released for use without radiological restrictions	No
Extrusion Pits	Filled with sand and covered with concrete during 1977 remedial action	No change - not addressed during 1995 remedial action	Yes
Oil Collection System			
Floor drains (FD1, FD2, and FD3)	Covered with concrete by GM (date unknown)	Residual uranium present	Yes
Manholes (M1, M2, M15, M16, & M25)	Manholes (M1, M2, M15, & M25) included in 1995 remedial actions. M16 filled with concrete by GM (date unknown).	M1 and M15 decontaminated to surface contamination criteria. Residual uranium present in M2, M16, & M25.	M2, M16, & M25 only
Drain lines A, B, C, D, E, F, G, H, & I, and electrical conduit lines from M1 and M15	Drain lines B, C, D, E, G, H, & I, and M1 and M15 electrical conduit lines included in the 1995 remedial actions. Drain line A filled with concrete by GM when filling M16 (date unknown).	Drain lines E and G, and M1 electrical conduit line decontaminated to total surface contamination criteria (removable portion unknown). Residual uranium present in Drain lines A, B, C, D, F, H, and I, and M15 electrical conduit line.	All drain lines and electrical conduit lines included. Drain lines A and F combined with M16 and M25, respectively, for assessment.
Sumps (42-in., sump #3, and oil trap pit)	Included in 1995 remedial actions	42-in. sump decontaminated to surface contamination criteria. Residual uranium present in sump #3 and oil trap pit.	Sump #3 and oil trap pit only

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3. DATA EVALUATION

3.1 BACKGROUND

The primary sources of information used in the GM site hazard assessment to determine existing radiological conditions include (1) *Radiological Survey of the Former Bridgeport Brass Company Special Metals Extrusion Plant, Adrian, Michigan* published in April, 1982 by ORNL (ORNL 1982), and (2) *Post Remedial Action Report (PRAR) for the Remedial Action at the General Motors Site in Adrian, Michigan* (BNI 1995a), (including the database associated with the PRAR). The 1982 ORNL survey report was generated from results of surveys and sampling conducted in 1976, 1977, and 1979 by ORNL. The PRAR includes the results of post-remedial action surveys conducted in April, May, and June of 1995.

The results from the post-remedial action surveys conducted in 1995 were used to assess conditions for drain lines B, C, D, E, G, H and I; manholes M1, M15 and their associated electrical conduit lines; sump #3, the 42-in. sump and the pipe chase. Both 1995 and historical data were used as support documentation for calculations, extrapolations, and assumptions pertaining to potential residual radioactivity remaining in connecting, similar, and inaccessible areas. "Historical data" refers primarily to the 1982 ORNL report. Historical information was utilized to assess radiological conditions for areas not surveyed in 1995 (due to access limitations) including the floor drains, extrusion pits, and manholes M16 and M2.

The following sections summarize the results of surveys conducted in each major area of the facility involved with uranium operations. These areas are grouped by similar physical characteristics or process functions, and include the extrusion pits; drain lines; sumps, pits, and manholes; floor drains; and the pipe chase. Results for most areas are reported as U-238 surface activity level in disintegrations per minute (dpm) per one-hundred square centimeters (100 cm^2). These results are used for comparison with the uranium surface activity limits specified in DOE Order 5400.5 of 5,000 dpm/100 cm^2 (average over 1 square meter [m^2]), 15,000 dpm/100 cm^2 (maximum over 100 cm^2), and 1,000 dpm/100 cm^2 removable activity. For some areas (e.g., extrusion pits) which could not be surveyed during the 1995 remedial actions, results from samples taken during previous surveys are reported in units of picocuries per gram (pCi/g).

3.2 EXTRUSION PITS

The data used for evaluation of the extrusion pits ("service pits" emptied of equipment, filled with sand and covered with concrete) were taken from the 1982 ORNL survey report. This report included sample results taken from boreholes drilled in the areas of the former extrusion pits ("through the concrete floor, sand, and into concrete surfaces in the bottom of the service pits").

A total of eleven samples were taken from nine locations within the two extrusion pits used for AEC operations. Results from these samples showed U-238 concentrations ranging from 0.6 pCi/g to 210 pCi/g with an average of 20.7 pCi/g. This average was calculated using the maximum U-238 concentration from each borehole. It represents an upper bound estimate of the true average U-238 concentration in the extrusion pit sands. The 95 percent upper confidence level (UCL_{95}) on the mean is 52 pCi/g for U-238. The UCL_{95} value was used as the uranium exposure point concentration for the extrusion pit sands. For comparison, results from analyses of offsite background soil samples in the vicinity of Adrian, Michigan showed U-238 concentrations ranging from 0.7 to 1.1 pCi/g (ORNL 1982), with an average of 0.95 pCi/g.

The state of Michigan uses a soil cleanup guideline of 35 pCi/g for total uranium (approximately 17.5 pCi/g for U-238). The extrusion pit sample results show that three of the eleven samples contained less than the average U-238 background concentration of 0.95 pCi/g, six samples showed U-238 greater than background, but contained less than 17.5 pCi/g U-238, and only two samples contained more than 17.5 pCi/g of U-238.

3.3 DRAIN LINES

Radiological surveys of the drain lines and electrical conduit lines were conducted using the Pipe Explorer™ survey system developed in support of the DOE Decontamination and Decommissioning (D&D) program by Science and Engineering Associates, Incorporated (SEA). The Pipe Explorer™ system provided the majority of radiological data used for drain line assessment at GM. This system was comprised of a compressed air supply unit attached to a pressurized deployment canister which utilized an air-tight, inverting membrane to transport radiological detection equipment into drain lines. Both manual and automated Pipe Explorer™ systems were used at the GM site. Each system (manual or automatic) utilized a specific type of beta detector.

The "BetaSnake" is a beta detector designed and calibrated by RUST Geotech, DOE Grand Junction Projects Office. This beta detector was designed as a "coaxial Bicron BC-408 plastic scintillation sleeve surrounding a non-scintillation Lucite™ light pipe to maximize beta response while minimizing detectable gamma radiation." The initial Pipe Explorer™ system with the BetaSnake detector required manual deployment (a hand crank), with a manual reading (count) taken every foot. The BetaSnake detector was deployed into drain lines H and I in April 1995. In May 1995, SEA personnel automated the Pipe Explorer™ system and began using a different detector (the SEA Beta Detector). This system incorporated automated deployment and counting techniques, and had a deployment rate of 0.5 inches per second (in./s). The automated Pipe Explorer™ system with the SEA Beta Detector was used for drain lines B, C, D, E, and G, and the electrical conduit line extending from manhole M1.

Both the BetaSnake and the SEA Beta Detector were calibrated specifically for U-238 equivalent by SEA personnel, utilizing a 4-in. pipe and a Sr-90/Y-90 source. The primary beta energy from Y-90 (2,284 kilo electron volt [keV]) closely matches the energy and abundance

of the primary beta (2,281 keV from protactinium-234m [Pa-234m]) from the decay of U-238. Thus, the beta activity results from the Pipe Explorer™ measurements are directly related to U-238 activity and are reported as "U-238 equivalent." Background levels were determined by obtaining measurements within the pressurized deployment canister or housing unit prior to deployment. Both detector types were effective for measuring uranium surface activity at levels near the limits for use without radiological restrictions. Minimum detectable activities (MDAs) for the drain line surveys ranged from 2,940 dpm/100 cm^2 to 7,840 dpm/100 cm^2.

Because the automated Pipe Explorer™ system collected data at 1-second intervals, a very large volume (up to 24 readings per foot) of data was generated by the drain line surveys. To simplify the evaluation of survey results, the data was averaged over 1-foot (-ft) intervals. Each 1-ft average was then ranked in order of increasing contamination level, and plotted as a cumulative frequency distribution. Cumulative frequency distribution plots were generated for each pipe section surveyed, and then used to evaluate the post-remedial action conditions. Information on the percent of the surveyed portion of each line above and below the surface activity cleanup guidelines is based on these plots. Table 3-1 provides a statistical summary of residual radioactivity levels remaining in individual drain lines, electrical conduit, sumps, and manholes. These values include the minimum, maximum, average, and UCL_{95} of the mean based on each 1-ft averaging unit. The UCL_{95} value for each drain line was used with the total as-built length of the line to calculate the estimated total remaining uranium activity in each line. Average and UCL_{95} values include negative results as zero, and results less than the MDA at the reported value. Because of these conventions, some calculated averages and UCL_{95} values for areas with low residual activity levels are less than the reported MDA level.

The following sections provide summaries of the residual uranium activity in drain lines B, C, D, E, G, H, and I (Figure 2-3). Cumulative frequency distribution graphs of residual U-238 surface activity levels for these drain lines are shown in Appendix A. These graphs were used to determine the fractions of each drain line that contain residual uranium above or below the average surface activity criteria. Residual total uranium activity calculations for each drain line are shown in Appendix B.

Drain Line A

Drain line A runs north to south, is located southwest of the pipe chase and has an as-built length of 120 ft. Drain line A was previously filled and inaccessible during remediation and characterization. Historical data used to assess remaining residual radioactivity levels within drain line A were based on measurements taken of sludge in M16 by ORNL (ORNL 1982). The maximum U-238 concentration measured at M16 (15,000 pCi/g) was used as a conservative exposure point concentration estimate for a combined assessment of M16 and drain line A.

Drain Line B

Drain line B runs north to south, is located south of the pipe chase and has an as-built length of 120 ft. Approximately 51 ft (43 percent) was accessible and surveyed. The results

Table 3-1. Summary of Results from Post-Remedial Action Surveys of the Oil Collection System and Pipe Chase

Location	Length Surveyed (ft)	As-Built Length (ft)	U-238 Equivalent Surface Activity				
			Minimum (dpm/ 100 cm²)	Maximum (dpm/ 100 cm²)	Average[a] (dpm/ 100 cm²)	Std. Dev. (dpm/ 100 cm²)	UCL_{95}[a] (dpm/ 100 cm²)
Line B	51	120	3,500[b]	32,720	7,760	7,756	9,580
Line C	112	200	7,840[b]	1,343,631	540,000	434,626	608,000
Line D	124	185	3,270[b]	10,941	1,850	2,024	2,150
Line E	82	170	2,940[b]	5,484	2,210	1,494	2,480
Line G	106	145	3,280[b]	3,307	1,110	642	1,220
Line H	21	45	36,637	1,314,289	361,000	356,619	789,000
Line I	19	60	18,668	752,077	166,000	226,859	256,000
Sump No. 3	264 sq ft	NA	790[b]	215,064	23,800	49,474	55,800
Oil Trap Pit	280 sq ft	NA	797[b]	108,933	9,020	18,637	12,900
42-in. Sump Pit	136 sq ft	NA	723[b]	4,391	1,150	1,360	2,380
M1	173 sq ft	NA	818[b]	4,727	600	656	754
M15	173 sq ft	NA	795[b]	13,598	1,920	2,392	2,480
M1 Elec. Conduit	117	145	3,350[b]	1,767	779	411	842
M15 Elec. Conduit	37	155	3,711	11,328	7,180	1,634	7,630
Pipe Chase	155	NA	741[b]	8,426	722	749	774

Notes:

Survey information (raw data) taken from BNI 1995a, with statistical analysis by Science Applications International Corporation (SAIC). Drain lines and M1 electrical conduit lines were surveyed with the Pipe Explorer™ by SEA personnel and are reported as U-238 equivalent dpm/100 cm². Statistical analysis for drain lines B, C, D, E, and G are based on 1-ft averages. Manual readings were taken every foot for drain lines H and I and did not require averaging. Results for sumps, manholes, and the pipe chase are reported as total beta dpm/100 cm² (total beta used as U-238 equivalent for dose calculations, see Section 3.1).

[a]Average and UCL_{95} calculations include negative results as zero, and results less than the detection limit (but greater than zero) as the value reported. Thus, in some cases where activity levels are low, it is possible for the calculated average (and UCL_{95}) to be less than the MDA.

[b]MDA reported where minimum result is <MDA.

NA: Not Applicable

of the survey of accessible areas showed U-238 surface activity ranging from less than 3,500 dpm/100 cm^2 (MDA) to 32,720 dpm/100 cm^2, with an average of 7,760 dpm/100 cm^2, and an UCL_{95} concentration of 9,580 dpm/100 cm^2. Approximately 46 percent of the surveyed portion of the line showed U-238 at less than 5,000 dpm/100 cm^2 with 45 percent of the line indicating no detectable activity (<MDA). The total remaining U-238 activity in drain line B is estimated as 5 microcuries (μCi). Drain line B was "plugged" (approximately 2 ft of foam in the end of the line) at the pipe chase.

Drain Line C

Drain line C runs south to north, is located south of the pipe chase and has an as-built length of 200 ft. Approximately 112 ft (56 percent) was accessible and surveyed. The results of the survey of accessible areas showed U-238 surface activity ranging from less than 7,840 dpm/100 cm^2 (MDA) to 1,343,631 dpm/100 cm^2, with an average of 540,000 dpm/100 cm^2, and an UCL_{95} concentration of 608,000 dpm/100 cm^2. Approximately 30 percent of the surveyed portion of the line showed U-238 less than the calculated MDA level of 7,840 dpm/100 cm^2. The total remaining U-238 activity in drain line C is estimated as 533 μCi. Drain line C was partially filled (an estimated 75 percent filled) with grout.

Drain Line D

Drain line D runs north to south, is located south of the pipe chase and has an as-built length of 185 ft. Approximately 124 ft (67 percent) was accessible and surveyed. The results of the survey of accessible areas showed U-238 surface activity ranging from less than 3,270 dpm/100 cm^2 (MDA) to 10,941 dpm/100 cm^2, with an average of 1,850 dpm/100 cm^2 and an UCL_{95} of 2,150 dpm/100 cm^2. Approximately 89 percent of the surveyed portion of the line showed U-238 less than 5,000 dpm/100 cm^2 with 87 percent of the line indicating no detectable activity (<MDA). The total remaining U-238 activity in drain line D is estimated as 1.7 μCi. Drain line D was plugged at the pipe chase as previously described for drain line B.

Drain Line E

Drain line E initially runs east to west, angles off to run north to south, is located south of the pipe chase and has an as-built length of 170 ft. Approximately 82 ft (48 percent) was accessible and surveyed. The results of the survey of accessible areas showed U-238 surface activity ranging from less than 2,940 dpm/100 cm^2 (MDA) to 5,484 dpm/100 cm^2, with an average of 2,210 dpm/100 cm^2 and an UCL_{95} of 2,480 dpm/100 cm^2. Approximately 98 percent of the surveyed portion of the line showed U-238 surface activity less than 5,000 dpm/100 cm^2 with 66 percent of the line indicating no detectable activity (<MDA). Drain line E did not exceed the U-238 criteria based on a limit of 5,000 dpm/100 cm^2 when averaged over any 1 m^2 area. However, it was included in this report since the removable portion of the uranium (in the surveyed area) could not be directly quantified using the Pipe Explorer™ system. The total remaining U-238 activity in drain line E was estimated as 1.85 μCi. Drain line E was plugged at the pipe chase.

Drain Line F

Drain line F runs south to north and has an as-built length of 30 feet. Drain line F was inaccessible due to GM production operations in the area. Because drain line F is only 30-ft long, it has a negligible impact on the overall oil collection system assessment. Because of its minor impact, and since no survey data is available, drain line F is not included separately in the dose calculations. It is considered in the use of conservative estimates of total (drain line F and M25) activity as part of the assessment of manhole M25. Drain line F was plugged at manhole M25.

Drain Line G

Drain line G runs west to east, is located north and parallel to the pipe chase and has an as-built length of 145 ft. Approximately 106 ft (73 percent) was accessible and surveyed. The results of the survey of accessible areas showed U-238 surface activity ranging from less than 3,280 dpm/100 cm^2 (MDA) to 3,307 dpm/100 cm^2, with an average of 1,110 dpm/100 cm^2 and an UCL_{95} of 1,220 dpm/100 cm^2. The total remaining U-238 activity in drain line G was estimated as 0.78 μCi. Approximately 100 percent of the surveyed portion of the line showed U-238 less than 5,000 dpm/100 cm^2 with 99 percent of the line indicating no detectable activity (<MDA). While drain line G did not exceed the total U-238 contamination criteria, it was included in this report since the amount of removable contamination could not be directly quantified with the Pipe Explorer™ system. Drain line G was plugged at M1.

Drain Line H

Drain line H runs west to east, is located south and parallel to the pipe chase and has an as-built length of 45 ft. Approximately 21 ft (47 percent) was accessible and surveyed. The results of the survey of accessible areas showed U-238 surface activity ranging from 36,637 dpm/100 cm^2 to 1,314,289 dpm/100 cm^2, with an average of 361,000 dpm/100 cm^2 and an UCL_{95} of 789,000 dpm/100 cm^2. The total remaining U-238 activity in drain line H is estimated as 156 μCi. Drain line H was filled with grout.

Drain Line I

Drain line I runs east to west, is located south and parallel to the pipe chase and has an as-built length of 60 ft. Approximately 19 ft (32 percent) was accessible and surveyed. The results of the survey of accessible areas showed U-238 surface activity ranging from 18,668 dpm/100 cm^2 to 752,077 dpm/100 cm^2, with an average of 166,000 dpm/100 cm^2 and an UCL_{95} of 256,000 dpm/100 cm^2. The total remaining U-238 activity in drain line I is estimated as 67 μCi. Drain line I was filled with grout.

3.4 SUMPS, PITS, AND MANHOLES

The following sections describe remaining residual radioactivity conditions in sumps, pits, and manholes. Unlike individual drain lines, most other areas at the site (including sumps, pits, and manholes) were surveyed with standard portable health physics instrumentation. Both direct and transferable residual radioactivity levels were measured, with beta/gamma surface activity being the limiting factor in determining areas meeting the uranium surface activity criteria. Because of this, only beta/gamma surface activity levels (in dpm/100 cm^2) are summarized in the following paragraphs. Like the Pipe Explorer™ system, the portable instruments were calibrated with a Sr-90/Y-90 source; therefore, total beta-gamma activity was assumed to be equivalent to U-238 activity for total residual activity and dose calculation purposes. Calculations of total residual uranium activity for each sump, pit, or manhole are included in Appendix B.

Sump No. 3

Sump No. 3 is a cylindrical unit approximately 20-ft deep (the first 3 ft being brick) with a 4-ft diameter, is located north of the pipe chase and is thought to have received effluent from M1 and drain line C. The results of the surveys at sump No. 3 showed surface activity ranging from less than the MDA of 790 dpm/100 cm^2 to 215,064 dpm/100 cm^2, with an average of 23,800 dpm/100 cm^2 and an UCL_{95} of 55,800 dpm/100 cm^2. The total remaining U-238 activity in sump No. 3 is estimated as 62 μCi. Sump No. 3 was backfilled with CLSM and concrete (top 4 ft).

Oil/Water Separator (Oil Trap Pit)

Results from the surveys of the oil/water separator (oil trap pit) showed surface activity ranging from less than the MDA of 797 dpm/100 cm^2 to 108,933 dpm/100 cm^2, with an average of 9,020 dpm/100 cm^2 and an UCL_{95} of 12,900 dpm/100 cm^2. The total remaining U-238 activity in the oil/water separator is estimated as 15 μCi. The oil/water separator was backfilled with CLSM and concrete (top 4 feet).

42-in. Sump

The 42-in. sump is a cylindrical unit approximately 11.5-ft deep with a 42-in. diameter, is located south of the pipe chase and extrusion pit areas, and is believed to have received effluent from drain lines H and I. Results from the radiological surveys showed surface activity ranging from less than the MDA of 723 dpm/100 cm^2 to 4,391 dpm/100 cm^2, with an average of 1,150 dpm/100 cm^2, and an UCL_{95} concentration of 2,380 dpm/100 cm^2. The 42-in. sump did not exceed the surface activity criteria for uranium. Thus, dose assessment is not required for this location. The 42-in. sump was backfilled with CLSM.

Manhole 1 (M1)

M1 is located northwest of the pipe chase. Like manholes M2, M15, M16, and M25, M1 is an octagonal-shaped pit with a depth of 6.5 ft and a diameter of 7 ft. Results from the radiological surveys showed surface activity ranging from less than the MDA of 818 dpm/100 cm^2 to 4,727 dpm/100 cm^2, with an average of 600 dpm/100 cm^2, and an UCL_{95} concentration of 754 dpm/100 cm^2. M1 did not exceed the surface activity criteria for uranium. Therefore, a hazard assessment for M1 is not required. M1 was filled to the top with CLSM.

M1 Electrical Conduit

Electrical conduit lines extended approximately 145 ft east, south and north of M1. Survey results from the Pipe Explorer™ system showed U-238 surface activity ranging from less than the MDA of 3,350 dpm/100 cm^2 to 1,767 dpm/100 cm^2, with an average of 779 dpm/100 cm^2 and an UCL_{95} concentration of 842 dpm/100 cm^2. M1 electrical conduit did not exceed the surface activity criteria for uranium. However, M1 electrical conduit is included in this report since the removable surface activity could not be directly quantified using the Pipe Exployer™. M1 electrical conduit was filled with CLSM.

Manhole 2 (M2)

M2 is located north of the pipe chase and is indirectly tied into drain line C. Located underneath a compressor room, M2 was inaccessible for sampling and remediation. M2 was indirectly backfilled with CLSM through the duct banks. Because no data is available on residual uranium levels in M2, a conservative estimate of U-238 concentration was based on the highest U-238 sludge concentration measured in the oil collection system during previous ORNL surveys. A sludge sample from the 42-in. sump inlet line contained 21,000 pCi/g of U-238 (ORNL 1982). This result was used as a source term estimate for M2.

Manhole 15 (M15)

M15 is located south of the pipe chase, east of the 42-in. sump. Results from the radiological surveys showed surface contamination ranging from less than the MDA of 795 dpm/100 cm^2 to 13,598 dpm/100 cm^2, with an average of 1,920 dpm/100 cm^2, and a UCL_{95} concentration of 2,480 dpm/100 cm^2. M15 was filled to the top with CLSM. Based on the post-remedial action survey data, M15 appears to contain residual uranium surface activity at concentrations less than the criteria for use without radiological restrictions ($<$ 5,000 dpm/100 cm^2 average, $<$ 15,000 dpm/100 cm^2 maximum, and $<$ 1,000 dpm/100 cm^2 removable. Therefore, M15 was not carried through the hazard assessment.

M15 Electrical Conduit

Electrical conduit lines extend approximately 155 ft east and west of M15. Results from radiological surveys using a thin wall Geiger-Mueller (G-M) detector (Eberline HP-270) showed

beta-gamma surface activity ranging from 3,711 dpm/100 cm^2 to 11,328 dpm/100 cm^2, with an average of 7,180 dpm/100 cm^2, and a UCL_{95} concentration of 7,630 dpm/100 cm^2. The remaining U-238 activity in M15 electrical conduit lines is estimated as 5.2 μCi. M15 electrical conduit lines were filled with CLSM.

Manhole 16 (M16)

M16 is connected to the south end of drain line A. M16 was previously filled with concrete by GM personnel and was inaccessible for 1995 site remediation efforts. Historical data (ORNL 1982) were used to determine residual radioactivity levels remaining in M16. Two samples were taken from M16 by ORNL and characterized as dirt, crud, and scale. Samples taken from the lip and bottom of M16 showed concentrations of 5,600 pCi/g and 15,000 pCi/g U-238, respectively. The maximum concentration of 15,000 pCi/g U-238 (30,000 pCi/g total uranium) was used as the source term concentration for M16, and drain line A which exits M16.

Manhole 25 (M25)

M25 is located south and directly tied into drain line F. M25 is located under a conveyer in use by GM personnel and was inaccessible for much of the 1995 sampling and remediation activities. A grab sample of sludge taken from M25 contained 86 pCi/g of U-238. This result was used to assess potential doses at M25. M25 was filled indirectly with CLSM.

3.5 FLOOR DRAINS

The 1982 ORNL analytical results were utilized to assess residual radioactivity concentrations in floor drains north of the extrusion pit area. Three floor drains were sampled, FD1, the lip of FD2, and FD3. The sample material was characterized as dirt, crud, and scale. Analytical results showed 20 pCi/g, 480 pCi/g, and 11,000 pCi/g U-238, for FD1, the lip of FD2, and FD3, respectively. The highest of these results, 11,000 pCi/g U-238 (22,000 pCi/g total uranium) was used as the exposure point concentration or source term for floor drains north of the extrusion pit area. The floor drains were previously covered with a concrete slab by GM.

3.6 PIPE CHASE

Remedial actions were required only for a 155-ft section of the pipe chase located north of the extrusion pit areas. Although not completely rectangular in geometry, the typical dimensions for this section of the pipe chase are a height of 5.5-ft and width of 3.5-ft.

Accessible areas of the pipe chase were remediated to uranium surface activity cleanup guidelines. Radiological surveys applicable to the pipe chase include inner pipe chase surfaces (floor and walls) and the pipe chase "cover" or iron grate. Results from radiological surveys showed surface contamination ranging from less than the MDA of 741 dpm/100 cm^2 to

8,426 dpm/100 cm^2, with an average of 722 dpm/100 cm^2, and a UCL_{95} concentration of 774 dpm/100 cm^2. After remedial actions, the pipe chase area did not exceed the uranium surface activity cleanup guidelines. Therefore, hazard assessment of the pipe chase is not required.

3.7 DATA EVALUATION SUMMARY

The following areas were decontaminated to levels less than the uranium surface activity cleanup guidelines and are not included in this hazard assessment: M1, M15, the 42-in. sump, and the pipe chase. The following areas may contain residual uranium at concentrations greater than the surface activity criteria, and are included in this hazard assessment: drain lines A, B, C, D, E, F, G, H, I, and the electrical conduit lines from M1 and M15; sump No. 3 and the oil trap pit; manholes M2, M16, and M25; and the extrusion pits and floor drains. A summary of the results from the post-remedial action surveys from the areas surveyed in 1995 is provided in Table 3-1.

4. EXPOSURE ASSESSMENT

4.1 INTRODUCTION

Most of the residual radioactive material from former AEC operations at the GM site was removed through remediation efforts conducted in 1976, 1977, and 1995. The only remaining areas with residual uranium greater than cleanup guidelines are the extrusion press pits, the oil collection system (including selected manholes, sumps, and drain lines), and the former floor drains under the existing floor of the plant in the area of former uranium extrusion operations. This assessment was designed to assess potential current and future doses to workers caused by exposure to the low-level uranium remaining in these areas. Because the facility has been an operating industrial plant for approximately 40 years, and land use is likely to remain industrial, only potential worker exposures were evaluated.

Because the remaining residual radioactivity at the GM site is contained in inaccessible areas which have been plugged or grouted closed or are under the floor slab, potential future exposures to workers are very unlikely. No workers are currently being exposed to the remaining uranium at the site. However, to assess the hazard associated with the remaining material, it was assumed that at some point workers could be exposed, either through non-routine maintenance work which required breaking into the grouted areas or through future activities which involve large scale demolition or renovation operations. With this in mind, two scenarios (a non-routine maintenance worker and a future renovation worker) were included in the dose assessment.

Residential exposures to residual radioactive materials on the site were not considered reasonable, since land use will likely remain industrial. However, a qualitative evaluation was performed of the potential for leaks from the sumps and drains system to soils beneath the plant, and then to groundwater. As part of the remedial action, a sample of sludge from the oil collection system was analyzed to determine its distribution coefficient (K_d). The K_d value provides a measure of how mobile the uranium compound is likely to be in the environment. Results from this analysis showed an average K_d value of 30,000 milliliter (ml)/g, indicating that the uranium from the GM site is highly immobile and, thus, is not likely to be a potential groundwater problem in the unlikely event that the system leaked. Work performed on the drain system during the 1995 remediation showed that the system was holding large volumes of oil and water. This observation suggests that the system is intact and that significant leakage to the soils under the facility is unlikely.

For purposes of developing supplemental standards, the receptors with the most likely potential for exposure are current or future workers at the facility. The exposure scenarios considered for this assessment included a current or future (non-routine) maintenance worker, and a future renovation worker. These exposure scenarios are discussed in detail in the following sections.

4.2 IDENTIFICATION OF EXPOSURE PATHWAYS

To determine radiation dose to a worker, it is necessary to understand how radioactive materials move from the source (pipes or sumps containing residual uranium) to the point where the material can come in contact with (expose) a worker. The course, or "exposure pathway" that uranium must move through in order to cause exposures can be described using a block diagram representing a conceptual exposure model. The conceptual site model for the worker exposure scenarios is shown in Figure 4-1 and discussed below.

4.2.1 Non-Routine Maintenance Worker Scenario

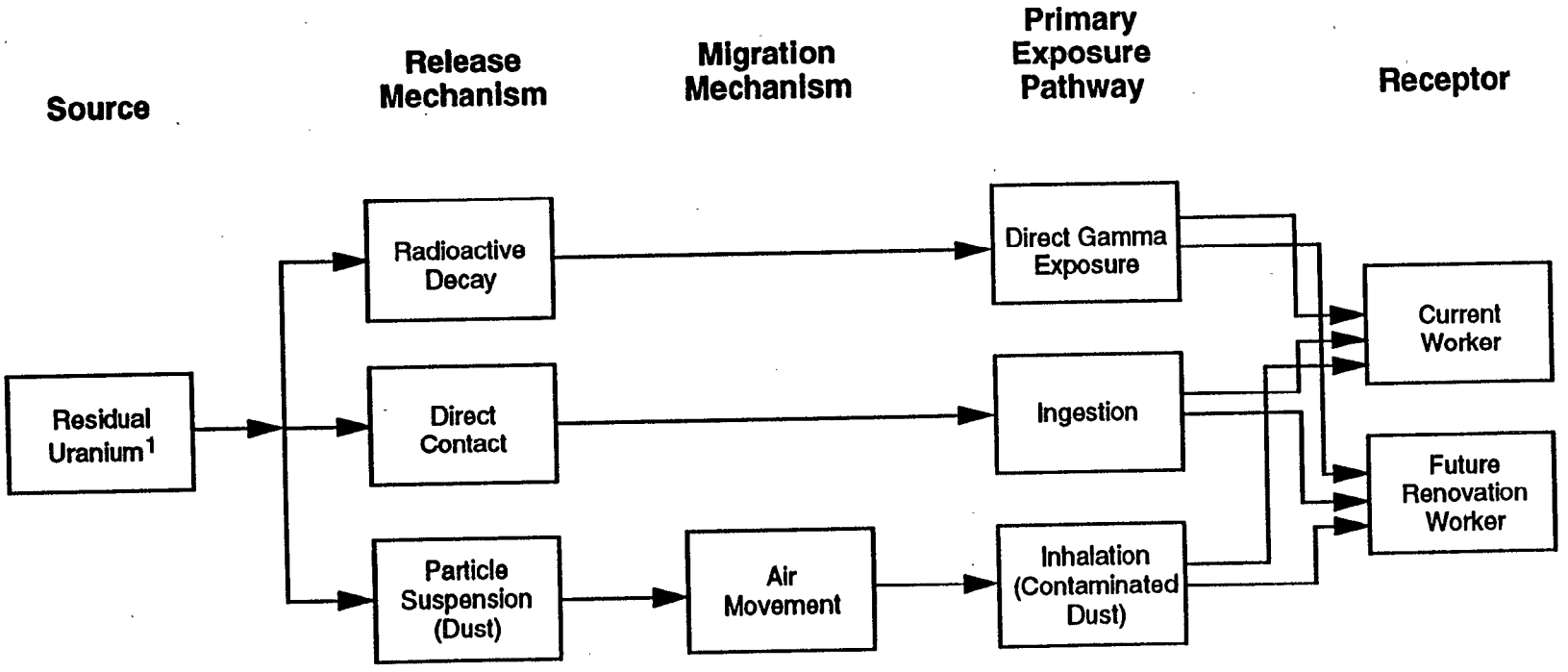
Under the non-routine maintenance worker scenario, doses were characterized for non-routine maintenance work which would involve short-term intrusive activities under the floor slab. This scenario is not meant to represent current maintenance worker activities. The non-routine maintenance scenario is intended to provide a reasonable estimate of potential radiation doses associated with future work activities which may involve breaking into the grouted floor drains, manholes, or drain lines, (e.g., excavation for new utility lines). It assumes that some physical activity must take place to bring the residual uranium in pipes or sumps into contact with a worker. However, the activities associated with non-routine maintenance work are of short-term duration and involve exposure to only a single contaminated location (e.g., one drain line or manhole, not the entire oil collection system). This scenario is intended to provide an assessment of potential doses based on realistic activities and exposures associated with likely assembly line process modifications.

Routes of exposure for the maintenance worker include direct exposure to external gamma radiation, inhalation of contaminated dust, and ingestion of contaminated material during intrusive work activities below the building floor.

4.2.2 Future Renovation Worker Scenario

Under the future renovation worker exposure scenario, it was assumed that workers could be exposed through participation in large scale renovation operations at the facility. Such renovation operations could consist of several activities including partial demolition of the building, removal of part of the floor in the extrusion press area to add new process equipment, or removal of selected portions of the old underground drain system to allow for new process equipment or drain lines.

Routes of exposure for the future renovation worker are the same as for the maintenance worker and include exposure to direct external gamma radiation, inhalation of contaminated dust, and ingestion of contaminated soil. The primary differences between the two projected exposure scenarios is the time of exposure, and the number of locations that a worker could be exposed. It is assumed that the future renovation worker could be exposed for a longer time period, and to potentially more contaminated locations than the non-routine maintenance worker. An example would be removal of the entire floor slab during building demolition. This would result



Notes: Model represents exposure conditions expected after remedial actions.
[1]Residual uranium located in the former extrusion pits, manholes, sumps, and drain lines.

Figure 4-1. Conceptual Site Model for the GM Site Hazard Assessment

in potential exposures to many (if not all) portions of the oil collection system. The future renovation worker scenario thus provides an estimate for the potential worst case future exposure.

4.3 EXPOSURE PARAMETERS

To the extent possible, exposure factors and parameters recommended by the U. S. Environmental Protection Agency (EPA) or NRC for conducting radiological dose and risk assessments were used in this assessment for standard exposure conditions. These standard exposure parameters were taken from *Risk Assessment Guidance for Superfund* (RAGS) (EPA 1989) and related guidance, documentation supporting the RESidual RADioactivity (RESRAD) computer model (Gilbert et al. 1989, Yu et al. 1993a, Yu et al. 1993b), and the NRC's NUREG CR 5512 *Residual Radioactive Contamination from Decommissioning - Technical Basis for Translating Contamination Levels to Annual Dose* (1992). Dose conversion factors from Federal Guidance Reports 11 and 12 were used to estimate annual radiation doses (EPA 1988, EPA 1993).

Because the conditions at the GM site are not very similar to a standard Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site, many of the default exposure assumptions used for EPA and NRC risk and dose assessments are not appropriate for use in this hazard assessment. For these situations, judgement was used to select parameters that represent anticipated future conditions. In particular, engineering estimates of the time required (days/year [yr]) for renovation or maintenance activities were used in place of the standard EPA worker default exposure frequency of 250 days/yr. The critical site-specific exposure parameters used in the analysis are presented in Table 4-1 and described in more detail in the following sections.

4.3.1 Maintenance Worker Scenario

The maintenance worker exposure scenario was based on the assumption that a worker could be exposed to residual uranium during non-routine maintenance work which involved cutting through the concrete floor and into the former extrusion pits, sumps, drain line system, or floor drains. The non-routine maintenance work was assumed to occur over a two-week (10-day) period, with a worker working for 10 hrs/day for most areas (drain lines and extrusion pits). This time frame is based on engineering estimates done by BNI of the work required to remove the drain system around the 42-in. sump. For more localized areas like a single manhole or the floor drains, 3 days of work at 10 hr/day was used to estimate doses from maintenance activities.

Table 4-1. Critical Exposure and Intake Parameters

Parameter	Non-Routine Maintenance Worker	Future Renovation Worker
Thickness of Residual Contamination (cm)	0.1	0.1
Density of Contaminated Material (g/cm^3)	1.5	1.5
Inhalation Rate (m^3/hr)	0.89	0.89
Mass Loading (g/m^3)	1.0×10^{-4}	1×10^{-4}
Respirable Fraction	30 %	30 %
Ingestion Rate (g/day)	0.1	0.1
Exposure Time (hr/day)	10	10
Exposure Frequency (days/yr)[a]		
Drain lines	10	43
Manholes, sumps, floor drains	3	18 (total group)
Extrusion pits	10	10
Total renovation		71 (total renovation)

[a]The non-routine maintenance worker is assumed to be exposed to any single area (e.g., a drain line, or a sump) for the exposure frequency listed. The renovation worker is assumed to be exposed to all areas of the site for a total of 71 days in a year. This exposure consists of 43 days work on the drain lines, 10 days work on the extrusion pits, and 3 days each at manholes M2, M16, M25, sump #3, the oil trap pit, and the floor drains (3 days for all floor drains).

The hypothetical maintenance worker was assumed to incidentally ingest 100 milligrams (mg) of contaminated material per day and have an inhalation rate of 0.89 m^3/hr (7,800 m^3/yr). This inhalation rate is based on a reasonable worst case for indoor work activities, and assumes 25 percent of the average day (24 hours) is spent at a resting activity level, 60 percent at a light activity level, 10 percent at a moderate activity level, and 5 percent at a heavy activity level (Yu et al. 1993b). The average indoor dust loading during non-routine maintenance work was estimated as 1×10^{-4} g/m^3 (NRC 1992). As a conservative estimate of airborne activity, it was assumed that the only source of dust is the radioactive material (i.e., the airborne dust is made up entirely of radioactive material) and that 30 percent of the dust particles are of respirable size (Paustenback 1989).

4.3.2 Future Renovation Worker Scenario

The renovation worker exposure scenario provides an upper bound estimate of potential future worker exposures inside the GM production facility. This scenario assumes that a renovation worker would conduct extensive intrusive activities including complete removal of the oil collection system and excavation/removal of the extrusion pits, manholes, and sumps. This exposure scenario is similar to the non-routine maintenance scenario, except that the work

activities are assumed to be much more extensive, and thus exposure times are longer for the future renovation worker scenario. Routes of exposure for the renovation worker include direct external gamma radiation, inhalation of contaminated dust, and ingestion of contaminated material during work activities around the oil collection system and other sub-floor locations.

Because the future renovation worker scenario could consist of several activities, the estimate of potential worker exposure time was based on the estimated number of days required to completely remove the existing drain line system, plus extrusion pits and other portions of the oil collection systems. As part of the remediation planning for the GM site, it was estimated that 43 days would be required to completely remove the drain lines associated with the oil collection system (BNI 1995c). Each work day was estimated as 10 hours long. The future renovation worker was assumed to spend a total of 43 days working at various portions of the drain lines, with the time spent around each individual drain line in proportion to the length of that line (i.e., it would take longer to remove the long lines than the short lines). In addition to the time spent in removal of the drain lines, it was assumed that a future renovation worker would spend approximately 10 days of work in removing the old extrusion press pits, 3 days in removal/demolition of each major sump or manhole (sump No. 3, the oil trap pit, M2, M16, and M25), and 3 days in removal of the old floor drains. This results in a total renovation period of 71 days.

The hypothetical renovation worker was assumed to ingest 100 mg of contaminated material each day and have an inhalation rate of 0.89 m^3/hr (7,800 m^3/yr). The overall average dust loading during renovation work was estimated as 1×10^{-4} g/m^3. As with the maintenance worker scenario, all of the airborne dust was assumed to originate from the residual uranium material, and 30 percent of this material was assumed to be of respirable size.

4.4 EXPOSURE POINT CONCENTRATIONS

4.4.1 General Source Term and Exposure Point Concentration Calculations

Exposure point concentrations are the radioactive material concentrations at the location where a receptor could be exposed. For most locations, exposure point concentrations were based on measurements taken during the 1995 remedial actions (described in detail in Section 3). For locations where measurements were not possible (e.g., extrusion press pits, floor drains, M2, M16, and M25), estimated exposure point concentrations were based on measurements taken by ORNL during the last (1976, 1977) remedial actions, if available, or estimated based on results for similar areas at the site.

For this assessment, the exposure point concentrations for both extrusion pit sands and pipe surface contamination were calculated using EPA guidance for baseline risk assessments under CERCLA. The UCL_{95} estimate of the mean concentration was used as the best estimate of the reasonable maximum exposure point concentration (RME) for each radionuclide, for each exposure point assessed.

While the facility handled depleted, enriched, and natural uranium, it is assumed that exposures can be characterized reasonably by treating the contamination as natural uranium. This assumption is supported by high volume air samples taken inside the facility by ORNL and analyzed for U-234, U-235, and U-238. Those air samples which collected a significant mass of uranium showed isotopic ratios consistent with natural uranium (ORNL 1982). For natural uranium in secular equilibrium with its decay products, the activity of U-234 is equal to the U-238 activity. In addition, based on the activity ratios for natural uranium, U-235 was assumed to be present at 4.6 percent of the U-238 activity concentration.

Most of the exposure point concentrations are based on direct contamination measurements taken during the 1995 remedial actions using the Pipe Explorer™ system. These contamination measurements are expressed as U-238 equivalent surface activity levels in dpm/100 cm^2. The measurements used from the 1982 ORNL survey report are based on samples of sludge or scale and are expressed in units of pCi/g of U-238. The U-238 equivalent exposure point concentrations for each area are summarized in Table 4-2 and discussed in the following sections.

4.4.2 Exposure Point Concentrations for Filled Drain Lines, Manholes, and Sumps

For exposures associated with the residual uranium in the sub-floor areas related to the oil collection system, it was assumed that a maintenance or renovation worker would perform intrusive activities which could cause contact with (or release of) contained radioactive materials. To cause inhalation or ingestion exposures, a worker would have to physically cut into the filled or plugged drain lines, sumps, or manholes; causing the residual radioactive material to be released as airborne contaminated dust, or as removable surface contamination. Similarly, direct gamma exposures would be possible only if the grout and concrete shielding in and over the sumps, manholes, extrusion pits, and drain lines were removed. The amount of material released and made available for inhalation, ingestion, and direct gamma exposures would be dependent on many variables including: the number of cuts made into the contaminated line or manhole; how much contaminated surface area was exposed in each cut; the type of equipment used for cutting, and its effectiveness; the amount of time necessary to cut into the grouted contaminated areas; and the geometry (distance) of the worker and the contaminated areas. While some exposures may be possible after grouting and plugging sumps, manholes, and drain lines, these containment measures will significantly reduce the exposure point concentrations, and thus the potential for future exposures.

To account for the reduced potential for exposure through concrete fill and/or plugging, the method used to calculate source term activity concentrations included use of a factor to account for the reduction of uranium concentrations by addition of foam, concrete (grout), or CLSM. The first step in this method was to calculate the remaining activity level (total activity inventory) for each area where residual uranium levels (greater than the DOE and NRC criteria) remain. The total activity calculations were based on the results of post remedial action survey measurements taken with field instrumentation (see Appendix B). Using the results of the total activity calculations, an average activity concentration (pCi/g) value was then determined for

Table 4-2. Exposure Point Concentrations

Exposure Point Location	Status	Pre-Fill Exposure Point Concentration (U-238 dpm/100 cm^2)	Source Term Reduction Factor	Post-Fill Exposure Point Concentration (U-238 dpm/100 cm^2)
Drain Lines				
B	plugged at pipe chase (foam)	9,580	1.2	7,983
C	partially filled (75 %) with grout	608,000	31	19,613
D	plugged at pipe chase (foam)	2,150	1.1	1,955
E	plugged at pipe chase (foam)	2,480	1.1	2,255
G	plugged at M1 (foam)	1,220	1.1	1,109
H	filled with grout	789,000	42	18,786
I	filled with grout	256,000	42	6,095
M1 elec. conduit	filled with grout	842	31	27
M15 elec. conduit	filled with grout	7,630	31	246
Manholes				
M2[a]	backfilled w/CLSM and concrete	21,000 pCi/g	12	1,750 pCi/g
M16	previously filled by GM	15,000 pCig	12	1,250 pCi/g
M25	backfilled w/CLSM	86 pCi/g	12	7 pCi/g
Sumps				
# 3	backfilled w/CLSM and concrete	55,800	342	163
Oil Trap Pit	backfilled w/CLSM and concrete	12,900	229	56
Extrusion Press Pits	filled with sand by GM	NA	NA	52 pCi/g
Floor Drains	covered with concrete by GM	11,000 pCi/g	10[b]	1,100

Notes:
[a]M2 was inaccessible, exposure point concentration based on the highest measured U-238 sample taken from a pre-remedial action sludge sample. Result from ORNL 1982 (Sludge data from 42-in. sump line).
[b]Floor drain source term reduction factor unknown, and since previously covered by GM assumed to be 10 as a conservative estimate.
NA = not applicable

each area of concern. This initial activity concentration calculation was based only on the total activity, and the estimated mass of the residual contamination. The estimated mass of contamination was based on an assumed contamination thickness of 0.1 cm, and density of contaminated material of 1.5 g/cm^3. Because most areas were flushed or pressure washed prior to contamination measurement, it is likely that most residual contamination is in the form of fixed pipe scale, and thus an estimated thickness of 0.1 cm is appropriate. Because the contaminated material removed from drain lines, sumps, and manholes was a gritty, oily material, a density of 1.5 g/cm^3 (approximately equal to soil) was considered reasonable. The methods described above for estimating activity concentration from surface activity measurements are consistent with methods approved for use in the *Baseline Risk Assessment for the St. Louis Site* (DOE 1993).

For those areas which contain residual uranium, and were filled with concrete or CLSM, a second activity concentration ("post-fill" concentration) calculation was performed using the total activity value, and the mass of the added fill material. The average post-fill concentration is simply the total residual activity for each drain line or manhole divided by the mass of the concrete or CLSM injected into that drain line or manhole. The post-fill activity concentration for each area provides a reasonable estimate of the actual average uranium concentration which could be encountered by a maintenance (or renovation) worker under expected future intrusive work activities. Similarly, the ratio of the "pre-fill" concentration to "post-fill" concentration provides an estimate of the activity concentration reduction, and thus potential dose reduction obtained by the containment measures utilized during the remedial actions. Table 4-2 includes a summary of the pre- and post-fill concentrations, and the "source term reduction factors" (ratio of pre-fill concentration to post-fill concentration) used for the dose assessment of grouted areas. It should be noted that while filling areas reduces the potential for exposures both by containment of radioactivity, and reduction of source term activity concentration (for the portion of the area filled), this method only takes credit for reducing the activity concentration. For calculation of doses (as discussed below), it is still assumed that the residual uranium is ultimately released from the concrete or grout containment and is made available for exposures.

4.4.3 Exposure Point Concentrations for the Extrusion Pits

The uranium exposure point concentrations for the former extrusion press pits are based on the results of core samples taken in the extrusion pits during the 1977 ORNL survey (ORNL 1982). For the 11 samples taken during this survey, U-238 concentrations ranged from 0.6 pCi/g to 210 pCi/g. The UCL_{95} estimate on the mean U-238 concentration, measured in samples of the extrusion pit fill sand taken by ORNL, was used as the exposure point estimate for the extrusion pit area. This exposure point concentration is 52 pCi/g U-238 (104 pCi/g total uranium).

4.4.4 Exposure Point Concentrations for the Former Floor Drains

The exposure point concentration used to represent the former floor drains areas is based on measurements taken during the 1977 ORNL survey (ORNL 1982). ORNL took three

samples from three floor drains in the area of the former extrusion press operations. The maximum U-238 concentration in these samples was 11,000 pCi/g. The maximum measured floor drain uranium concentration of 11,000 pCi/g U-238 (22,000 pCi/g total uranium was used as the exposure point concentration for the floor drains.

5. DOSE CHARACTERIZATION

5.1 DOSE CHARACTERIZATION METHODS

The methods used to calculate potential future radiation doses associated with residual uranium at the GM site are based on methods used for assessing doses from residual radioactivity in soils following remedial actions. Because the GM site is not a typical environmental restoration site with primarily soil contamination, these standard methods were modified to incorporate site-specific conditions. In particular, residual radioactivity at the GM site is confined to enclosed areas such as drain lines, sumps, and manholes. In addition, at most locations where uranium could not be completely removed, flowable concrete or CLSM was pumped into the area (drain line, sump, or manhole) to further contain any residual uranium. To account for these differences, a method for reducing the source term concentration based on the amount of dilution or containment afforded by the grouting process was developed (as described in Section 4.4.3).

For calculating future doses associated with grouted or filled areas, the original source term (exposure point) concentration was divided by the concentration reduction factor (determined by methods described in Section 4.4.3) for that location to determine the likely exposure point concentration to a worker under intrusive work conditions. In addition, doses were calculated without consideration of the containment methods (i.e., it was assumed that at some point in the future some work activity would cause partial release of the uranium) to provide a very conservative worst case comparison value.

Dose conversion factors (DCFs) used in calculation of total doses are based on DCFs listed in EPA Federal Guidance Reports 11 and 12. To simplify the dose calculations, the DCFs for U-238, U-234, and U-235 were combined into a single total uranium DCF value including all short-lived decay products. The total uranium DCF was calculated as an activity-weighted average for natural uranium, based on the U-238, U-234, and U-235 natural activity ratio of 1:1:0.046. Results from contamination measurements of U-238 equivalent were converted to total uranium equivalent by multiplying by two prior to use with the total uranium DCFs.

Because the non-routine maintenance worker scenario is a short-term exposure scenario, the results from dose calculations for each significant exposure point are considered separately. It is reasonable to assume that a worker could perform all of the estimated maintenance work at a single exposure point location (10 days for drain lines or extrusion pits, 3 days for a manhole, sump, or floor drains). Thus, the maximum dose at any single exposure point location should provide an upper bound estimate of the potential dose for a future maintenance worker.

Unlike the short term maintenance worker scenario, potential doses to a renovation worker would likely be caused by exposures at several locations. Because future renovation of the oil collection system would take approximately 43 days, it is likely that a worker would not be exposed at a single location, but would perform work at numerous locations associated with

the oil collection system. To account for this movement, a total pro-rated dose was calculated for a renovation worker performing 43 days of work on the entire drain line system. A single dose for each significant exposure point location was first calculated by assuming that a worker performed 43 days of work at that location. Then each exposure point dose was pro-rated (multiplied by the fraction of 43 days expected at that location) and summed to give the total estimated renovation worker dose for all drain lines. The fractions used to pro-rate individual location doses were based on the length of each line compared with the total length of line. Exposure times of 3 days for each major manhole, sump, or pit (and all floor drains), and 10 days for the extrusion pits were used to calculate separate doses for these areas. As a worst case estimate for the renovation worker, doses from each of the separate exposure point locations were summed. The summed renovation worker dose represents the total dose for work over 71 days (43 days for drain lines, 10 days for extrusion pits, and 18 days total for manholes, sumps, and floor drains).

5.2 DOSE CHARACTERIZATION RESULTS

Results from the dose calculations for the non-routine maintenance worker and renovation worker scenarios are summarized for each major exposure group (area of concern) in Tables 5-1 and 5-2. Detailed dose calculation spreadsheets are provided in Appendix C. The three general exposure groups for dose assessment were established on the basis of similar process history (e.g., drain lines, sumps), or similar type of characterization information (e.g., manholes and areas previously filled by GM). Results for each scenario with consideration of containment methods (i.e., plugging or filling drain lines with foam or grout, filling manholes with grout or CLSM) are shown in Table 5-1 and should be considered most representative of likely future conditions.

The doses shown in Tables 5-1 and 5-2 for the maintenance worker scenario are the maximum doses calculated for any single location within the exposure group. For the maintenance worker, if containment is considered, estimated doses (based on the maximum dose from a single location within each group) are 0.8 mrem/yr for the drain lines (drain line C); 0.7 mrem/yr for the manholes and areas filled by GM group; and 0.002 mrem/yr for the sumps group. As discussed in Section 3, the doses shown for the non-routine maintenance scenario are based on all work around a single contaminated location to simulate the potential exposures from installation or removal of process equipment. Ingestion of contaminated material and inhalation of contaminated dust are the primary pathways contributing to these doses.

For the renovation worker scenario, dose estimates are based on the assumption of a large scale renovation or demolition project which involves exposures to all areas of the drain lines for 43 days, exposures to the major manholes, pits, and floor drains for a total of 18 days and exposures to the extrusion pits for 10 days (for a total of 71 days of exposure). If containment measures are considered, estimated doses to a renovation worker are 0.9 mrem/yr for the overall drain line system; 1.6 mrem/yr for the manholes and areas previously filled by GM group; and 0.003 mrem/yr from the sumps group, for a total worst case estimate of

Table 5-1. Estimated Doses From Residual Uranium for the Maintenance and Renovation Worker Scenarios (With Consideration of Containment Measures)

Exposure Group	Non-Routine Maintenance Worker (mrem/yr)	Renovation Worker (mrem/yr)
Drain lines[a]	0.8	0.9
Manholes and areas previously filled by GM[b]	0.7	1.6
Sumps[c]	0.002	0.003
Estimated worst-case condition	Maximum = 0.8 mrem/yr	Total = 2.5 mrem/yr

[a]Includes drain lines B, C, D, E, G, H, and I.
[b]Includes M2, M16, M25, floor drains, and the extrusion pits.
[c]Includes sump #3 and the oil trap pit.
- Doses shown for the non-routine maintenance worker are the maximum dose for any component in the group (e.g., drain line C).
- Doses shown for the renovation worker are total doses from exposure to all areas or components within each group (e.g., total for all drain lines).

Table 5-2. Estimated Doses From Residual Uranium for the Maintenance and Renovation Worker Scenarios (Without Consideration of Containment Measures)

Exposure Group	Non-Routine Maintenance Worker (mrem/yr)	Renovation Worker (mrem/yr)
Drain lines[a]	30	24
Manholes, sumps, and pits[b]	8.1	18
Areas previously remediated by GM[c]	0.6	0.8
Estimated worst-case condition	Maximum = 30 mrem/yr	Total = 43 mrem/yr

[a]Includes drain lines B, C, D, E, G, H, and I.
[b]Includes M2, M16, M25, floor drains, and the extrusion pits.
[c]Includes sump #3 and the oil trap pit.
- Doses shown for the non-routine maintenance worker are the maximum dose for any component in the group (e.g., drain line C).
- Doses shown for the renovation worker are total doses from exposure to all areas or components within each group (e.g., total for all drain lines).

2.5 mrem during a year. As with the maintenance worker scenario, renovation worker doses are due primarily to ingestion and inhalation of contaminated material.

Table 5-2 provides a summary of estimated worker doses if containment measures are not considered in the dose calculations. Without consideration of containment measures, estimated doses to a maintenance worker are 30 mrem/yr for the drain line group (drain line C); 8.1 mrem/yr for the manholes and areas previously filled by GM group; and 0.6 mrem/yr for the sumps group. For the renovation worker scenario, the estimated doses without containment measures are 24 mrem/yr for the drain line group; 18 mrem/yr for the manholes and areas previously filled by GM group; and 0.8 mrem/yr for the sumps group for a total worst case renovation worker dose of 43 mrem/yr.

The results shown in Table 5-2 do not include consideration of contaminant methods, and could only be considered reasonable estimates of possible exposures if no grout or CLSM had been used during the remedial actions. These results are shown as a basis for assessing the significance of the containment measures and the methods used to account for these measures in the dose calculations. They provide a reference point for evaluation of the relative value of the containment measures, and for determining if the methods for accounting for these measures are reasonable. They should not be considered representative of possible worst case conditions, since they assume that the areas were left accessible after remedial actions, and this is not the case.

6. UNCERTAINTIES

To estimate potential future worker doses from residual uranium in the oil collection system at the General Motors site several simplifying assumptions were made concerning future site conditions. To the extent possible, measured site-specific data were used to limit the amount of uncertainty associated with future dose estimates. However, there are several areas in the dose assessment process where site-specific data are not available, and assumptions based on average or upper bound estimates of reasonable conditions must be used. The net effect of this use of multiple conservative assumptions is that the estimates of future dose are usually much higher than what is really likely to occur. This section outlines the major uncertainties associated with the dose assessment and summarizes how those uncertainties impact the overall dose estimates. The discussion of uncertainties is grouped by the following topic areas: data collection and evaluation, source term concentration calculations, and exposure point concentration calculations.

6.1 DATA COLLECTION AND EVALUATION

How data is collected can have a significant effect on determination of the average or UCL_{95} concentration estimate used for dose calculations. At most sites with soil contamination, a set of representative samples are used to estimate the site-wide average contaminant level. At the GM site, much of the oil collection system was inaccessible and could not be sampled using normal methods. To collect sufficient data for dose assessment and remedial action decisions, a state-of-the-art pipe surveying system was used to measure residual contamination in the pipes (as described in Section 3). This system provided contamination data over every foot (in some cases several data points per foot) of pipe length surveyed. Collection of such a high volume of data points allows very accurate determination of average contamination conditions, as well as high assurance that localized spots of contamination would not be missed if present within the area surveyed. Thus, the measurement techniques used for the drain lines help to reduce the overall uncertainties for those areas surveyed. All portions of all drain lines could not be surveyed (using any method), and this represents one of the uncertainties in the GM site Hazard Assessment. However, this is true for any site. As an example, it is physically impossible to collect soil samples from every area of most sites with soil contamination. Because extensive data was collected over large portions of each of the major drain lines, this data set is believed to be representative of overall remaining conditions over the entire drain line system. Thus, dose estimates based on this measured data should be representative of the entire drain line system.

The other significant uncertainty in data collection and evaluation involved use of maximum concentrations taken from previous surveys (ORNL 1982) for locations which were inaccessible during the 1995 remedial actions (e.g., M16, M2, and floor drains). The use of maximum concentrations should provide an overestimate of actual average contamination conditions.

The net effect of uncertainties in the data collection and evaluation process is likely an over-estimation of doses due to use of the UCL_{95} uranium concentration rather than the mean concentration for dose calculations.

6.2 SOURCE TERM CONCENTRATION CALCULATIONS

To calculate potential doses associated with surface contamination, some assumptions must be made with regard to the thickness of the contamination layer and the density of the contamination. These values are important because ultimately, it is the total amount of radioactivity (pCi) taken into the body (or exposing the body externally) which will determine the potential dose to a worker. In order to determine the amount of radioactivity available for intake, the radioactivity concentration in pCi/g is multiplied by the grams of material ingested or inhaled each year during work activities. Thus, the dose (mrem) is directly related to the activity concentration (pCi/g) of the material available for intake or exposure. The higher the activity concentration, the higher the dose will be.

Calculation of the source term concentration in pCi/g is critical to estimation of doses and the potential uncertainty associated with those dose estimates. For this assessment the source term values were actual U-238 surface activity measurements. These surface activity measurements in dpm/100 cm^2 were converted to activity concentration in pCi/g using estimated values for the thickness and density of the surface contamination layer. Selection of the thickness of the contamination layer is a significant uncertainty for the hazard assessment. Since the actual contamination thickness was impossible to measure, a conservative estimate was developed based on literature values, and information related to the cleanup methods for this site. The source term concentration (pCi/g) is calculated by dividing the surface activity level by the thickness and density values as shown below:

$$pCi/g = (SC \times CF)/(T \times \rho)$$

where, SC = source concentration in dpm/cm^2
CF = conversion factor of 0.45 pCi/dpm
T = thickness of surface activity (cm)
ρ = density of contamination

As shown in the above equation, the source term concentration is very sensitive to the contamination thickness assumed in the assessment. The thicker the layer of contamination, the lower the source term concentration value will be. In NUREG CR/5512, a default contamination thickness value of 1 cm is recommended by the NRC for assessments related to building occupancy or demolition (NRC 1990). Many of the drain lines at the GM site are constructed of carbon steel. It is unlikely that contamination could penetrate uniformly as deep as 1 cm into carbon steel (or even clay tile pipes). In addition, these drain lines were cleaned using high pressure wash systems. Thus, any residual contamination would likely be confined

to a thin layer fixed tightly to the surface of the pipe. For these reasons, a default contamination thickness value of 0.1 cm (10 times more conservative than that recommended by NUREG CR/5512) was used for all contamination measurement conversions. This is the same surface contamination thickness used by Argonne National Laboratory (ANL) in the St. Louis Baseline Risk Assessment (DOE 1993). A default value of 1.5 g/cm^3 (approximate soil density) was used as a conservative estimate of contamination density.

The net effect of the uncertainty in the source term concentration calculations is likely an over-estimation of doses due to the conservative assumption used for contamination thickness.

6.3 EXPOSURE POINT CONCENTRATION CALCULATIONS

The exposure point concentration is the concentration or amount of radioactivity that is available at the location where a worker could be exposed (either now or in the future). The exposure point concentration is related to the source term (the original amount of radioactivity present at the site), but it is not exactly the same thing. In many assessments, the exposure point concentration must be predicted by modeling, using the source term and other information on how the radioactivity will travel through the environment to a potential receptor. An example of this is contamination of groundwater miles away from a site, caused by burial of radioactivity on the site. In the case of the GM site, the source term consists of the material remaining in drain lines, manholes, and sumps. The exposure point concentration is the concentration that realistically could be expected to escape from these areas under work conditions, and be available for inhalation, ingestion, or direct exposure of future workers. To predict the exposure point concentrations for the GM site, the encapsulation or containment of the source term (original activity in pipes, sumps, and/or manholes) by grouting must be accounted for through modeling or other methods. This is analogous to the groundwater exposure point concentration modeling described above.

To account for this containment of source term uranium and the resulting reduction of potential exposure point concentrations, a very simple dilution method was used in this assessment. The grout (flowable concrete or CLSM) effectively reduces or dilutes the concentration of source term material, as well as containing the radioactive material so that release is unlikely. In this assessment, it was assumed that at some point in the future the material could be released, so no credit was taken for complete containment by grouting. In reality, this release of uranium is highly unlikely, and represents another conservative assumption in the Hazard Assessment. The resulting exposure point concentration (after release), was reduced in part by accounting for dilution caused by the grout material. Thus the exposure point concentration calculation approach used in this assessment essentially assumes eventual release of the grouted uranium, but at a reduced concentration than would have been possible without the grout fill.

It is possible that under certain conditions (such as cutting through a steel pipe with a cutting torch) surface activity attached to the steel could be released with the steel particles

without substantial release of the surrounding (encapsulating) grout. Under these circumstances, the grout material would not significantly dilute the radioactivity. However, the dose assessment includes evaluation of worker exposures under conditions with no containment or dilution by grout. Doses to a worker under the conditions described previously for cutting steel would likely fall within the range of doses described in this report for conditions with and without encapsulation. In addition, it is likely that respiratory protection would be utilized by a worker cutting through steel and concrete with a torch or a saw. Respiratory protection was not considered in the dose estimates reported in this assessment, but potential doses would be substantially reduced with use of respiratory protection if required for other construction safety or industrial hygiene considerations.

The net effect of the uncertainty in the exposure point concentration calculations is likely an over-estimation of doses due to the assumption of ultimate release of the contained residual uranium.

7. SUMMARY AND CONCLUSIONS

Based on the calculations performed in this assessment, it is concluded that potential future exposures from residual uranium in the oil collection system and extrusion pits at the GM plant are substantially below the international and national radiation protection guidelines for protection of the general public (100 mrem/yr). Conservative dose estimates based on post-remedial action conditions indicate that the potential annual dose to a future maintenance worker performing non-routine intrusive work in the areas with residual uranium would be less than 1 mrem. Even under projected major renovation conditions where a worker is exposed to all areas of the plant with residual uranium, the estimated dose is approximately 2.5 mrem for a renovation event (assumed to occur within a one year period). These doses are well below the public dose limit of 100 mrem/yr from all pathways, and less than the proposed NRC and draft EPA site cleanup standards of 15 mrem/yr.

Even if no containment measures (e.g., filling lines and manholes with grout) had been taken, projected worst case doses range from approximately 30 mrem to 43 mrem for a maintenance worker and renovation worker, respectively. Both, the maintenance and renovation events are assumed to occur over a one year period. While these estimates are still less than the 100 mrem/yr public dose limit, they are based on assumptions that do not represent actual conditions at the site (i.e., no containment measures) and thus should be considered a gross over-estimate of actual conditions at the site.

Some uncertainties are present in the data set used to calculate doses. These uncertainties include use of historical survey results for areas which were not accessible during the 1995 remedial actions. However, in most cases when historical data were used, the maximum result available was used to calculate dose. Thus, the annual doses shown above are likely over-estimates of actual future potential doses.

The estimated removal cost of just the drain lines at the GM site is $1.2 million (BNI 1995c). This cost estimate does not include remediation of the extrusion pits, manholes, sumps, and floor drains associated with the former extrusion operations. It also does not include the cost to GM of shutting down this plant for the major excavation work which would be required for complete removal of all residual uranium. It is likely that the total costs associated with complete removal of all uranium exceeding guidelines would be in excess of $2 million.

The results of the dose calculations show that supplemental limits, as described in DOE Order 5400.5, are warranted for the GM site. Leaving the residual uranium in place does not pose a significant potential future risk, and the cost of removal of all uranium is very high relative to the long-term benefits that would result.

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8. REFERENCES

BNI (Bechtel National Incorporated) 1995a. *Post Remedial Action Report (PRAR) for the Remedial Action at the General Motors Site in Adrian, Michigan* (Draft).

BNI 1995b. "Draft Calculation Package for the Cost Estimate for Examination and Removal of Drain Systems at GM - Engineer Estimate," Oak Ridge, TN, April.

DOE (U.S. Department of Energy) 1986. *Formerly Utilized Sites Remedial Action Program, Summary Protocol, Identification - Characterization - Designation - Remedial Action - Certification*, Washington, D.C. January.

DOE 1990. Order 5400.5, "Radiation Protection of the Public and the Environment," June.

DOE 1993. *Baseline Risk Assessment for the St. Louis Site for Exposure to Contaminants at the St. Louis Site, St. Louis*, Missouri, DOE/OR/23701-41.1, ANL-Environmental Assessment Division, Oak Ridge, TN, November.

EPA (U.S. Environmental Protection Agency) 1988. *Federal Guidance Report No. 11: Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, EPA-520/1-88-020, ORNL, Oak Ridge, TN, September.

EPA 1989. *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A)*, EPA/540/1-89/002, Washington, D.C., December.

EPA 1993. *Federal Guidance Report No. 12: External Exposure to Radionuclides in Air, Water, and Soil*, EPA-402-R-93-081, ORNL, Oak Ridge, TN, September.

EPA 1994. *40 CFR Part 196, Environmental Protection Agency Radiation Site Cleanup Guideline* (Preliminary Staff Working Draft for Public Discussion and Comment), May.

Gilbert, T.L.; C. Yu; Y.C. Yuan; A.J. Zielen; M.J. Jusko; and A. Wallo, III 1989. *A Manual for Implementing Residual Radioactive Material Guidelines*, DOE/CH/8901, Argonne National Laboratory, Argonne, IL. June.

NRC (U. S. Nuclear Regulatory Commission) 1992. *Residual Radioactive Contamination from Decommissioning - Technical Basis for Translating Contamination Levels to Annual Dose*, NUREG/CR-5512, Pacific Northwest Laboratory, Richmond, WA, October.

REFERENCES (continued)

ORNL (Oak Ridge National Laboratory) 1982. *Radiological Survey of the Former Bridgeport Brass Company Facility Special Metals Extrusion Plant, Adrian, Michigan*, DOE/EV-005/28, ORNL-5713, Health and Safety Research Division, Oak Ridge, Tennessee, April.

Paustenbach, D.J., 1989. *A Comprehensive Methodology for Assessing the Risks to Humans and Wildlife Posed by Contaminated Soils: A Case Study Involving Dioxin, in D.J. Paustenbach (ed.), The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies*, John Wiley & Sons, New York, pp. 296-328.

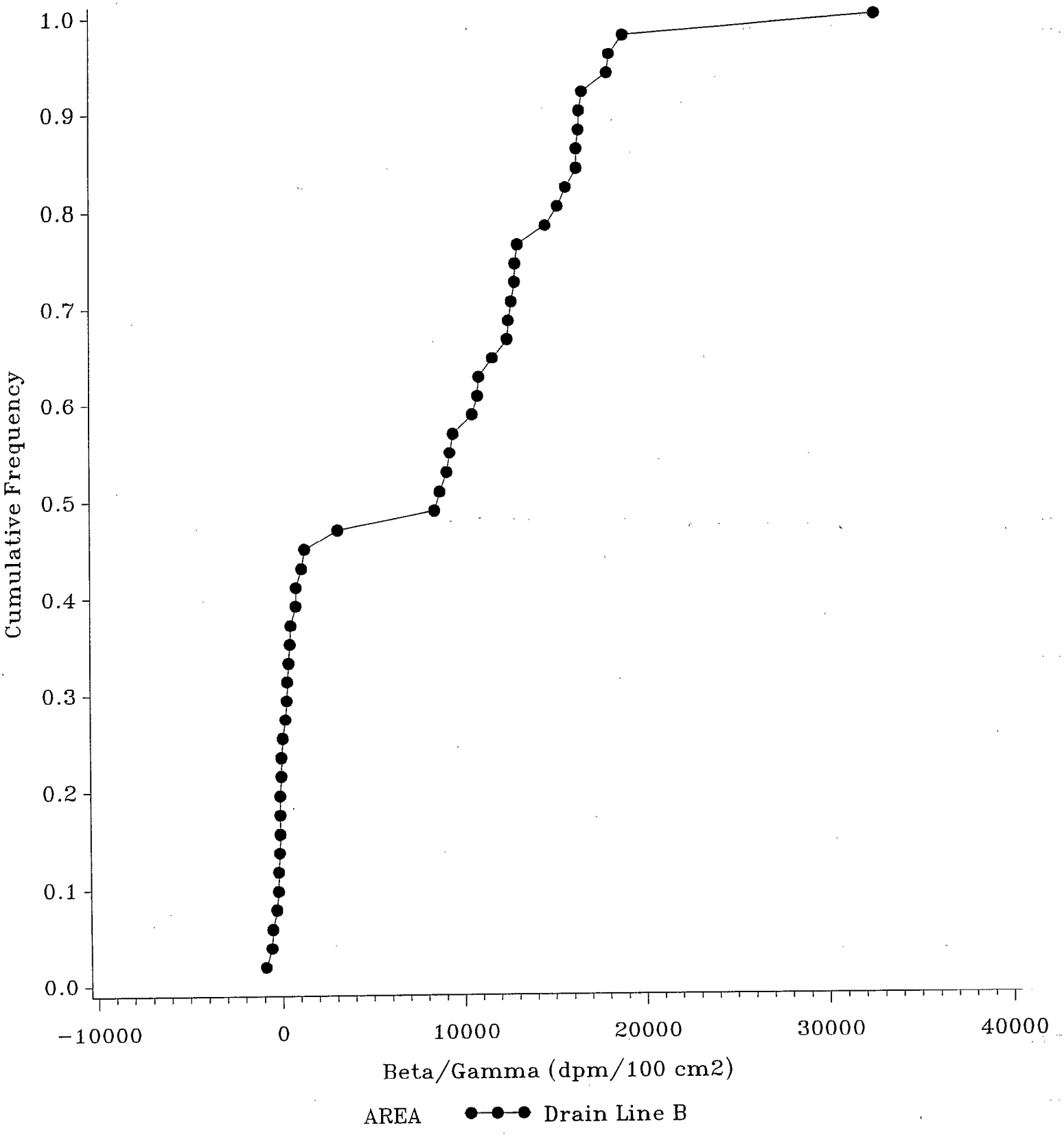
Yu, C.; A.J. Zielen, J. Cheng, Y. Yuan, L. Jones, D. LePoire, et.al 1993a. Manual for Implementing Residual Radioactive Material Guidelines Using Resrad Version 5.0 (working draft), ANL/EAP/D-2, ANL-Environmental Assessment Division, Argonne, Illinois, September.

Yu, C.; C. Loureiro; J.J. Cheng; L.G. Jones; Y.Y. Wang; Y.P. Chia; and E. Faillace 1993b. *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil*, ANL/EAIS-8. Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, IL. April.

APPENDIX A

RESIDUAL ACTIVITY PLOTS

GM Adrian Site
Average by Foot
Drain Line B



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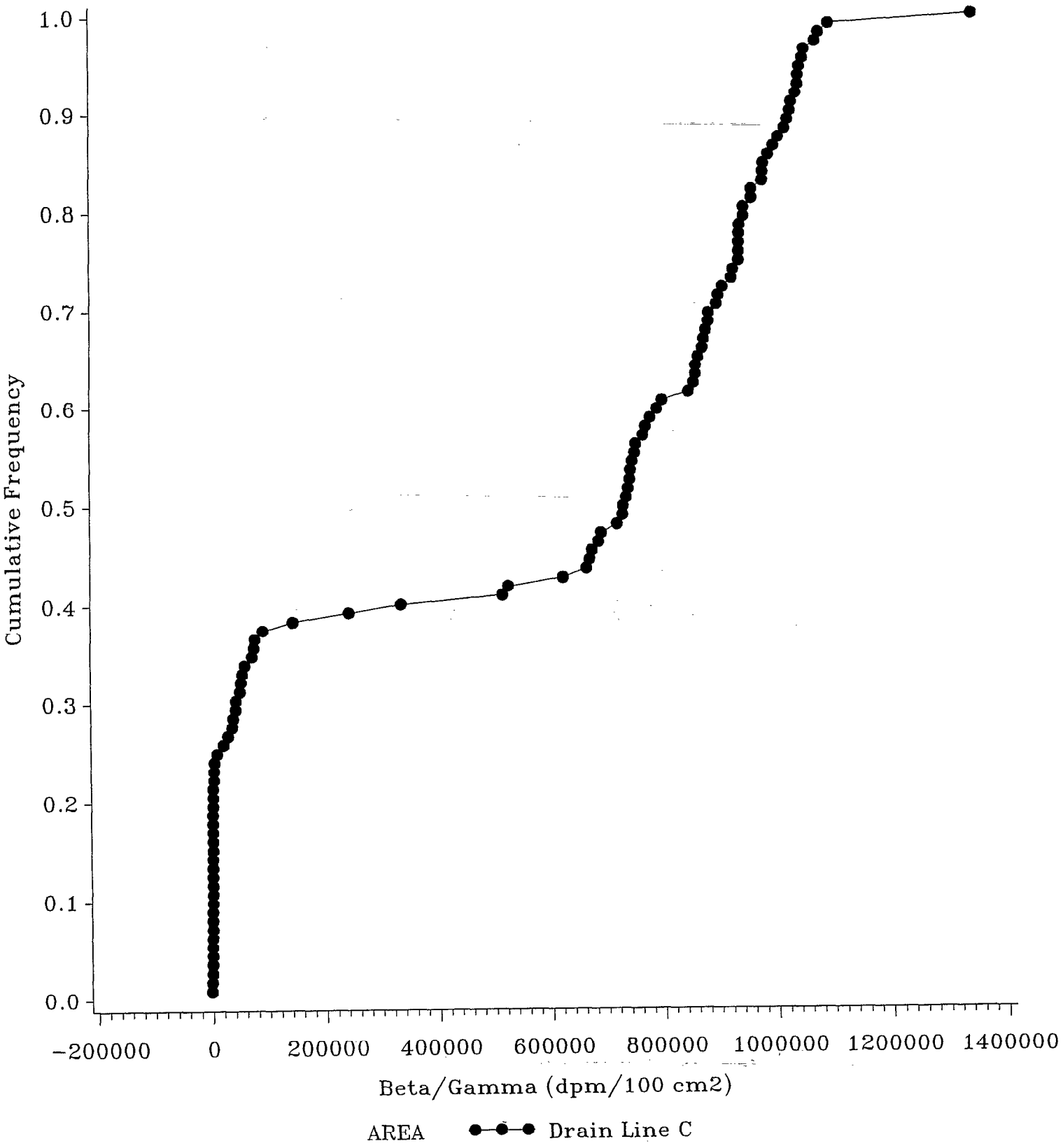
GM Adrian Site
Average by Foot
Drain Line C



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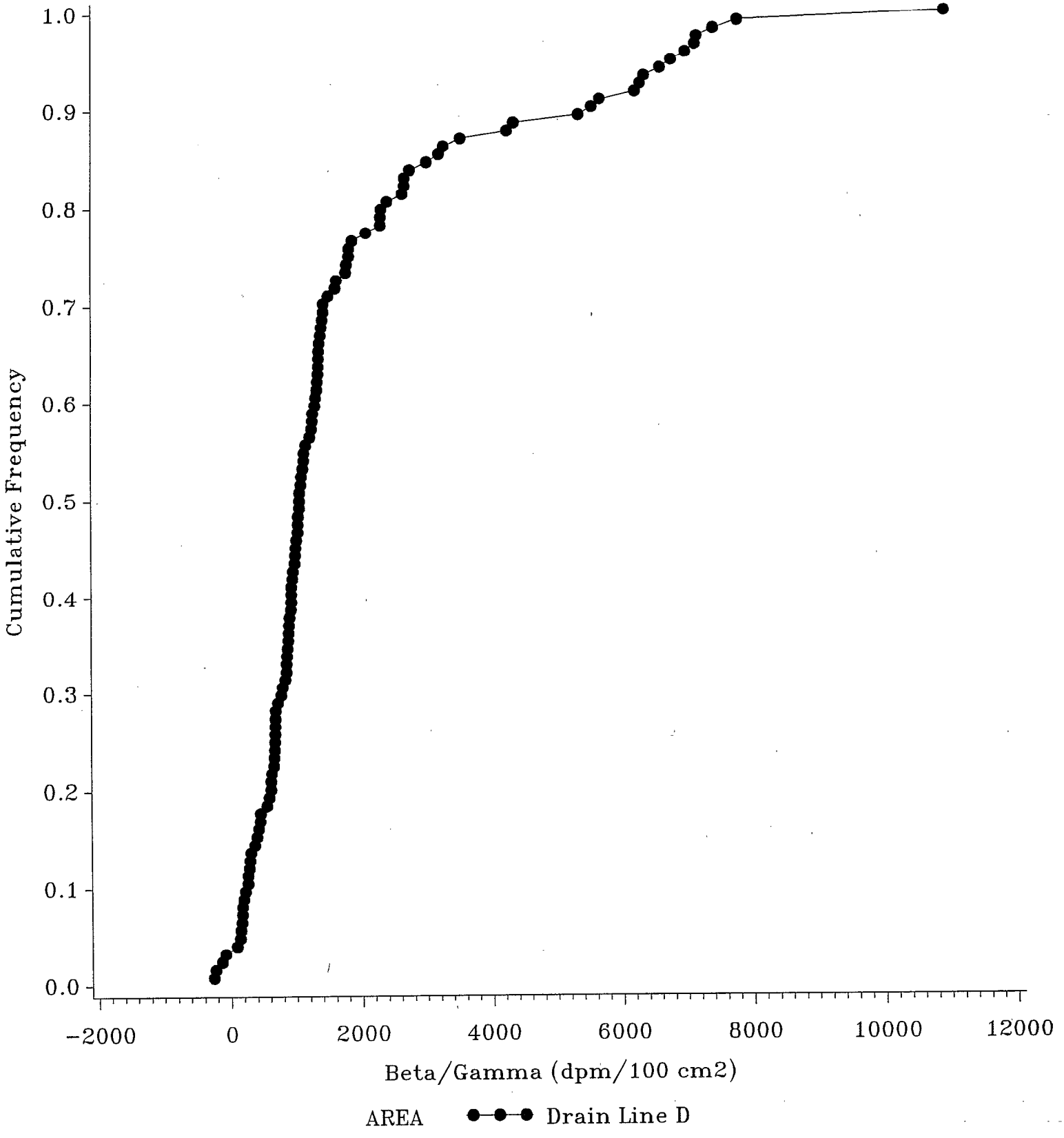
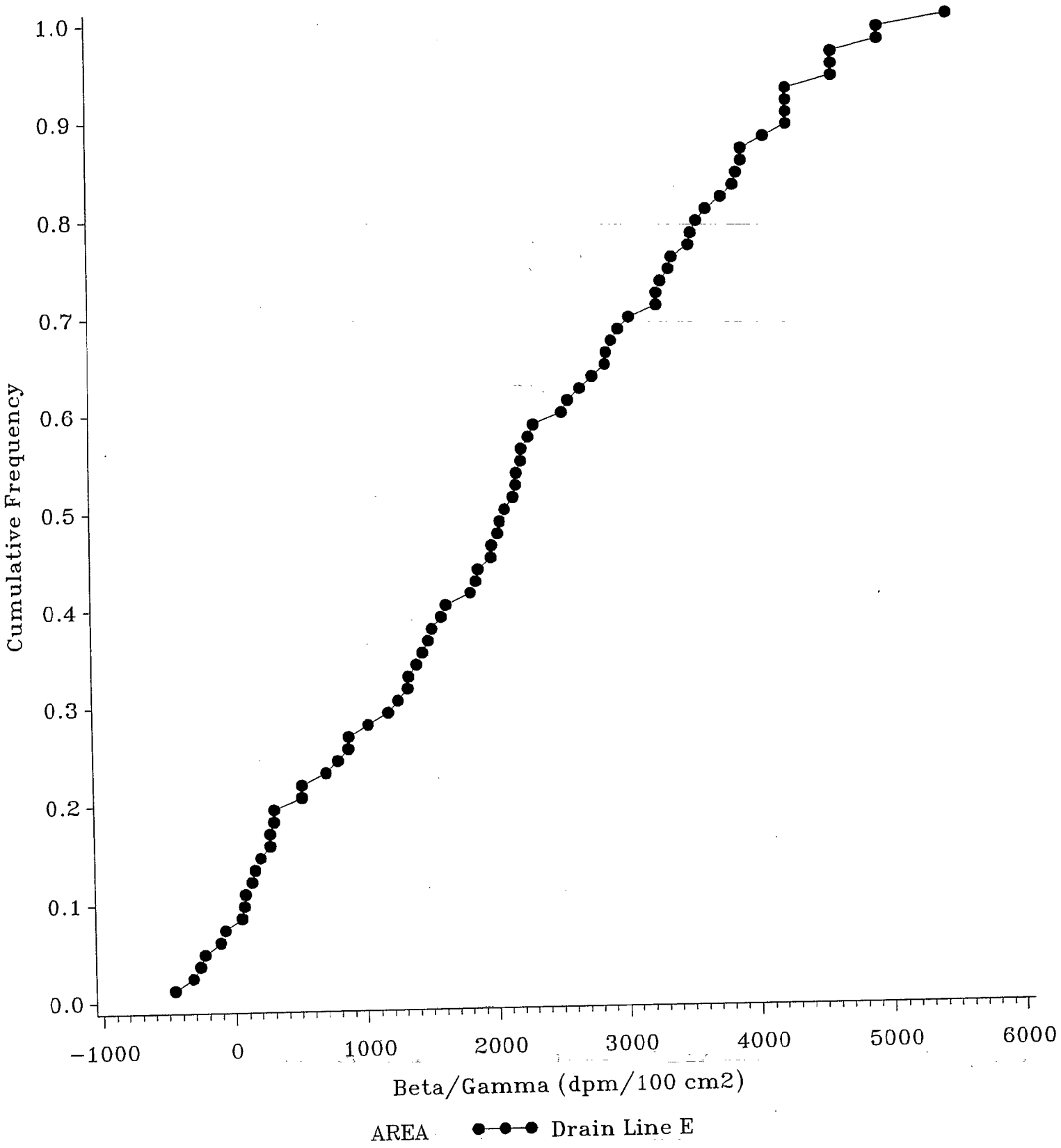
GM Adrian Site
Average by Foot
Drain Line D



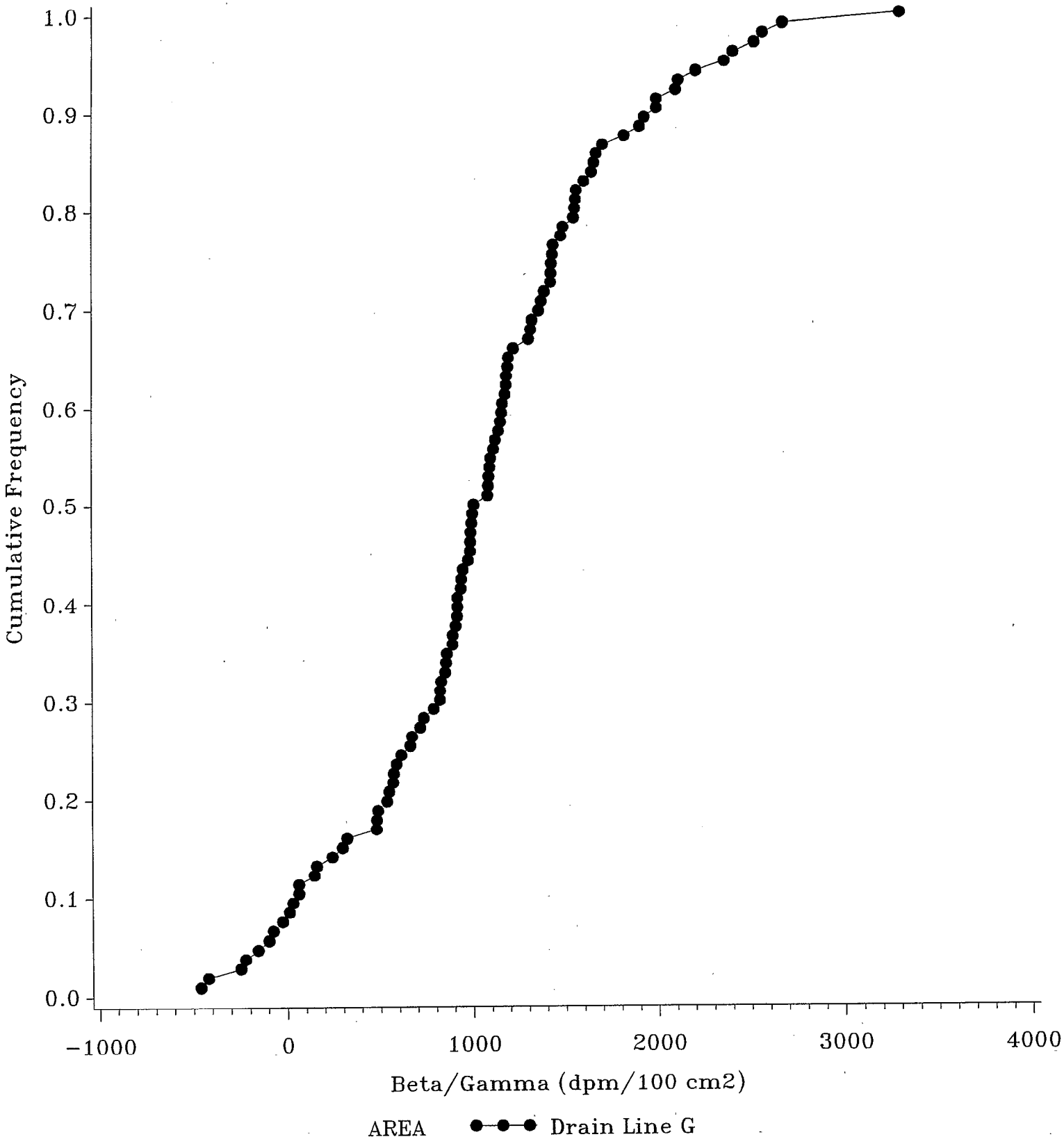
Generated by program plotcdf2 on 18DEC95 at 16:16 using datasets lib.pipe.

GM Adrian Site
Average by Foot
Drain Line E



Generated by program plotcdf2 on 18DEC95 at 16:19 using datasets lib.pipe.

GM Adrian Site
Average by Foot
Drain Line G



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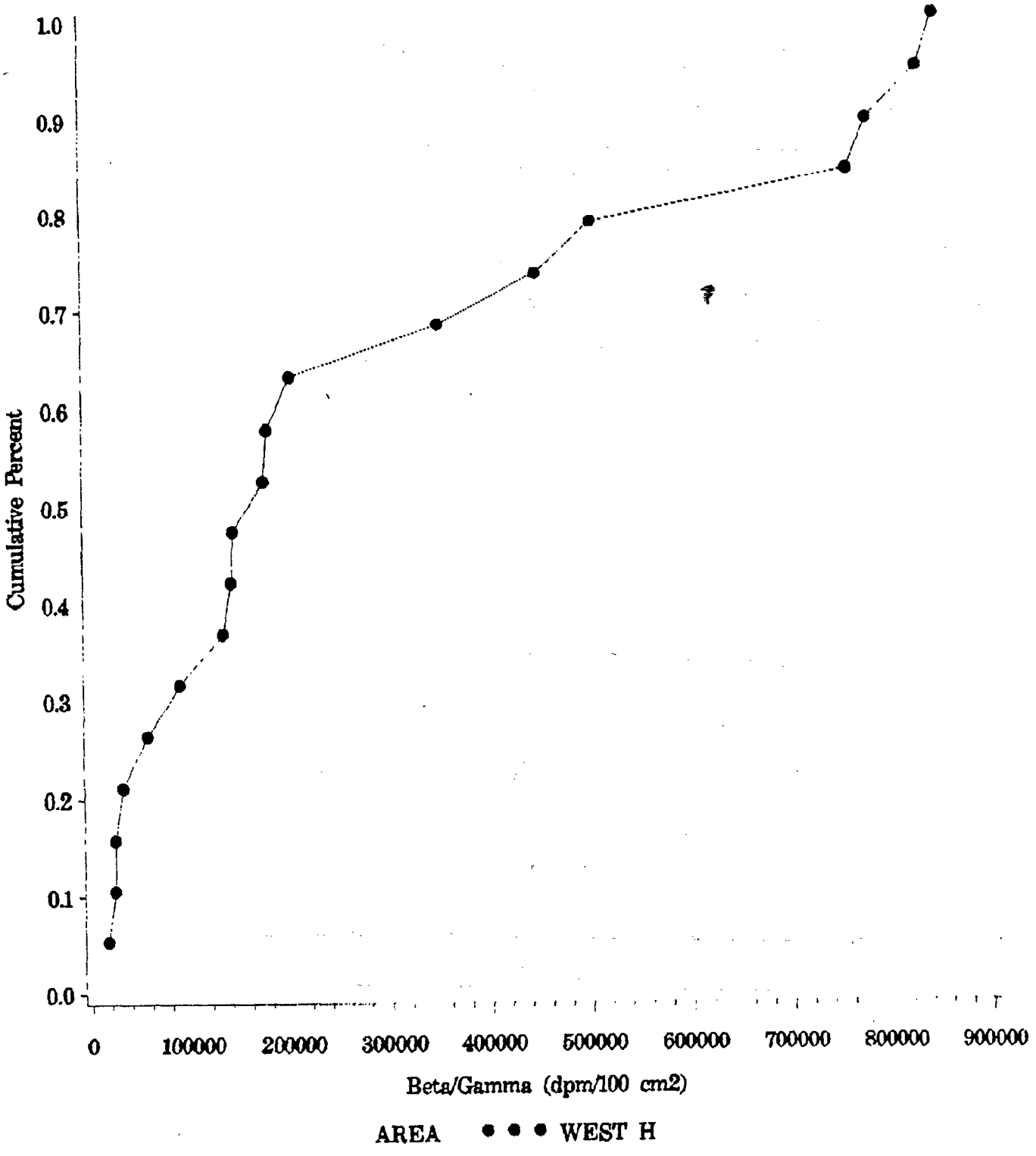
GM Adrian Site
Drain Line H



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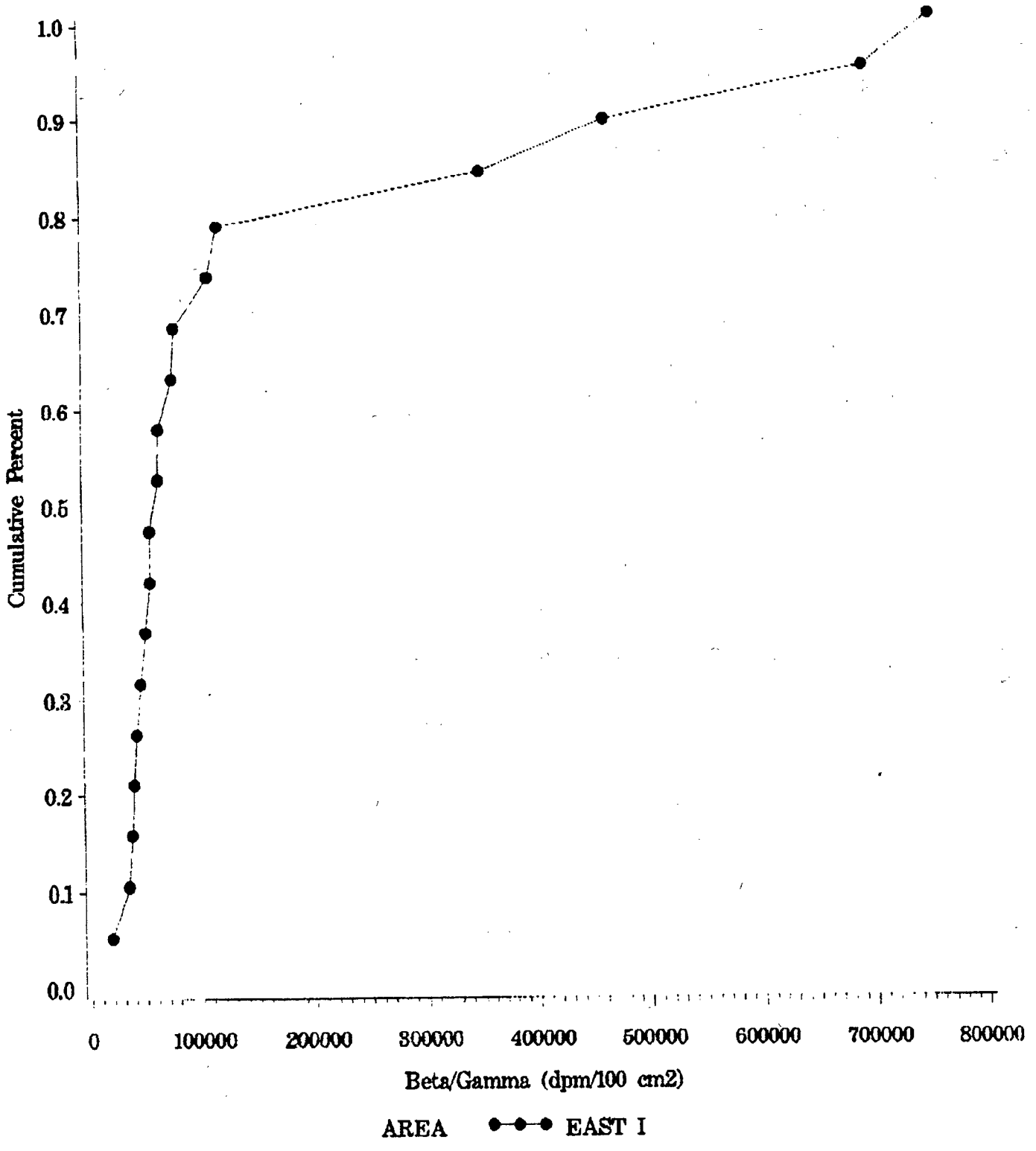
GM Adrian Site
Drain Line I



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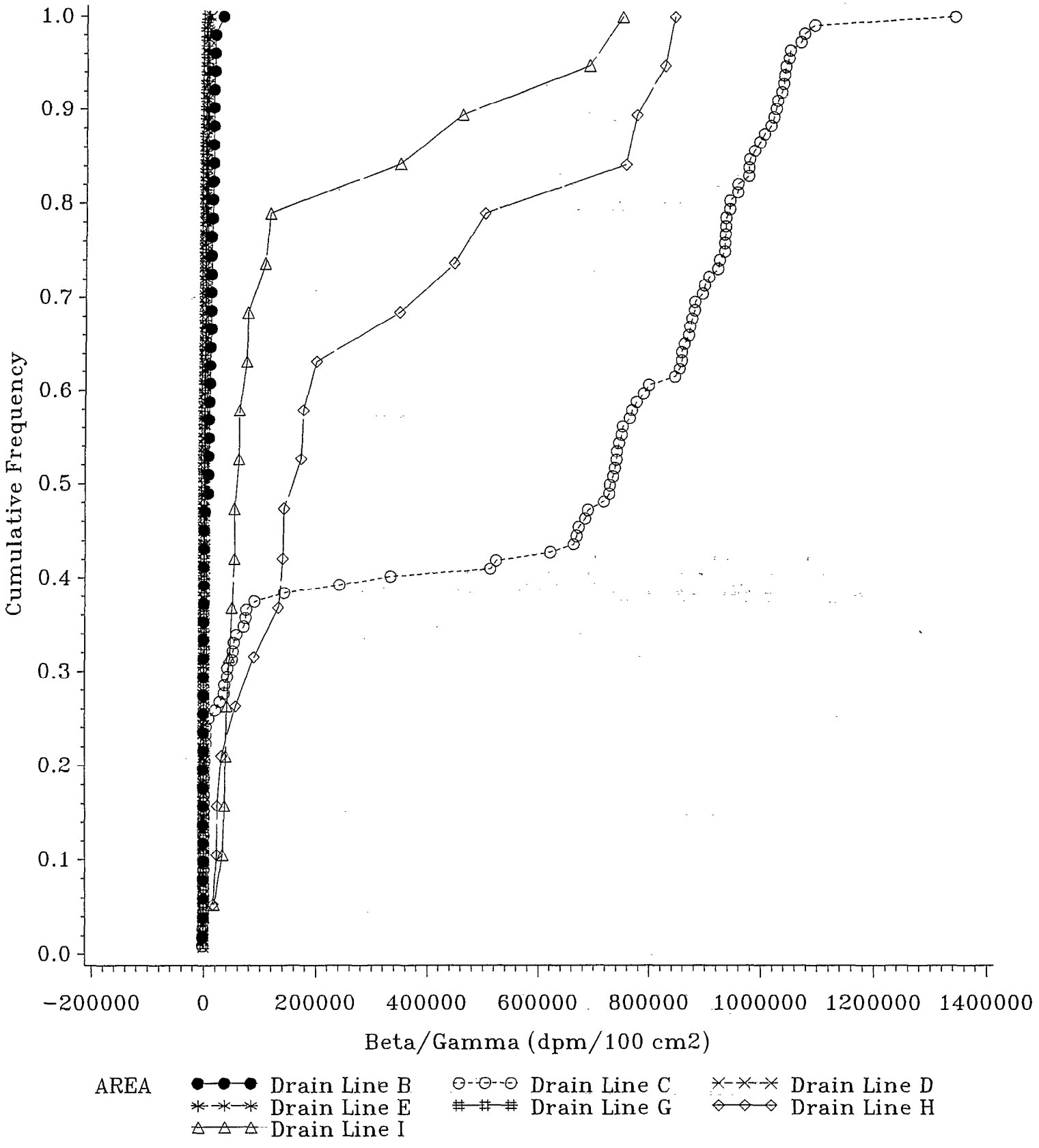
GM Adrian Site
Average by Foot



Generated by program plotcdf5 on 21SEP95 at 13:26 using datasets lib.pipe.

APPENDIX B

ACTIVITY CALCULATIONS

Total Activity Inventory Calculations - Drainlines
General Motors Hazard Assessment

Line	Residual Activity (UCL95) (RA) (U-238 dpm/100 cm2) (1)	Diameter (D) (in.)	Length (L) (ft.)	Activity Inventory (AI) (U-238 pCi)	Activity Mass (AM) (g)	Pre-Fill Conc. (PFG) (pCi/g)	Fill Mass (FM) (g) (2)	% of Line Filled (%F)	Post Fill Conc. (POFC) (pCi/g)	Source Term Red. Factor (STRF)
B	9580	4	120	5.04E+06	1.75E+04	288	2.97E+03	2	246	1.2
C	608000	4	200	5.33E+08	2.92E+04	18258	8.90E+05	75	580	31
D	2150	4	185	1.74E+06	2.70E+04	65	2.29E+03	1	60	1.1
E	2480	4	170	1.85E+06	2.48E+04	74	2.10E+03	1	69	1.1
G	1220	4	145	7.75E+05	2.12E+04	37	1.79E+03	1	34	1.1
H	789000	4	45	1.56E+08	6.57E+03	23694	2.67E+05	100	569	42
I	256000	4	60	6.73E+07	8.76E+03	7688	3.56E+05	100	185	42
M1 conduit	842	4	145	5.35E+05	2.12E+04	25	6.31E+05	100	1	31
M15 conduit	7630	4	155	5.18E+06	2.26E+04	229	6.74E+05	100	7	31
Total				7.71E+08	1.79E+05	4312	2.83E+06	40	257	17

Assumptions:

Density of contaminated material (P) (g/cm3)	1.5
Thickness of contaminated material (T) (cm)	0.1
Density of fill material (FD) (g/cm3)	
- grout	2.4
- CLSM	1.76
- foam	0.5

Equations:

AI = [(RA/100) x (2pi x D/2 x 2.54) x (L x 12 x 2.54)]/2.22
AM = (2pi x D/2 x 2.54) x (L x 12 x 2.54) x T x P
FM =(pi x (2.54 x D/2)^2) x (L x 12 x 2.54) x FD x %F
PFG = AI/AM
POFC =AI/(FM + AM)
STRF = PFC/POFC

Notes:

1) Measured residual U-238 suface activity.
2) Grout fill used for drainlines C, H,and I. Drainlines B, D, E,and G plugged with approximately 2 ft. of foam. The M15, and M1 electrical conduit lines were fiilled with CLSM.

Detailed equations and calculation explanations provided in the General Motors Hazard Assessment Calculation Package.

Total Activity Inventory Calculations - Manholes
(Manholes with data used from previous surveys)
General Motors Hazard Assessment

Location	U-238 Sludge Concentration (SC) (pCi/g)	Side Width (SW) (ft)	Side Length (SL) (ft)	Floor Surf. Area (SA) (cm2)	Manhole Volume (MV) (cm3)	Sludge (Cont.) Volume (CV) (cm3)	Activity Inventory (AI) (U-238 pCi)	Pre-Fill Conc. (PFC) (pCi/g)	Fill Mass (FM) (g)	% Filled	Post Fill Conc. (POFC) (pCi/g)	Source Term Red. Factor (VCR)
M2	21000	2.68	6.5	3.22E+04	6.38E+06	6.38E+05	2.01E+10	2.10E+04	1.12E+07	100	1790	12
M16	15000	2.68	6.5	3.22E+04	6.38E+06	6.38E+05	1.44E+10	1.50E+04	1.12E+07	100	1278	12
M25	86	2.68	6.5	3.22E+04	6.38E+06	6.38E+05	8.23E+07	8.60E+01	1.12E+07	100	7	12
Total							3.46E+10					

Assumptions:

Density of contaminated material (P) (g/cm3) 1.5
Density of fill (CLSM) material (FD) (g/cm3) 1.76
Sludge (contamination) volume assumed to be 1/10 of total manhole volume
Sludge concentration results based on ORNL surveys conducted prior to remedial actions (ORNL 1982)

Equations:

Manhole floor surface area : SA = 4.82843 x (SW x 12 x 2.54)^2 (see calculation package for equation source)
Manhole volume (MV) = SA x SL x 12 x 2.54
AI = SC x P x CV
PFC = Measured sludge concentration (pCi/g) (SC)
FM = MV x FD x % filled
POFC =AI/FM
STRF = PFC/POFC

Total Activity Inventory Calculations - Sumps (No. 3 and the Oil Trap Pit)
General Motors Hazard Assessment

Location	Residual U-238 Activity (UCL95) (RA) (dpm/100 cm2)	Diameter (D) (in.)	Depth (L) (ft.)	Surf. Area (SA) (cm2	Activity Inventory (AI) (U-238 pCi)	Activity Mass (AM) (g)	Pre-Fill Conc. (PFC) (pCi/g)	Fill Mass (FM) (g)	% Filled	Post Fill Conc. (POFC) (pCi/g)	Source Term Red. Factor (STRF)
Sump 3	55800	48	20	2.45E+05	6.16E+07	3.68E+04	1.68E+03	1.25E+07	100	5	342
Oil Trap Pit	12900			2.62E+05	1.52E+07	3.93E+04	3.87E+02	8.98E+06	100	2	229
Total					7.68E+07						

Assumptions:

Density of contaminated material (P) (g/cm3)	1.5
Thickness of contaminated material (T) (cm)	0.1
Density of fill (CLSM) material (FD) (g/cm3)	1.76

Equations:

Surface Area

Sumps: SA = (2pi x D/2 x 2.54) x (L x 12 x 2.54) + pi (D/2 x 2.54)^2

Pits: SA = (see calculation package - pit consists of 3 separate units with a toal interior surface area of 2.62E5 cm2)

AI = (RA/100) x SA/2.22 (as U-238 equivalent)

AM = SA x T x P

PFC = AI/AM

FM = (Vol. of sump or pit) x FD x % filled

POFC =AI/FM

STRF = PFC/POFC

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APPENDIX C

APPENDIX C-1

DOSE CALCULATIONS WITH CONSIDERATION OF CONTAINMENT MEASURES

General Motors Hazard Assessment
Estimated Doses From Contaminated Surfaces (thin layer of contamination)
Non-Routine Maintenance Worker Scenario
Drain Lines
With consideration of containment methods

Drain Line	U Surface Contamination			Ingestion			Inhalation			External		Annual
	(dpm/100cm2) (a)	STRF (b)	(pCi/cm2) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (d)	Dose (mrem/yr)	Dose Rate (mrem/yr) (e)
B	9580	1.2	71.92	4.79E+02	2.69E-04	0.129	1.28E+00	1.25E-01	0.160	2.10E-02	0.017	0.31
C	608000	31.0	176.69	1.18E+03	2.69E-04	0.317	3.15E+00	1.25E-01	0.393	2.10E-02	0.042	0.75
D	2150	1.1	17.61	1.17E+02	2.69E-04	0.032	3.13E-01	1.25E-01	0.039	2.10E-02	0.004	0.07
E	2480	1.1	20.31	1.35E+02	2.69E-04	0.036	3.62E-01	1.25E-01	0.045	2.10E-02	0.005	0.09
G	1220	1.1	9.99	6.66E+01	2.69E-04	0.018	1.78E-01	1.25E-01	0.022	2.10E-02	0.002	0.04
H	789000	42.0	169.24	1.13E+03	2.69E-04	0.304	3.01E+00	1.25E-01	0.377	2.10E-02	0.041	0.72
I	256000	42.0	54.91	3.66E+02	2.69E-04	0.098	9.77E-01	1.25E-01	0.122	2.10E-02	0.013	0.23
M1 elec. conduit	842	31.0	0.24	1.63E+00	2.69E-04	0.000	4.36E-03	1.25E-01	0.001	2.10E-02	0.000	0.00
M15 elec. conduit	7630	31.0	2.22	1.48E+01	2.69E-04	0.004	3.95E-02	1.25E-01	0.005	2.10E-02	0.001	0.01

Maximum Estimated Dose Rate = 0.75

Source Term Equation:

SC = ((dpm/100 cm2) x 2)/(100*2.22*STRF) (as total uranium equivalent)

Total Dose Equation (for each line):

TD (mrem/yr) = [SC x IR x EF x DCF(ing) / (D x T)] + [SC x INH x DL x RF x EF x ET x DCF(inh) / (D x T)] + [SC x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency (EF) (days/yr)	10
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction (RF)	3.00E-01
Density (D) (g/cm3)	1.50
Thickness (T) (cm)	0.10

Notes:
a) U-238 dpm/100 cm2 as measured during remedial actions.
b) STRF (Source Term Reduction Factor) is the factor to account for reduction of the source term due to containment and dilution with grout or concrete
c) Source term used for dose calculations including consideration of STRF, and conversion of U-238 equivalent measurement to total uranium equivalent.
d) Units for the external DCF are mrem/yr per pCi/cm2
e) Annual dose rate for each drainline is based on the assumption of 10 days of work at that location during a work year.

GM Hazard Assessment
Supplemental Limit Evaluation
Table C1A-2

General Motors Hazard Assessment
Estimated Doses From Residual Uranium
Non-routine Maintenance Worker Scenario
Manholes and Areas Previously Filled or Remediated by General Motors
With consideration of containment measures

Location (Manhole or Sump)	U-tot Contamination			Ingestion			Inhalation			External		Total Dose (mrem/yr)
	pCi/g (a)	STRF (b)	(pCi/g) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (mrem/yr)/(pCi/cm2)	Dose (mrem/yr)	
M2	42000	12	3500	1.05E+03	2.69E-04	0.28	2.80E+00	1.25E-01	0.35	2.10E-02	0.04	0.67
M16/Line A	30000	12.00	2500	7.50E+02	2.69E-04	0.20	2.00E+00	1.25E-01	0.25	2.10E-02	0.03	0.48
M25	172	12.00	14	4.30E+00	2.69E-04	0.00	1.15E-02	1.25E-01	0.00	2.10E-02	0.00	0.00
Floor Drains	22000	10.00	2200	6.60E+02	2.69E-04	0.18	1.76E+00	1.25E-01	0.22	2.10E-02	0.02	0.42
Extrusion Pits	NA	NA	104	1.04E+02	2.69E-04	0.03	2.78E-01	1.25E-01	0.03	2.10E-02	0.00	0.07

Maximum Estimated Dose Rate	0.67

Total Dose Equation:

DR (mrem/yr) = [SC x IR x EF x DCF(ing)] + [SC x INH x DL x RF x EF x ET x DCF(inh)] + [SC x (D x T) x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency - manholes and drains (EF) (days/yr)	3
Exposure frequency - extrusion pits (EF) (days/yr)	10
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction	3.00E-01
Density (D) (g/cm3)	1.50
Thickness (T) (cm)	0.10

Notes:
a U-tot pCi/g as measured before grout placed.
b STRF (Source Term Reduction Factor) is the factor used to account for containment (and dilution) of residual contamination by grout or concrete fill.
c Source term (U-tot pCi/g) as measured after grout placement, or calculated using pre-grout measurements and the STRF value.

GM Hazard Assessment
Supplemental Limit Evaluation
Table C1A-3

General Motors Hazard Assessment
Estimated Doses From Contaminated Surfaces (thin layer of contamination)
Non-routine Maintenance Worker Scenario
Sumps
With consideration of containment measures

Location (Manhole or Sump)	U Surface Contamination (dpm/100cm2) (a)	STRF (b)	(pCi/cm2) (SC) (c)	Ingestion Intake (pCi/yr)	Ingestion DCF (mrem/pCi)	Ingestion Dose (mrem/yr)	Inhalation Intake (pCi/yr)	Inhalation DCF (mrem/pCi)	Inhalation Dose (mrem/yr)	External DCF (mrem/yr)/(pCi/cm2)	External Dose (mrem/yr)	Total Dose (mrem/yr)
Sump No. 3	55800	341.00	1.47	2.95E+00	2.69E-04	0.001	7.87E-03	1.25E-01	0.001	2.10E-02	0.0001	0.002
Oil Trap Pit	12900	228.00	0.51	1.02E+00	2.69E-04	0.000	2.72E-03	1.25E-01	0.000	2.10E-02	0.0000	0.001

Maximum Estimated Dose Rate = 0.002

Source Term Equation:

SC = ((dpm/100 cm2) x 2)/(100 x 2.22 x STRF) (as total uranium equivalent)

Total Dose Equation:

DR (mrem/yr) = [SC x IR x EF x DCF(ing) / (D x T)] + [SC x INH x DL x EF x RF x ET x DCF(inh) / (D x T)] + [SC x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency (EF) (days/yr)	3
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction (RF)	3.00E-01
Density (D) (g/cm3)	1.50E+00
Thickness (T) (cm)	1.00E-01

Notes:
a U-238 dpm/100 cm2 as measured after remedial actions.
b STRF (Source Term Reduction Factor) is the factor used to account for containment (and dilution) of residual contamination by grout or concrete fill.
c Surface Contamination value used in dose calculations including consideration of STRF, and conversion of U-238 equivalent measurement to total uranium equivalent.

GM Hazard Assessment
Supplemental Limit Evaluation
Table C1B-1

General Motors Hazard Assessment
Estimated Doses From Contaminated Surfaces (thin layer of contamination)
Renovation Worker Scenario
Drain Lines
With consideration of containment methods

Drain Line	U Surface Contamination			Ingestion			Inhalation			External		Drain Line	Line	Prorated Dose
	(dpm/100cm2) (a)	STRF (b)	(pCi/cm2) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (d)	Dose (mrem/yr)	Dose Rate (mrem/yr) (e)	Length (ft)	(mrem/yr) (f)
B	9580	1.2	71.92	2.06E+03	2.69E-04	0.55	5.50E+00	1.25E-01	0.69	2.10E-02	0.07	1.32	120	0.13
C	608000	31.0	176.69	5.07E+03	2.69E-04	1.36	1.35E+01	1.25E-01	1.69	2.10E-02	0.18	3.24	200	0.53
D	2150	1.1	17.61	5.05E+02	2.69E-04	0.14	1.35E+00	1.25E-01	0.17	2.10E-02	0.02	0.32	185	0.05
E	2480	1.1	20.31	5.82E+02	2.69E-04	0.16	1.55E+00	1.25E-01	0.19	2.10E-02	0.02	0.37	170	0.05
G	1220	1.1	9.99	2.86E+02	2.69E-04	0.08	7.65E-01	1.25E-01	0.10	2.10E-02	0.01	0.18	145	0.02
H	789000	42.0	169.24	4.85E+03	2.69E-04	1.31	1.30E+01	1.25E-01	1.62	2.10E-02	0.17	3.10	45	0.11
I	256000	42.0	54.91	1.57E+03	2.69E-04	0.42	4.20E+00	1.25E-01	0.53	2.10E-02	0.06	1.01	60	0.05
M1 elec. conduit	842	31.0	0.24	7.01E+00	2.69E-04	0.00	1.87E-02	1.25E-01	0.00	2.10E-02	0.00	0.00	145	0.00
M15 elec. conduit	7630	31.0	2.22	6.36E+01	2.69E-04	0.02	1.70E-01	1.25E-01	0.02	2.10E-02	0.00	0.04	155	0.01
													1225	

Total Estimated Dose = 0.9

Source Term Equation:

SC = ((dpm/100 cm2) x 2)/(100*2.22*STRF) (as total uranium equivalent)

Total Dose Equation (for each line):

TD (mrem/yr) = [SC x IR x EF x DCF(ing) / (D x T)] + [SC x INH x DL x RF x EF x ET x DCF(inh) / (D x T)] + [SC x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency (EF) (days/yr)	43
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction (RF)	3.00E-01
Density (D) (g/cm3)	1.50
Thickness (T) (cm)	0.10

Notes:
a) U-238 dpm/100 cm2 as measured during remedial actions.
b) STRF (Source Term Reduction Factor) is the factor to account for reduction of the source term due to containment and dilution with grout or concrete
c) Source term used for dose calculations including consideration of source term reduction factor, and conversion of U-238 equivalent measurement to total uranium equivalent.
d) Units for the external DCF are mrem/yr per pCi/cm2
e) Annual dose rate for each drainline is based on the assumption of 43 days of work at that location during a work year.
f) Total dose is the sum of the prorated individual drain line doses. Each drainline annual dose rate is prorated by multiplying by the fraction of the 43 day work period estimated to complete that drainline (drainline length/total line length).

GM Hazard Assessment
Supplemental Limit Evaluation
Table C1B-2

General Motors Hazard Assessment
Estimated Doses From Residual Uranium
Renovation Worker Scenario
Manholes and Areas Previously Filled or Remediated by General Motors
With consideration of containment measures

Location (Manhole or Sump)	U-tot Contamination			Ingestion			Inhalation			External		Total Dose (mrem/yr)
	pCi/g (a)	STRF (b)	(pCi/g) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (mrem/yr)/(pCi/cm2)	Dose (mrem/yr)	
M2	42000	12	3500	1.05E+03	2.69E-04	0.28	2.80E+00	1.25E-01	0.35	2.10E-02	0.04	0.67
M16/Line A	30000	12	2500	7.50E+02	2.69E-04	0.20	2.00E+00	1.25E-01	0.25	2.10E-02	0.03	0.48
M25	172	12	14	4.30E+00	2.69E-04	0.00	1.15E-02	1.25E-01	0.00	2.10E-02	0.00	0.00
Floor Drains	22000	12	1833	5.50E+02	2.69E-04	0.15	1.47E+00	1.25E-01	0.18	2.10E-02	0.02	0.35
Extrusion Pits	NA	NA	104	1.04E+02	2.69E-04	0.03	2.78E-01	1.25E-01	0.03	2.10E-02	0.00	0.07

Total Estimated Dose Rate = 1.57

Total Dose Equation:

DR (mrem/yr) = [SC x IR x EF x DCF(ing)] + [SC x INH x DL x RF x EF x ET x DCF(inh)] + [SC x (D x T) x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency - manholes and drains (EF) (days/yr)	3
Exposure frequency - extrusion pits (EF) (days/yr)	10
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction	3.00E-01
Density (D) (g/cm3)	1.50
Thickness (T) (cm)	0.10

Notes:
a U-tot pCi/g as measured before grout placed.
b STRF (Source Term Reduction Factor) is the factor used to account for containment (and dilution) of residual contamination by grout or concrete fill.
c Source term (U-tot pCi/g) as measured after grout placement, or calculated using pre-grout measurements and the STRF value.

GM Hazard Assessment
Supplemental Limit Evaluation
Table C1B-3

General Motors Hazard Assessment
Estimated Doses From Contaminated Surfaces (thin layer of contamination)
Renovation Worker Scenario
Sumps
With consideration of containment measures

Location	U Surface Contamination			Ingestion			Inhalation			External		Total
(Manhole or Sump)	(dpm/100cm2) (a)	STRF (b)	(pCi/cm2) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (mrem/yr)/(pCi/cm2)	Dose (mrem/yr)	Dose (mrem/yr)
Sump No. 3	55800	341.00	1.47	2.95E+00	2.69E-04	0.001	7.87E-03	1.25E-01	0.001	2.10E-02	0.0001	0.002
Oil Trap Pit	12900	228.00	0.51	1.02E+00	2.69E-04	0.000	2.72E-03	1.25E-01	0.000	2.10E-02	0.0000	0.001

Total Estimated Dose Rate = 0.003

Source Term Equation:

SC = ((dpm/100 cm2) x 2)/(100 x 2.22 x STRF) (as total uranium equivalent)

Total Dose Equation:

DR (mrem/yr) = [SC x IR x EF x DCF(ing) / (D x T)] + [SC x INH x DL x EF x RF x ET x DCF(inh) / (D x T)] + [SC x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency (EF) (days/yr)	3
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction (RF)	3.00E-01
Density (D) (g/cm3)	1.50E+00
Thickness (T) (cm)	1.00E-01

Notes:
a U-238 dpm/100 cm2 as measured after remedial actions.
b STRF (Source Term Reduction Factor) is the factor used to account for containment (and dilution) of residual contamination by grout or concrete fill.
c Surface Contamination value used in dose calculations including consideration of STRF, and conversion of U-238 equivalent measurement to total uranium equivalent.

APPENDIX C-2

DOSE CALCULATIONS WITHOUT CONSIDERATION OF CONTAINMENT MEASURES

GM Hazard Assessment
Supplemental Limit Evaluation
Table C2A-1

General Motors Hazard Assessment
Estimated Doses From Contaminated Surfaces (thin layer of contamination)
Non-Routine Maintenance Worker Scenario
Drain Lines
Without consideration of containment methods

Drain Line	U Surface Contamination			Ingestion			Inhalation			External		Annual
	(dpm/100cm2) (a)	STRF (b)	(pCi/cm2) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (d)	Dose (mrem/yr)	Dose Rate (mrem/yr) (e)
B	9580	1.0	86.31	5.75E+02	2.69E-04	0.155	1.54E+00	1.25E-01	0.192	2.10E-02	0.021	0.37
C	608000	1.0	5477.48	3.65E+04	2.69E-04	9.823	9.75E+01	1.25E-01	12.187	2.10E-02	1.313	23.32
D	2150	1.0	19.37	1.29E+02	2.69E-04	0.035	3.45E-01	1.25E-01	0.043	2.10E-02	0.005	0.08
E	2480	1.0	22.34	1.49E+02	2.69E-04	0.040	3.98E-01	1.25E-01	0.050	2.10E-02	0.005	0.10
G	1220	1.0	10.99	7.33E+01	2.69E-04	0.020	1.96E-01	1.25E-01	0.024	2.10E-02	0.003	0.05
H	789000	1.0	7108.11	4.74E+04	2.69E-04	12.747	1.27E+02	1.25E-01	15.816	2.10E-02	1.704	30.27
I	256000	1.0	2306.31	1.54E+04	2.69E-04	4.136	4.11E+01	1.25E-01	5.132	2.10E-02	0.553	9.82
M1 elec. conduit	842	1.0	7.59	5.06E+01	2.69E-04	0.014	1.35E-01	1.25E-01	0.017	2.10E-02	0.002	0.03
M15 elec. conduit	7630	1.0	68.74	4.58E+02	2.69E-04	0.123	1.22E+00	1.25E-01	0.153	2.10E-02	0.016	0.29

Maximum Estimated Dose Rate = 30.27

Source Term Equation:

SC = ((dpm/100 cm2) x 2)/(100*2.22*STRF) (as total uranium equivalent)

Total Dose Equation (for each line):

TD (mrem/yr) = [SC x IR x EF x DCF(ing) / (D x T)] + [SC x INH x DL x RF x EF x ET x DCF(inh) / (D x T)] + [SC x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency (EF) (days/yr)	10
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction (RF)	3.00E-01
Density (D) (g/cm3)	1.50
Thickness (T) (cm)	0.10

Notes:
a) U-238 dpm/100 cm2 as measured during remedial actions.
b) STRF (Source Term Reduction Factor) is the factor to account for reduction of the source term due to containment and dilution with grout or concrete
c) Source term used for dose calculations including consideration of STRF, and conversion of U-238 equivalent measurement to total uranium equivalent.
d) Units for the external DCF are mrem/yr per pCi/cm2
e) Annual dose rate for each drainline is based on the assumption of 10 days of work at that location during a work year.

GM Hazard Assessment
Supplemental Limit Evaluation
Table C2A-2

General Motors Hazard Assessment
Estimated Doses From Residual Uranium
Non-routine Maintenance Worker Scenario
Manholes and Areas Previously Filled or Remediated by General Motors
Without consideration of containment measures

Location	U-tot Contamination			Ingestion			Inhalation			External		Total
(Manhole or Sump)	pCi/g (a)	STRF (b)	(pCi/g) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (mrem/yr)/(pCi/cm2)	Dose (mrem/yr)	Dose (mrem/yr)
M2	42000	1	42000	1.26E+04	2.69E-04	3.39	3.36E+01	1.25E-01	4.21	2.10E-02	0.45	8.05
M16/Line A	30000	1	30000	9.00E+03	2.69E-04	2.42	2.40E+01	1.25E-01	3.00	2.10E-02	0.32	5.75
M25	172	1	172	5.16E+01	2.69E-04	0.01	1.38E-01	1.25E-01	0.02	2.10E-02	0.00	0.03
Floor Drains	22000	1	22000	6.60E+03	2.69E-04	1.78	1.76E+01	1.25E-01	2.20	2.10E-02	0.24	4.22
Extrusion Pits	NA	NA	104	1.04E+02	2.69E-04	0.03	2.78E-01	1.25E-01	0.03	2.10E-02	0.00	0.07

Maximum Estimated Dose Rate	8.05

Total Dose Equation:

DR (mrem/yr) = [SC x IR x EF x DCF(ing)] + [SC x INH x DL x RF x EF x ET x DCF(inh)] + [SC x (D x T) x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency - manholes and drains (EF) (days/yr)	3
Exposure frequency - extrusion pits (EF) (days/yr)	10
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction	3.00E-01
Density (D) (g/cm3)	1.50
Thickness (T) (cm)	0.10

Notes:
a U-tot pCi/g as measured before grout placed.
b STRF (Source Term Reduction Factor) is the factor used to account for containment (and dilution) of residual contamination by grout or concrete fill.
c Source term (U-tot pCi/g) as measured after grout placement, or calculated using pre-grout measurements and the STRF value.

GM Hazard Assessment
Supplemental Limit Evaluation
Table C2A-3

General Motors Hazard Assessment
Estimated Doses From Contaminated Surfaces (thin layer of contamination)
Non-routine Maintenance Worker Scenario
Sumps
Without consideration of containment measures

Location	U Surface Contamination			Ingestion			Inhalation			External		Annual
(Manhole or Sump)	(dpm/100cm2) (a)	STRF (b)	(pCi/cm2) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (mrem/yr)/(pCi/cm2)	Dose (mrem/yr)	Dose (mrem/yr)
Sump No. 3	55800	1.00	502.70	1.01E+03	2.69E-04	0.270	2.68E+00	1.25E-01	0.336	2.10E-02	0.0362	0.642
Oil Trap Pit	12900	1.00	116.22	2.32E+02	2.69E-04	0.063	6.21E-01	1.25E-01	0.078	2.10E-02	0.0084	0.148

Maximum Estimated Dose Rate	0.642

Source Term Equation:

SC = ((dpm/100 cm2) x 2)/(100 x 2.22 x STRF) (as total uranium equivalent)

Total Dose Equation:

DR (mrem/yr) = [SC x IR x EF x DCF(ing) / (D x T)] + [SC x INH x DL x EF x RF x ET x DCF(inh) / (D x T)] + [SC x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency (EF) (days/yr)	3
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction (RF)	3.00E-01
Density (D) (g/cm3)	1.50E+00
Thickness (T) (cm)	1.00E-01

Notes:
a U-238 dpm/100 cm2 as measured after remedial actions.
b STRF (Source Term Reduction Factor) is the factor used to account for containment (and dilution) of residual contamination by grout or concrete fill.
c Surface Contamination value used in dose calculations including consideration of STRF, and conversion of U-238 equivalent measurement to total uranium equivalent.

General Motors Hazard Assessment
Estimated Doses From Contaminated Surfaces (thin layer of contamination)
Renovation Worker Scenario
Drain Lines
Without consideration of containment methods

Drain Line	U Surface Contamination			Ingestion			Inhalation			External		Drain Line	Line	Prorated Dose
	(dpm/100cm2) (a)	STRF (b)	(pCi/cm2) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (d)	Dose (mrem/yr)	Dose Rate (mrem/yr) (e)	Length (ft)	(mrem/yr) (f)
B	9580	1.0	86.31	2.47E+03	2.69E-04	0.67	6.61E+00	1.25E-01	0.83	2.10E-02	0.09	1.6	120	0.15
C	608000	1.0	5477.48	1.57E+05	2.69E-04	42.24	4.19E+02	1.25E-01	52.41	2.10E-02	5.65	100.3	200	16.37
D	2150	1.0	19.37	5.55E+02	2.69E-04	0.15	1.48E+00	1.25E-01	0.19	2.10E-02	0.02	0.4	185	0.05
E	2480	1.0	22.34	6.40E+02	2.69E-04	0.17	1.71E+00	1.25E-01	0.21	2.10E-02	0.02	0.4	170	0.06
G	1220	1.0	10.99	3.15E+02	2.69E-04	0.08	8.41E-01	1.25E-01	0.11	2.10E-02	0.01	0.2	145	0.02
H	789000	1.0	7108.11	2.04E+05	2.69E-04	54.81	5.44E+02	1.25E-01	68.01	2.10E-02	7.33	130.1	45	4.78
I	256000	1.0	2306.31	6.61E+04	2.69E-04	17.78	1.77E+02	1.25E-01	22.07	2.10E-02	2.38	42.2	60	2.07
M1 elec. conduit	842	1.0	7.59	2.17E+02	2.69E-04	0.06	5.81E-01	1.25E-01	0.07	2.10E-02	0.01	0.1	145	0.02
M15 elec. conduit	7630	1.0	68.74	1.97E+03	2.69E-04	0.53	5.26E+00	1.25E-01	0.66	2.10E-02	0.07	1.3	155	0.16
													1225	

Total Estimated Dose = 23.7

Source Term Equation:

SC = ((dpm/100 cm2) x 2)/(100*2.22*STRF) (as total uranium equivalent)

Total Dose Equation (for each line):

TD (mrem/yr) = [SC x IR x EF x DCF(ing) / (D x T)] + [SC x INH x DL x RF x EF x ET x DCF(inh) / (D x T)] + [SC x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency (EF) (days/yr)	43
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction (RF)	3.00E-01
Density (D) (g/cm3)	1.50
Thickness (T) (cm)	0.10

Notes:
a) U-238 dpm/100 cm2 as measured during remedial actions.
b) STRF (Source Term Reduction Factor) is the factor to account for reduction of the source term due to containment and dilution with grout or concrete
c) Source term used for dose calculations including consideration of source term reduction factor, and conversion of U-238 equivalent measurement to total uranium equivalent.
d) Units for the external DCF are mrem/yr per pCi/cm2
e) Annual dose rate for each drainline is based on the assumption of 43 days of work at that location during a work year.
f) Total dose is the sum of the prorated individual drain line doses. Each drainline annual dose rate is prorated by multiplying by the fraction of the 43 day work period estimated to complete that drainline (drainline length/total line length).

GM Hazard Assessment
Supplemental Limit Evaluation
Table C2B-2

General Motors Hazard Assessment
Estimated Doses From Residual Uranium
Renovation Worker Scenario
Manholes and Areas Previously Filled or Remediated by General Motors
Without consideration of containment measures

Location (Manhole or Sump)	U-tot Contamination			Ingestion			Inhalation			External		Total Dose (mrem/yr)
	pCi/g (a)	STRF (b)	(pCi/g) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (mrem/yr)/(pCi/cm2)	Dose (mrem/yr)	
M2	42000	1	42000	1.26E+04	2.69E-04	3.39	3.36E+01	1.25E-01	4.21	2.10E-02	0.45	8.05
M16/Line A	30000	1	30000	9.00E+03	2.69E-04	2.42	2.40E+01	1.25E-01	3.00	2.10E-02	0.32	5.75
M25	172	1	172	5.16E+01	2.69E-04	0.01	1.38E-01	1.25E-01	0.02	2.10E-02	0.00	0.03
Floor Drains	22000	1	22000	6.60E+03	2.69E-04	1.78	1.76E+01	1.25E-01	2.20	2.10E-02	0.24	4.22
Extrusion Pits	NA	NA	104	1.04E+02	2.69E-04	0.03	2.78E-01	1.25E-01	0.03	2.10E-02	0.00	0.07

Total Estimated Dose Rate = 18.11

Total Dose Equation:

DR (mrem/yr) = [SC x IR x EF x DCF(ing)] + [SC x INH x DL x RF x EF x ET x DCF(inh)] + [SC x (D x T) x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency - manholes and drains (EF) (days/yr)	3
Exposure frequency - extrusion pits (EF) (days/yr)	10
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction	3.00E-01
Density (D) (g/cm3)	1.50
Thickness (T) (cm)	0.10

Notes:
a U-tot pCi/g as measured before grout placed.
b STRF (Source Term Reduction Factor) is the factor used to account for containment (and dilution) of residual contamination by grout or concrete fill.
c Source term (U-tot pCi/g) as measured after grout placement, or calculated using pre-grout measurements and the STRF value.

GM Hazard Assessment
Supplemental Limit Evaluation
Table C2B-3

General Motors Hazard Assessment
Estimated Doses From Contaminated Surfaces (thin layer of contamination)
Renovation Worker Scenario
Sumps
Without consideration of containment measures

Location	U Surface Contamination			Ingestion			Inhalation			External		Total
(Manhole or Sump)	(dpm/100cm2) (a)	STRF (b)	(pCi/cm2) (SC) (c)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	Intake (pCi/yr)	DCF (mrem/pCi)	Dose (mrem/yr)	DCF (mrem/yr)/(pCi/cm2)	Dose (mrem/yr)	Dose (mrem/yr)
Sump No. 3	55800	1.00	502.70	1.01E+03	2.69E-04	0.270	2.68E+00	1.25E-01	0.336	2.10E-02	0.0362	0.642
Oil Trap Pit	12900	1.00	116.22	2.32E+02	2.69E-04	0.063	6.21E-01	1.25E-01	0.078	2.10E-02	0.0084	0.148

Total Estimated Dose Rate = 0.791

Source Term Equation:

SC = ((dpm/100 cm2) x 2)/(100 x 2.22 x STRF) (as total uranium equivalent)

Total Dose Equation:

DR (mrem/yr) = [SC x IR x EF x DCF(ing) / (D x T)] + [SC x INH x DL x EF x RF x ET x DCF(inh) / (D x T)] + [SC x EF x ET x DCF(ext) / 8760]

Exposure Assumptions:

Ingestion rate (IR) (g/day)	0.1
Exposure time (ET) (hr/day)	10
Exposure frequency (EF) (days/yr)	3
Inhalation rate (INH) (m3/hr)	0.89
Dust loading (DL) (g/m3)	1.00E-04
Respirable Fraction (RF)	3.00E-01
Density (D) (g/cm3)	1.50E+00
Thickness (T) (cm)	1.00E-01

Notes:
a U-238 dpm/100 cm2 as measured after remedial actions.
b STRF (Source Term Reduction Factor) is the factor used to account for containment (and dilution) of residual contamination by grout or concrete fill.
c Surface Contamination value used in dose calculations including consideration of STRF, and conversion of U-238 equivalent measurement to total uranium equivalent.