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Focused Risk Assessment
Mound Plant
Miami–Erie Canal, Operable Unit 4

Donald R. Rogers and Donald F. Dunning

September 29, 1994

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Miami-Erie Canal, Operable Unit 4

Donald R. Rogers and Donald F. Dunning*

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Executive Summary

In 1969, an underground waste line at Mound Plant ruptured and released plutonium-238 in a dilute nitric acid solution to the surrounding soils. Most of the acid was neutralized by the native soils. The plutonium, which in a neutral solution is tightly sorbed onto clay particles, remained within the spill area. During remediation, a severe storm eroded some of the contaminated soil. Fine grained plutonium-contaminated clay particles were carried away through the natural drainage courses to the remnants of the Miami-Erie Canal adjacent to Mound Plant, and then into the Great Miami River. Some of the plutonium-contaminated soil settled in the canal and was covered by additional sediment in some areas.

In 1974, Mound Plant personnel performed a comprehensive study to determine the extent, cause, and health and safety impacts of the plutonium-238 released to the Miami-Erie Canal and adjacent waterways. The study showed plutonium activity concentrations above background to a depth of approximately 5 ft in the sediments of the canal. The study, through conservative exposure modeling, concluded that the contaminated sediments did not present a current or future hazard to human health, considering the then-current conditions, future predicted worst-case conditions, and allowable exposure guidelines. This conclusion was supported by independent assessments and subsequent environmental monitoring data.

Since 1974, many radiation protection and internal dosimetry guidelines have been updated. The International Commission on Radiological Protection (ICRP) has developed a new system of internal dosimetry based upon the committed effective dose equivalent and new data on plutonium metabolism and dosimetry. In addition, the U.S. Department of Energy (DOE) has lowered the dose equivalent guideline for members of the general population from 500 to 100 mrem/yr (DOE Order 5400.5) in response to recommendations from the ICRP and other authorities. Based on these changes, the DOE Environmental Restoration Program determined that it would be prudent to reevaluate the Mound Plant exposure assessment contained in the 1974 study in order to incorporate current technologies and guidelines for determining the risk from internally deposited radionuclides. Mound Plant was listed on the National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act in November 1989; consequently, a risk assessment based on the U.S. Environmental Protection Agency's Superfund protocols has been deemed appropriate. This report presents a revised assessment of the potential health risk from the

plutonium-238 contamination in the portion of the Miami-Erie Canal adjacent to Mound Plant.

This focused risk assessment considers exposure pathways relevant to site conditions, including incidental ingestion of contaminated soils, ingestion of drinking water and fish, and inhalation of resuspended soils and sediments. For each potential exposure pathway, a simplified conceptual model and exposure scenarios have been used to develop conservative estimates of potential radiation dose equivalents and health risks. The conservatism of the dose and risk estimates provides a substantive margin of safety in assuring that the public health is protected.

Results of this preliminary risk assessment indicate that current plutonium-238 concentrations at the site present no significant danger to human health. The incremental health risk to the maximally exposed individual from plutonium-238 contamination at the canal is estimated to be 1.0×10^{-6}. The dominant exposure pathway, in terms of contribution to risk, is incidental ingestion of contaminated soil by young children. The committed effective dose equivalent to the maximally exposed individual is estimated to be 0.17 mrem/yr for children and 0.039 mrem/yr for adults. The most important pathways, in terms of contribution to committed dose equivalent, are ingestion of contaminated soil from incidental hand-to-mouth contact (for children only), ingestion of contaminated drinking water, and inhalation of resuspended contamination. As a point of comparison, the average annual dose equivalent from natural background radiation in various regions of the United States is approximately 40 to 300 mrem/yr, with fluctuations of 5 to 30 mrem/yr in any specific location.

The results of this focused risk assessment are based upon many conservative and generic assumptions. In particular, because of current data limitations, plutonium-238 is the only contaminant of concern addressed in this assessment. Additional site characterization is planned to determine whether any other contaminants require consideration at this site.

This focused risk assessment is a program document that was written and released in draft form in 1990 and is now being published with minor editorial changes.

1. Introduction

1.1. Site Background and Setting

Mound Plant is located in Montgomery County on the outskirts of Miamisburg, Ohio, approximately 12 miles (19 km) southwest of Dayton, Ohio (Figure 1.1). Mound Plant was established as a technical organization in 1943 to determine the chemical and metallurgical properties of polonium as part of the Manhattan Engineering District (DOE 1986). This work was performed for the federal government at several locations in the area of Dayton, Ohio. In 1946, 182 acres on the outskirts of the city of Miamisburg, Ohio, were purchased for the permanent Mound Plant site. Work being performed at the Dayton units was moved to this site in 1948. More recently, Mound Plant obtained an additional 120 acres south of the original site.

Mound Plant is now an integrated research, development, and production facility that operates in support of the U.S. Department of Energy (DOE) weapons and energy programs. Mound Plant manufactures nonnuclear components and tritium-containing components for nuclear weapons. In addition, Mound Plant assembles and tests small heat sources for space and terrestrial applications. The production of heat sources uses the radionuclide plutonium-238 because of its short half-life (87.74 yr) and high specific alpha activity.

The major topographic feature in the region is the Great Miami River which flows from north to south approximately 0.5 mile west of the facility. Population patterns tend to be industrial, residential, and commercial along the river, with rural farmland in other areas. The original Mound Plant occupied 182 acres on two adjacent hills overlooking a section of the abandoned Miami-Erie Canal and the Great Miami River.

In 1969, an underground waste line at Mound Plant ruptured, releasing a plutonium-238 waste solution to the surrounding soils. During the ensuing remedial action, a severe rainstorm occurred and some of the plutonium-238-contaminated soil was carried offsite to a section of the abandoned Miami-Erie Canal and then to the Great Miami River (Rogers 1975). In 1974, Mound Plant personnel prepared a comprehensive risk-based study of plutonium-238 contamination in the surface waterways adjacent to the facility. The study included an analysis of the health risk to the general population around Mound Plant. Under the regulatory framework of the time, the study concluded that the risk to local inhabitants was negligible from the plutonium-contaminated soils in the Miami-Erie Canal adjacent to the Mound Plant site (Rogers 1975).

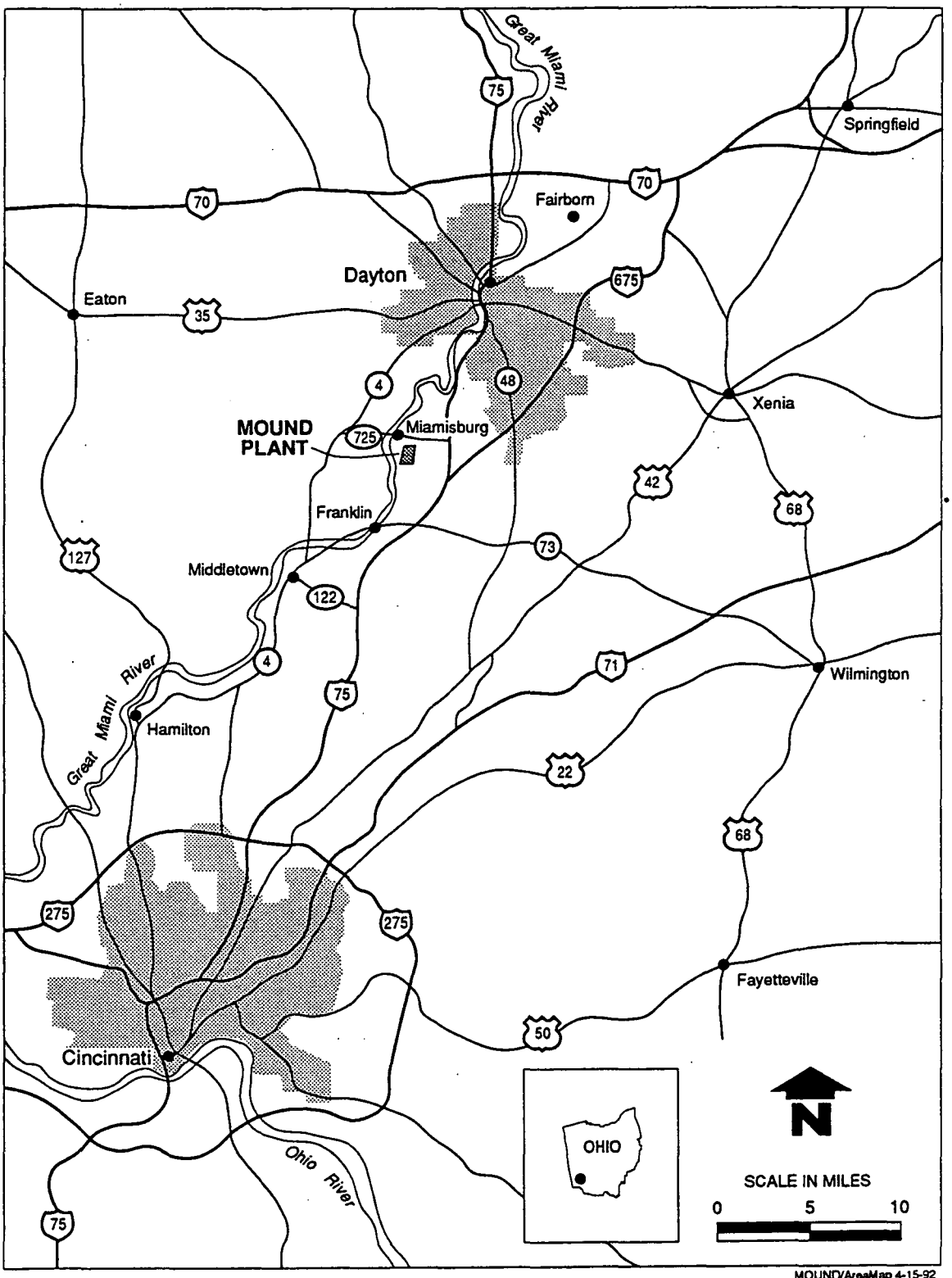

Figure 1.1. Location of Mound Plant.

The Ohio Department of Health, the Ohio Environmental Protection Agency (Ohio EPA), and the U.S. Environmental Protection Agency (EPA) concurred on the following issues regarding the health impact of the Miami-Erie Canal (Cashman and Whitman 1974):

- The elevated plutonium-238 concentrations in the canal segments and ponds of the Miamisburg Municipal Park did not present an imminent or immediate threat to public health.

- It was not necessary to restrict use of the land in the park. Normal activities, swimming, fishing, or accidental ingestion of small amounts of soil would not produce radiation doses in excess of regulatory limits.

- Significant health impacts from inhalation of contaminated sediments may occur if sediments are excavated, stockpiled, and allowed to dry. However, this type of activity may be easily prevented or controlled.

The 1974 assessment focused on three topics regarding the plutonium release to a section of the abandoned Miami-Erie Canal. These were the plutonium distribution in the environment, an investigation of causes and dispersion mechanisms, and a health and safety analysis. The health and safety analysis compared measured concentrations in the environment with applicable 1974 guidelines. Analytical models were also used to estimate future environmental concentrations and human exposures to plutonium-238. Both methods indicated that any human uptake of plutonium-238 would be well below established standards.

Since 1974, new techniques have been developed for determining risk from internally deposited radionuclides. The International Commission on Radiological Protection (ICRP) has completely revised the methodology of estimating internal dose (ICRP 1977, 1979). The concepts of critical organ and maximum permissible body burden have been replaced by the committed effective dose equivalent. Guidelines for acceptable maximum annual radiation dose equivalent to members of the general public have been lowered from 500 to 100 mrem/yr for chronic exposure (ICRP 1977, NCRP 1987). A large amount of research has been conducted, providing better values for environmental and metabolic transfer factors for plutonium. Additional risk assessments have been developed for plutonium contamination in the environment, and formal risk assessment guidance has been developed by the EPA for evaluation of Superfund sites (EPA 1986, 1988a, 1989a, 1989b, 1989c). Mound Plant was listed on the National Priority List (NPL) in November 1989, under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). For these reasons, the DOE has determined that it is prudent to reexamine the health impact analysis for the

Miami-Erie Canal, to incorporate current techniques and guidelines for assessing potential health risks.

1.2. Scope of Risk Assessment

Environmental compliance documentation for Mound Plant is being prepared in accordance with the requirements of CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. Cleanup actions at Mound Plant are subject to CERCLA compliance because the facility is listed on EPA's NPL. In accordance with CERCLA, a remedial investigation/feasibility study (RI/FS) is being undertaken for the facility. Mound Plant has been divided into six operable units to expedite the RI/FS process. These six operable units are described in detail in the Site-Wide RI/FS Work Plan.[1] The Miami-Erie Canal is one of these six operable units.

Performance of a risk assessment is a key element of the RI/FS process. Separate risk assessments will be prepared for each of the six operable units. These individual risk assessments will then be combined into a comprehensive site-wide assessment, which will become part of the RI/FS report. This will be done because it is necessary to evaluate the facility as a whole to account for cumulative effects as they relate to an evaluation of the risks to human health and the environment.

The risk assessment process consists of three separate, but interconnected, activities. These are a baseline risk assessment, refinement of preliminary remediation goals, and a risk evaluation of the remedial action alternatives. The first activity, the baseline risk assessment, is a key component of the RI and is conducted to assess the magnitude and sources of current and potential future risks at a site and to determine whether response action is required. A baseline risk assessment is performed concurrently with site characterization activities and is used to help focus RI activities pertinent to risk assessment. The second activity, refinement of preliminary remediation goals, follows from the results of the baseline risk assessment and consists of developing contaminant- and media-specific cleanup criteria for the site. Finally, risk evaluation plays an important role in the detailed screening of the remedial action alternatives in the FS.

The EPA has developed detailed guidance documents for preparation of risk assessments for CERCLA actions. This guidance is presented in two volumes. The first volume is the Human Health Evaluation Manual (EPA 1989a), and the second volume is the Environmental Evaluation Manual (EPA 1989b).

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[1]*This document was issued in May of 1992 (DOE 1992).*

These volumes describe the various steps necessary to perform a human health and environmental risk assessment.

This focused risk assessment reassesses the potential human health risks associated with plutonium-238 contamination in the Miami-Erie Canal and associated drainage areas and is, therefore, very narrow in scope. This assessment is limited to the plutonium-238 contamination using existing data, primarily from the 1974 study, since adequate data are not yet available on the nonradiological contaminants, current conditions, and additional radionuclides that may be present.

An overview of the baseline risk assessment process is shown in Figure 1.2 and is based on recent EPA guidance (EPA 1989a). The manner in which these four activities are conducted in this focused assessment is as follows:

- ***Data Collection and Evaluation***. The only contaminant evaluated in this assessment is plutonium-238. Historical data were used to quantify the amount of plutonium-238 present in the canal. A sampling effort is planned[2] to determine whether additional hazardous or radioactive constituents, which should also be considered, are present in the canal area. This additional site characterization will also help to determine the adequacy of the 1974 data in describing plutonium-238 concentrations at the site and will provide some indication whether any migration has occurred and whether changes in the chemical form of the plutonium have occurred with aging.

- ***Exposure Assessment***. The exposure assessment was limited to the near-field; onsite exposure pathways are considered as the limiting case. No additional migration in the environment is assumed. Exposure scenarios consider only current land-use patterns.

- ***Toxicity Assessment***. The toxicity assessment was limited to the radiological health hazards posed by plutonium-238.

- ***Risk Characterization***. The risk characterization was limited to be consistent with the scope of the previous three activities.

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[2]*Note added in proof. This special sampling effort was completed in 1992 (DOE 1993). The study concluded that chemical contamination in the canal soils is limited to trace amounts of polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), and lead. Radioactive contaminants include plutonium-238, thorium, and tritium, with trace quantities of natural uranium. A separate sampling effort in the south pond indicated concentrations of organic and inorganic constituents and plutonium-238 were all below regulatory guidelines (Halford 1990).*

A complete baseline risk assessment for the Miami-Erie Canal will be completed following site characterization. This focused assessment should provide insight into the extent of the human health impact at the canal from plutonium-238 contamination, as indicated by current methods and standards, and will be helpful in planning and prioritizing future activities at the Miami-Erie Canal.

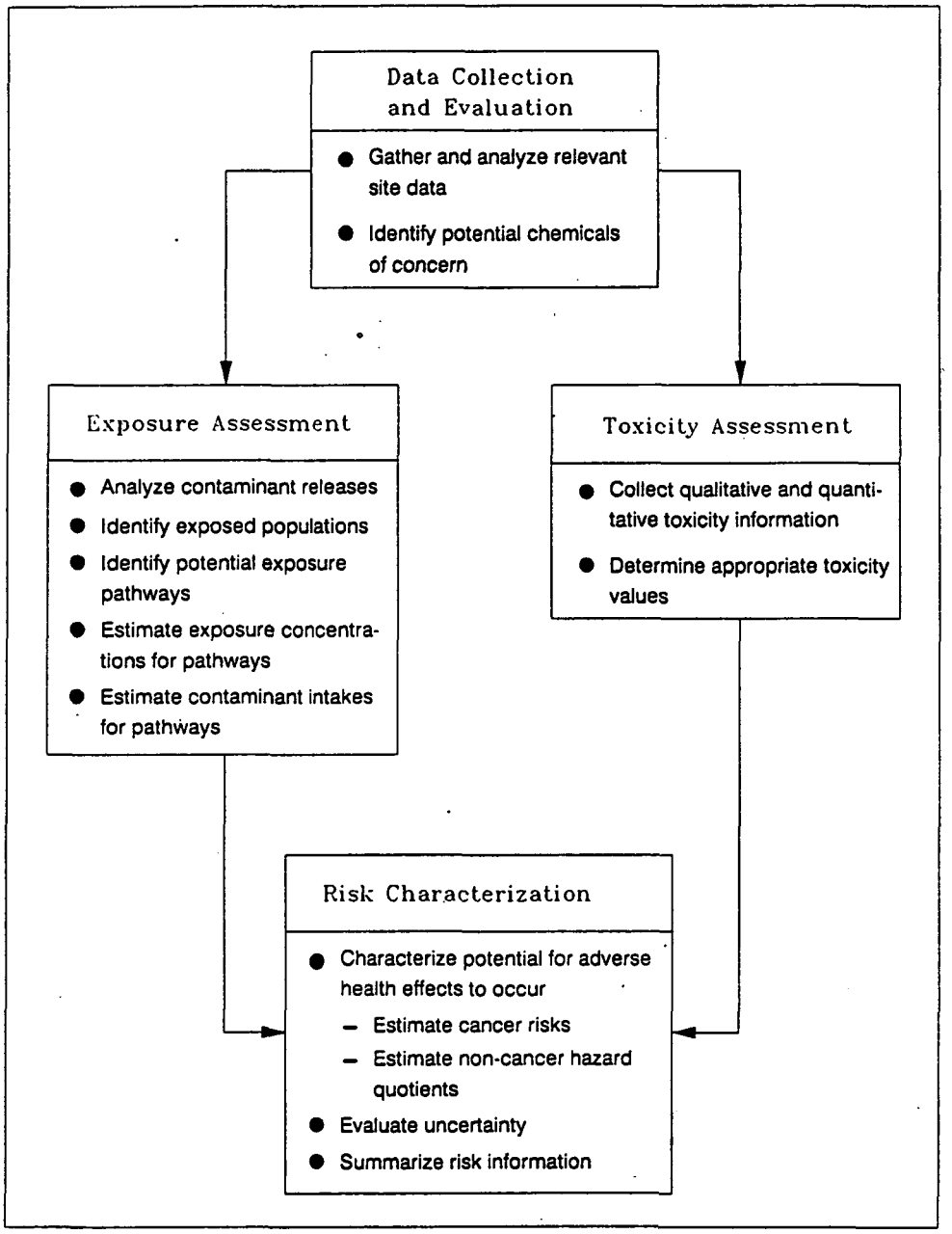

Figure 1.2. Overview of the Baseline Risk Assessment Process.

2. Site Characterization

2.1. Contaminant Release Description

The 1969 waste line rupture occurred between the SM Building and the WD Building at Mound Plant and released a dilute solution of plutonium-238 in nitric acid to the surrounding soil. Figure 2.1 shows the location of the release in relation to the adjacent waterways. The plutonium-238 concentration of the solution was estimated as 4.6 ppm in greater than 1 molar (M) nitric acid (Rogers 1975). Plant workers noticed a liquid discharge at the soil surface, as well as fumes from the chemical reaction of the nitric acid with the native soils, and shut down the waste transfer operation.

Remediation of contaminated soils started immediately after the accident and consisted of excavation and drumming of soil for disposal at an approved disposal facility. During remediation, the contaminated soil was exposed and a severe rainstorm occurred. At the time, it was thought that no plutonium was released from the accident site during the intense storm. However, core sampling performed as part of an upgrade of the environmental monitoring program in 1974 indicated that plutonium had migrated from the rupture site to the remnants of the abandoned Miami-Erie Canal and the Great Miami River.

The 1974 study (Rogers 1975) presented a detailed, postulated release scenario for plutonium-238 from the ruptured pipeline. As the acidic solution contacted the native soils, it was quickly neutralized by the calcium minerals present. The plutonium-238 was then strongly sorbed onto the surface of the clay particles in the soil because of the large cation exchange capability of the natural clays. Clay particles from the soil exposed during excavation were then washed from the rupture site down the natural drainage courses to the Great Miami River.

The drainage from the rupture site followed a concrete flume off the hillside to the natural main drainage basin between the two high areas at Mound Plant and then off the Mound Plant site to a remnant of the Miami-Erie Canal. The sediment-bearing water was diverted into the north and south portions of the canal. The water entering the north canal was again diverted into the north and south ponds at the northern terminus, which drains into the Miamisburg storm sewer system and finally into the Great Miami River. Water entering the south canal flowed down the canal, under the railroad, to a weir connecting with a culvert under the Dayton-Cincinnati road. The culvert then carried the water and sediment to an overflow ditch that drained into the Great Miami River. A smaller amount of water and sediment was transported directly down the hillside to a runoff hollow between

the Mound Plant boundary and the Conrail Railroad berm. Figure 2.1 shows the location of all major portions of the drainage system that were contaminated with plutonium-238 during the 1969 release.

Sediment deposition from the storm runoff water apparently occurred wherever the water velocity decreased and flow became laminar instead of turbulent in nature. Portions of the north and south canals were wide and contained heavy vegetation in the form of cattail reeds. These regions apparently received the greatest deposition of contaminated sediments when water velocities decreased. Minimal concentrations of plutonium-238 were observed in the sediments of the north and south ponds, suggesting that most of the contaminated sediments had been deposited before the water reached these areas. Although some plutonium-238-bearing sediments were carried into the river during the release, the flow in the river greatly diluted their concentration. The amount of plutonium-238 reaching the river was estimated as 1.9 to 3.8 Ci, and the maximum activity concentration observed in the river sediments was 37 pCi/g on the east bank near the canal outfall (Rogers 1975).

Significant land use changes have occurred in the area around the Miami-Erie Canal since 1974. The strip of land between the north canal and the Conrail Railroad berm is now a municipal park owned by the city of Miamisburg (Figure 2.2). The remainder of the land adjacent to the canals and the overflow ditch is owned by the Miami Conservancy District and the Conrail Railroad.

Since 1974, several changes have also been made in the surface water system adjacent to the Mound Plant. A drainage control system, consisting of three interconnected retention basins for sediment settling and an overflow pond, was installed on the drainage ditch from Mound Plant during 1975 to 1979. Water is released from the retention ponds to a section of the abandoned Miami-Erie Canal at a National Pollutant Discharge Elimination System (NPDES)-permitted outfall, number 002. Continuous controlled releases occur from this pond to the drainage ditch and the south canal. Water entering the canal at this outfall must flow south because the north canal segment has been blocked. The water flows through the south canal under the railroad to a weir, connecting a culvert under the Dayton-Cincinnati road. Once under the road, the water flow follows the overflow ditch to an outfall on the Great Miami River (Figure 2.1).

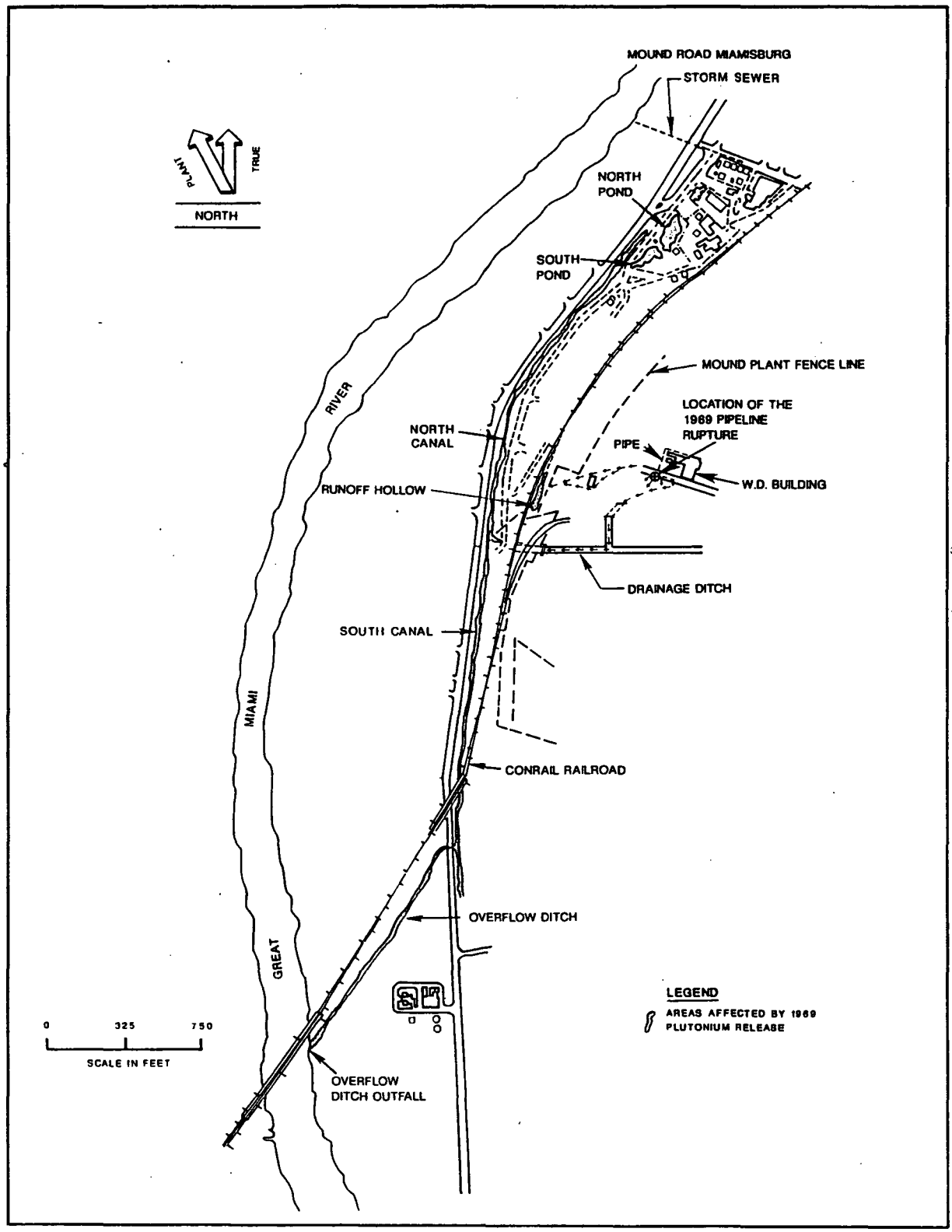

Figure 2.1. Areas affected by the 1969 plutonium-238 release.

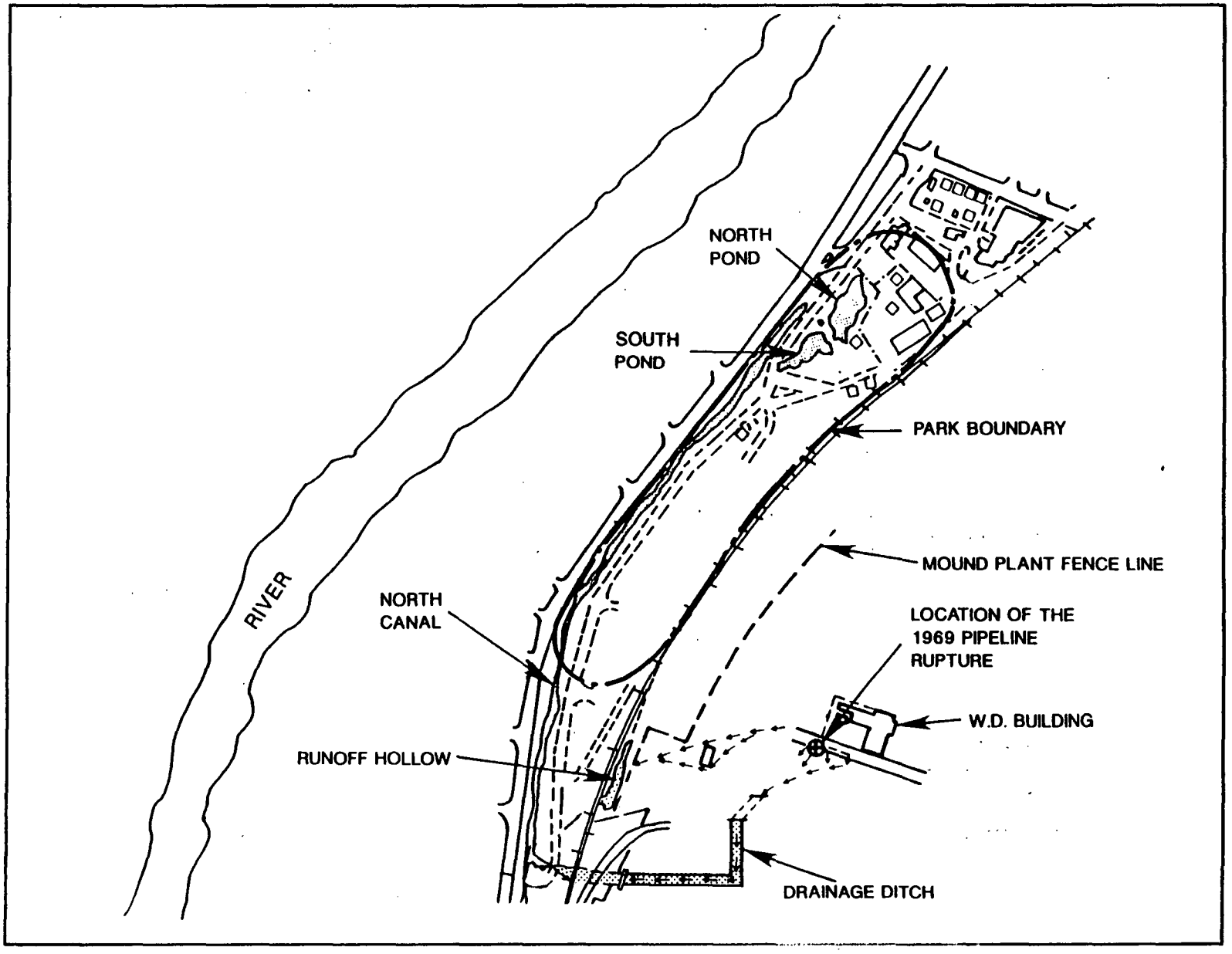

Figure 2.2. Approximate boundaries of Miamisburg Municipal Park.

Both the north and south ponds have been altered by the city of Miamisburg. The north pond was converted into a lined solar heating pond[3] for the municipal park swimming pool, while the south pond was enlarged to create a fishing pond for the same park.

Because of the drainage control system installed by Mound Plant, very little water currently enters the canal system. The north canal is totally dry and heavily vegetated with grass, and the south canal contains a meandering channel with 4 to 8 inches of water. This flow greatly increases after heavy rains. The banks of the south canal are also heavily vegetated. Soil was removed from the north and south ponds in the park development and was used as fill underneath tennis courts and to construct a berm in the park. Mound Plant personnel monitored the construction activities in both ponds and concluded that there was no hazard to workers or the public from the movement of contaminated soil (Farmer and Carfagno 1979).

Because of the current control systems at Mound Plant, flow velocities in the canal system are slow. Therefore, the transport of contaminated sediments from the canal system to the Great Miami River is unlikely. Additional sedimentation in the canal system is also unlikely because the majority of the particles will be retained in the retention basins on the Mound Plant site. Any contaminants released either from the canal system or from Mound Plant would be greatly diluted in the Great Miami River. Average flow rates in the south canal and the Great Miami River were 0.56 and 2100 million gallons per day, respectively, in 1986 (MRC 1987).

2.2. Identification of Contaminants of Concern

While plutonium-238 was the principal radionuclide in the release, it is likely that other radionuclides were present in lesser quantities as isotopic impurities. Table 2.1 presents a summary of isotopic composition and impurities typical of plutonium-238 used at Mound Plant at the time of the release. Although plutonium-238 comprises only 80% of the total isotopic composition, it represents nearly all of the potential health risks because of its greater specific activity. Only plutonium-238 is considered in this focused risk assessment. Detailed characterization of other potential contaminants in the canal area is currently being evaluated. The risks from additional contaminants that may be present will be incorporated as additional data become available to confirm their presence.

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[3]*Note added in proof. This pond is no longer used. The liner was removed in 1991 and the city has begun to fill in the pond.*

Table 2.1. TYPICAL ISOTOPIC COMPOSITION AND IMPURITIES IN MOUND PLANT PLUTONIUM-238

Isotope	Weight[a] (%)	Half-Life[b] (yr)
Plutonium-238	80.0	8.77×10^{1}
Plutonium-239	16.5	2.41×10^{4}
Plutonium-240	2.7	6.54×10^{3}
Plutonium-241	0.7	1.44×10^{1}
Uranium-234	0.19	2.44×10^{5}
Plutonium-242	0.1	3.76×10^{5}
Americium-241	0.05	4.32×10^{2}
Neptunium-237	0.03	2.14×10^{6}
Protactinium-231	<0.1	3.28×10^{4}
Thorium-232	<0.1	1.41×10^{10}
Uranium-232	<0.1	7.20×10^{1}
Uranium-235	<0.1	7.04×10^{8}
Uranium-236	<0.1	2.34×10^{7}
Actinium-227	<0.1	2.18×10^{1}

[a]Reference: Rogers 1975.

[b]Reference: ICRP 1983.

3. Exposure Assessment

The purpose of the exposure assessment is to determine the possible extent of human exposure to the contaminants of concern. This assessment involves the identification of exposed populations, the determination of contaminant concentrations at exposure points, and the estimation of contaminant intake through potential exposure pathways. These estimated contaminant intakes are subsequently used in the health risk evaluation (Section 5).

3.1. Identification of Exposure Pathways

The environmental fate of plutonium-238 is determined by its physical and chemical characteristics. Plutonium-238 concentrations in waterway sediments will decrease by one-half because of radioactive decay every 87.74 yr. Plutonium-238 emits alpha particles in decay and is transformed into uranium-234. The uranium-234 daughter activity will be negligible in comparison to that of plutonium-238 because of the much greater half-life (2.445×10^5 yr) of uranium-234. Assuming that the plutonium-238 was initially free of uranium-234 and that the sediments remain undisturbed, the maximum concentration of uranium-234 would be reached after approximately 1000 years and would be 3.5×10^{-4} of the initial plutonium-238 parent activity.

In the original 1969 waste solution, the plutonium-238 was soluble in the acidic solution as $Pu(NO_3)_4$. When the solution contacted the local soil, it was quickly neutralized and the Pu^{4+} ions and oxy/hydroxy complexes were sorbed onto the clay particles in the soil. Plutonium in the tetravalent state is very strongly retained in the clay soils and will not be displaced by other environmental cations. Very strong acids are required to significantly change the plutonium solubility, and the calcarious soil/sediment is a natural buffer. The strong adsorption potential of the natural soils makes the plutonium extremely insoluble in the offsite waterways.

Plutonium-238 may be heterogeneously redistributed in the environment by a combination of chemical and environmental processes and selective uptake in biological organisms. The plutonium-238-contaminated sediments in the waterways adjacent to Mound Plant may be transported to man through a number of pathways. The primary exposure pathways to man are ingestion of contaminated soil, ingestion of contaminated food and water, and inhalation of airborne contaminated particles. Pertinent exposure pathways are summarized in Figure 3.1.

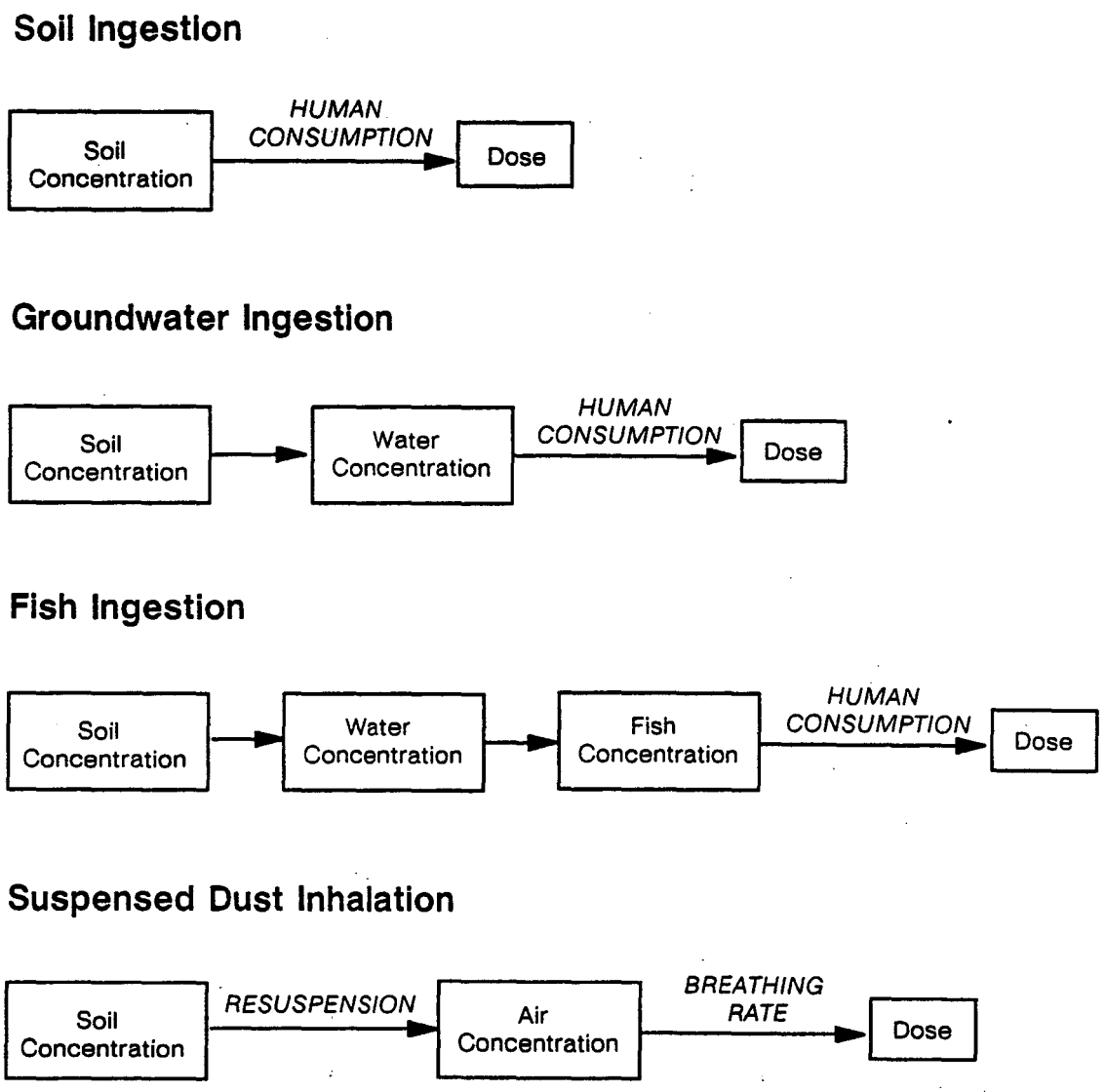

Figure 3.1. Exposure pathways.

Some of the plutonium-238-contaminated sediments in the waterways may have been redistributed and/or washed to the Great Miami River since the sampling and analysis in 1974. If the sediments have been significantly redistributed since 1974, it is probable that dilution would have occurred and that concentrations would be lower than those reported in the 1974 assessment. Therefore, for the purposes of this risk assessment, the distribution of plutonium-238 in the offsite sediments is conservatively estimated from the 1974 data. Also, any plutonium-238 reaching the river would be greatly diluted and should not impact public health. The maximum plutonium-238 activity concentration observed in the river during the Mound Plant environmental monitoring program since 1979 is 1.8×10^{-11} μCi/mL (0.018 pCi/L) (MRC 1980); this value is several orders of magnitude below the DOE-derived concentration guide of 4×10^{-8} μCi/mL (DOE 1990) and the proposed Nuclear Regulatory Commission (NRC) effluent concentration limit of 2×10^{-7} μCi/mL (NRC 1986).[4] The future water dispersion of plutonium-238-contaminated sediments is considered negligible because of the water flow control measures instituted at the Mound Plant.

The most direct pathway for the plutonium-238 to reach humans is by direct contact with contaminated soils and sediments. Direct dermal exposure to contaminated soils and sediments could occur for members of the general population who frequent the canal areas. Primary routes of dermal exposure would be for children playing in contaminated areas and for adults engaged in gardening or construction activities in contaminated areas. However, because of the very low dermal absorption rate of plutonium, this pathway is not considered to present a significant hazard. Direct ingestion of contaminated soils and sediments, however, may be an important exposure pathway. Young children (ages 1-6 yr) are particularly likely to ingest soil inadvertently from hand-to-mouth contact during play.

Plutonium-238 may also be transported to man by incorporation in foodstuffs grown in contaminated areas. The 1974 investigation showed that plutonium-238 concentrations in or on vegetation growing in the immediate area of the contamination were from 0.002 to 3.0 pCi/g (dry weight) (Rogers 1975). The maximum concentration of 3.0 pCi/g was observed on the east bank of the south canal, just south of the overflow ditch. This concentration may have been partially elevated by sediments attached to the plant surfaces. In 1974, plutonium-238 levels in grass from seven locations in the general Mound Plant area ranged from <0.001 to 0.017 pCi/g (dry weight) (MRC 1975). Although the concentrations are above background levels, the local vegetation consists primarily of grass and is unlikely to be consumed by

[4]*Note added in proof. The final NRC rule was issued in 1991 and the effluent concentration limit was revised to 2×10^{-8} (NRC 1991).*

humans. No gardening is currently conducted in the contaminated area, and the physical characteristics of the site make future production of foodstuffs for human consumption in this area very unlikely. The transfer factor for plutonium from soil to vegetables is small and has been estimated to range from 10^{-6} to 10^{-2}, with a recommended value of 4.5×10^{-5} (Baes et al. 1984). Therefore, the ingestion of contaminated fruits and vegetables is not considered to be an important exposure pathway for this site.

Plutonium-238 from the contaminated soils and sediments may be transferred to fish and animals in the environment. Fish may accumulate plutonium directly from the water, from ingestion of algae in the surface streams, and from ingestion of sediments with food. Humans eating contaminated fish may be internally exposed to plutonium-238. This pathway was analyzed because the south pond and overflow ditch are currently used for fishing. In the 1974 sampling program, slight bioaccumulations were observed in algae collected from the water surface and from carp inhabiting the waterways of the Miami-Erie Canal system. Plutonium-238 activity concentrations of 2.39 and 0.00512 pCi/g (dry weight) were observed in algae and carp (edible portion), respectively, from the contaminated area (Rogers 1975).

Animals inhabiting the contaminated areas may ingest contaminated vegetation and small amounts of soil. Some of the ingested plutonium-238 will be retained in the edible portions of the animal and may, in turn, be ingested by humans consuming the meat or milk. However, no livestock animals are currently raised in the contaminated areas, and there is no known human consumption of smaller mammals inhabiting the Miami-Erie Canal area. Given these conditions and the very low transfer coefficients for plutonium (Baes et al. 1984), the ingestion of contaminated meat or milk is not considered to be an important exposure pathway.

Plutonium sorbed on the canal sediments may be dissolved by the surface water in the canal waterways. The contaminated water could then be ingested by man. This pathway is limited by the low water flow in the canals and by the low solubility of the plutonium in water. As current water flow in the canals would not support a reasonable drinking water source, and the plutonium sorbed on sediments is very insoluble, this pathway is expected to represent an insignificant hazard to man. Any contaminated water entering the Great Miami River is greatly diluted and does not present a hazard downstream. No drinking water intakes from the river currently exist in the vicinity downstream from Mound Plant. Mound Plant measures plutonium-238 activity concentrations in the Great Miami River as part of the environmental monitoring program, and all measured concentrations are well below DOE concentration guidelines (DOE 1988a). Similarly, incidental

water ingestion and dermal absorption while swimming in the river are not considered to be significant exposure pathways.

Infiltration of precipitation through the sediments in the canal may transport plutonium-238 into the underlying Buried Valley aquifer and to downgradient drinking water wells. This pathway is considered unlikely to yield significant exposures because of the extremely low solubility and the slow migration rate of the plutonium-238 in the contaminated soils. The 1974 assessment measured the distribution factor between soil and water as 1×10^{-5} pCi/mL per pCi/g (Rogers 1975). Water infiltration through the native clay soil is also small, ranging from 0.1 to 1.0 m/yr. From these data, the migration rate for plutonium-238 was estimated as 1×10^{-6} to 1×10^{-5} m/yr (Rogers 1975). Monitoring of wells downgradient from the canal shows that plutonium-238 concentrations have been well below established guidelines since 1976, and have been largely indistinguishable from environmental levels since 1983. Additional Mound monitoring wells adjacent to the canal area have not been sampled for plutonium.

Contaminated soils and sediments may be resuspended in the atmosphere by both natural wind action and any construction activities or other soil disturbance in the contaminated area. Once in the atmosphere, particles contaminated with plutonium-238 may be inhaled by humans. Resuspension of the sediments in the canal is expected to be small because of the current conditions in the canal system. Both canals are heavily vegetated, and the soils remain moist for most of the year. Much of the canal and ditch area is also located in surface depressions lined with tall vegetation, which should reduce wind speeds in contaminated areas. These factors combine to limit the possible resuspension of sediments by natural wind erosion. Vigorous activities in the contaminated area, such as periodic brush clearing operations in the canal, excavation and construction, and maintenance of sewers and utilities, might increase the amount of resuspended contaminated sediment, but these effects tend to be transitory. Over the last 15 years, Mound has conducted special air monitoring during excavation and mowing operations. These data have demonstrated the safety of city workers and the public at large during even these types of activities. The effect of these operations is insignificant on the annual average air concentrations measured by the permanent air monitoring stations in these same areas.

3.2. Estimation of Exposure Point Concentrations

In 1974, an extensive sampling effort was undertaken to determine the amount of plutonium-238 released, the areal and vertical extent of plutonium in the waterway sediments, and the plutonium potentially available for human exposure (Rogers 1975). The characterization measured plutonium-238 concentrations in soil, air, water, fish, and vegetation in, and

adjacent to, the waterways. Approximately 1750 measurements were made to assess the distribution of plutonium-238 in the offsite areas (Robinson et al. 1974).

Sediment samples were obtained in the drainage ditch off the site, the north canal, the south canal, the south pond, the north pond, the overflow ditch, and the runoff hollow. Measurements were made of both the "very surface"[5] concentration and the contamination with depth. The 1974 study described "very surface" measurements as the portion of the sediments that became suspended in water by *in situ* vigorous agitation of the water near the sediment interface. These particles were usually less than 50 μm in size, and it was postulated that these very surface concentrations approximated the air-suspendible plutonium-238, should the sediments ever become dry and exposed (Rogers 1975). Numerous boreholes were sampled to a depth of 5 ft or more throughout all major sedimentation areas and in the Great Miami River. The maximum plutonium-238 activity concentrations observed in the "very surface" soils for all areas are presented in Table 3.1, for areas in the waterways, areas occasionally flooded, and for areas adjacent to the waterways not subject to flooding. The data in Table 3.1 show that the maximum "very surface" activity concentration observed was 450 pCi/g in the drainage ditch off the site. Maximum activity concentrations observed in each 1-ft layer, from 0 to 5 ft in depth, are presented in Table 3.2.

In the current assessment, average and ninety-fifth percentile concentrations and sample standard deviations were calculated as a function of depth for each sedimentation area from the data of the 1974 investigation; these results are presented in Tables 3.3 and 3.4. These concentrations are conservative estimates because of the assumptions made in the calculations. Appendix A presents the calculation of the average and ninety-fifth percentile activity concentrations. An activity concentration of 4560 pCi/g was observed in the north canal at a depth of 2 to 3 ft and was the maximum activity concentration observed anywhere in the areas studied. The average activity concentrations in the top 1 ft in the south and north canals were 832 and 418 pCi/g, respectively; ninety-fifth percentile concentrations for these waterways were 1798 and 985 pCi/g, respectively.

Area-weighted average and ninety-fifth percentile concentrations for the contaminated area were estimated as approximately 530 pCi/g and 1200 pCi/g, respectively. These values are based on approximate areas for each of the contaminated waterway segments as follows: 116,000 ft^2 for the north canal, 112,000 ft^2 for the south canal, 40,000 ft^2 for the overflow ditch,

[5] *"Very surface" refers to the top 0.1 mm of soil or sediment.*

Table 3.1. MAXIMUM VERY SURFACE PLUTONIUM-238 CONCENTRATIONS IN THE MIAMI-ERIE CANAL WATERWAYS (pCi/g)

Area	Area in the Waterway	Area Occasionally Flooded	Area Not Flooded
South Canal	395	60.9	0.75
North Canal	267	54.0	NM
Drainage Ditch	450	NM	NM
Overflow Ditch	270	11.6	NM
Runoff Hollow	NA	28.6	NM
South Pond	208	1.7	0.23
North Pond	22.3	1.7	0.23

Reference: Rogers 1975.

NM - Indicates that measurements were not performed

NA - Not Applicable

5000 ft^2 for the drainage ditch, and 5000 ft^2 for the runoff hollow. The two ponds are not included in these estimates since the contaminated sediments are routinely covered by water.

Measurements of plutonium-238 concentrations in the vegetation adjacent to the canal were performed in areas subject to frequent flooding, as well as in areas not subject to frequent flooding. The activity concentrations in grass for areas not subject to flooding averaged 0.018 pCi/g, while the activity concentration in grass for areas subject to flooding averaged 0.87 pCi/g (Rogers 1975). In 1974, plutonium-238 levels in grass from seven background locations in the general Mound Plant area averaged 0.007 pCi/g (MRC 1975). Surface contamination of the grass was hypothesized as part of the cause of the elevated activity concentrations.

Plutonium activity concentrations in fish and surface water were also measured in the 1974 study. Maximum activity concentrations in fish (edible portion) from the canal area were 0.00079 and 0.0051 pCi/g for bluegill and

carp, respectively, while the maximum surface water concentration was 14 pCi/L, measured in the south canal (Rogers 1975). Plutonium-238 activity concentrations in air, measured during 1974 in the municipal park, ranged from 5.6×10^{-16} to 7.2×10^{-15} μCi/mL (Robinson et al. 1974) and were well below the derived concentration guides (DCG) for the general population (4×10^{-14} μCi/mL [DOE 1990]).

Table 3.2. MAXIMUM PLUTONIUM-238 CONCENTRATIONS IN ONE-FOOT BOREHOLE SOIL SAMPLES FROM THE MIAMI-ERIE CANAL WATERWAYS (pCi/g)

Area	Depth (ft)				
	0-1	1-2	2-3	3-4	4-5
South Canal					
East Bank	1280	895	39.7	25.1	12.5
Canal	3800	3370	576	230	28.4
West Bank	622	636	37.5	20.2	20.1
North Canal					
East Bank	53.0	2.6	2.6	2.4	1.8
Canal	1140	3330	4560	3580	3070
West Bank	54.2	7.6	11.1	2.4	12.2
Drainage Ditch					
South Bank	749	238	152	38.5	22.2
Ditch	157	287	45.1	1.6	18.4
North Bank	596	221	7.5	42.1	49.7
Overflow Ditch					
East Bank	18.8	0.7	0.6	0.8	2.4
Ditch	74.4	71.1	2.4	5.4	3.2
West Bank	2.1	<0.0001	<0.0001	0.1	0.2
Runoff Hollow	31.4	5.8	0.7	0.2	0.2
South Pond	30.9	1.2	0.6	0.1	5.1
North Pond	6.2	0.1	0.2	1.3	0.6

Reference: Rogers 1975.

Table 3.3. AVERAGE AND SAMPLE STANDARD DEVIATION FOR PLUTONIUM-238 CONCENTRATIONS IN ONE-FOOT BOREHOLE SOIL SAMPLES FROM THE MIAMI-ERIE CANAL WATERWAYS (pCi/g)

Area	Depth (ft) 0-1	1-2	2-3	3-4	4-5
South Canal					
East Bank	392 ± 381	378 ± 420	12.4 ± 13.8	9.5 ± 5.3	4.4 ± 4.0
Canal	832 ± 542	555 ± 562	45.6 ± 68.6	12.2 ± 21.9	4.9 ± 5.0
West Bank	252 ± 228	117 ± 230	15.0 ± 12.8	9.4 ± 8.4	5.2 ± 6.7
North Canal					
East Bank	19.4 ± 23.0	1.4 ± 1.1	1.1 ± 1.3	1.1 ± 1.2	0.7 ± 0.7
Canal	418 ± 326	396 ± 370	208 ± 361	70.3 ± 191	50.0 ± 141
West Bank	19.2 ± 22.7	3.6 ± 3.2	3.3 ± 4.8	0.8 ± 1.0	2.7 ± 4.4
Drainage Ditch					
South Bank	332 ± 210	81.5 ± 100	28.5 ± 47.1	8.9 ± 12.1	8.4 ± 11.0
Ditch	84.0 ± 59.2	92.0 ± 77.4	8.6 ± 12.3	0.8 ± 0.4	4.8 ± 6.4
North Bank	149 ± 223	55.3 ± 94.6	2.0 ± 2.6	10.4 ± 17.2	13.6 ± 21.1
Overflow Ditch					
East Bank	14.6± 5.7	0.4 ± 0.1	0.4 ± 0.2	0.3 ± 0.3	0.8 ± 1.0
Ditch	31.8 ± 37.1	24.5 ± 40.3	0.8 ± 0.2	0.9 ± 0.8	0.5 ± 0.4
West Bank	1.8 ± 0.2	<0.1 (NA)	<0.1 (NA)	0.1 (NA)	0.1 (NA)
Runoff Hollow	14.7± 9.6	2.5 ± 2.4	0.4 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
South Pond	16.3 ± 12.7	0.7 ± 0.4	0.3 ± 0.2	0.1 ± 0	1.3 ± 2.1
North Pond	2.7 ± 2.3	0.1 (NA)	0.2 (NA)	0.6 ± 0.6	0.6 (NA)

(NA) - Sample standard deviation is not applicable because only one measurement was made ≥0.1 pCi/g, or the average concentration was <0.1 pCi/g.

Table 3.4. NINETY-FIFTH PERCENTILE VALUES OF THE PLUTONIUM-238 DISTRIBUTIONS IN ONE-FOOT BOREHOLE SOIL SAMPLES FROM THE MIAMI-ERIE CANAL WATERWAYS (pCi/g)[a]

Area	Depth (ft) 0-1 (N)	1-2 (N)	2-3 (N)	3-4 (N)	4-5 (N)
South Canal					
East Bank	1,132 (7)	1,224 (6)	39.2 (7)	19.8 (7)	12.2 (7)
Canal	1,798 (13)	1,564 (12)	168 (13)	23.7 (13)	13.8 (13)
West Bank	684 (8)	564 (7)	39.3 (8)	25.3 (8)	17.9 (8)
North Canal					
East Bank	73.5 (4)	4.6 (3)	4.9 (3)	4.6 (3)	2.7 (3)
Canal	985 (18)	1,040 (18)	834 (19)	404 (17)	294 (19)
West Bank	67.6 (5)	11.1 (4)	17.3 (3)	3.2 (4)	13.1 (4)
Drainage Ditch					
South Bank	945 (3)	373 (3)	166 (3)	44.2 (3)	40.5 (3)
Ditch	257 (3)	318 (3)	44.5 (3)	2.0 (3)	45.2 (2)
North Bank	800 (3)	331 (3)	9.6 (3)	60.6 (3)	75.2 (3)
Overflow Ditch					
East Bank	50.6 (2)	1.0 (2)	1.7 (2)	2.2 (2)	7.1 (2)
Ditch	140 (3)	142 (3)	2.1 (2)	6.0 (2)	3.0 (2)
West Bank	3.1 (2)	NA (1)	NA (1)	NA (1)	NA (1)
Runoff Hollow	34.0 (6)	7.3 (6)	0.9 (4)	0.3 (5)	0.3 (4)
South Pond	41.9 (6)	1.5 (6)	0.8 (4)	0.1 (2)	5.8 (5)
North Pond	7.3 (6)	NA (1)	NA (1)	2.4 (3)	NA (1)

[a] Ninety-fifth percentile calculated according to

$$x_{0.95} = \bar{x} + s\,(t_{N-1,\,1-\alpha/2}) \quad \text{(Gilbert 1987)}$$

(N) - Number of measurements ≥0.1 contributing to the associated ninety-fifth percentile. Where N<3, the calculated value is highly uncertain.

NA - Not applicable because only one measurement was made ≥0.1 pCi/g, or the average concentration was <0.1 pCi/g.

The Mound Plant environmental monitoring program continues to measure plutonium-238 concentrations in air, water, and vegetation to ensure that environmental levels are well below applicable standards and guidelines. The results of these measurements are reported in annual environmental monitoring reports.

As part of the Mound Plant comprehensive environmental monitoring program, plutonium-238 activity concentrations in air are measured continuously at six locations (stations 104, 122, 123, 211, 214, and 215) that may be influenced by the contaminated sediments of the offsite waterways.

The activity concentrations measured from 1974 to 1988 are summarized in Table 3.5, and the locations are illustrated in Figure 3.2. Locations 211, 214, and 215 are on the Mound Plant site and may be influenced by plutonium-238 releases from sources other than the waterway sediments. Location 119 is 28 miles away, in the least prevalent wind direction, and may be considered a background location. Station 105 is located across the river on a hill and probably would not be affected by resuspension from the canal. The average plutonium-238 concentration measured at the six monitoring stations most likely to be affected by resuspension from the canal area (104, 122, 123, 211, 214, and 215) over the period 1974 to 1988 is 5×10^{-17} μCi/mL, and the ninety-fifth percentile concentration is 16×10^{-17} μCi/mL. The activity concentrations of plutonium-238 in air, presented in Table 3.5, are all well below the DOE-derived concentration guide of 4×10^{-14} μCi/mL (DOE 1990) and the proposed NRC effluent concentration limit of 2×10^{-14} μCi/mL (NRC 1986).[6]

The environmental monitoring program also measures plutonium-238 activity concentrations in four private wells downgradient from the contaminated waterways. These well locations are shown in Figure 3.3, and data from 1976 to 1988 are presented in Table 3.6. Again, the measured concentrations are well below the DOE standard of 4×10^{-8} μCi/mL for waterborne releases to the environment (DOE 1990) and the proposed NRC reference level concentration of 2×10^{-7} μCi/mL (NRC 1986).[6] The average plutonium-238 concentration observed in these four offsite drinking water wells over the period 1976-1988 is approximately 7×10^{-12} μCi/mL (0.007 pCi/L), with a ninety-fifth percentile concentration of approximately 2×10^{-11} μCi/mL (0.02 pCi/L).

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[6]*Note added in proof. The effluent concentration limits in the final NRC rule (NRC 1990) are 2×10^{-14} μCi/mL for air and 2×10^{-8} μCi/mL for water.*

Table 3.5. SUMMARY OF AIR MONITORING ADJACENT TO THE MIAMI-ERIE CANAL FROM 1974 TO 1988

Year	Average Plutonium-238 Concentration (10^{-17} μCi/mL)[a] Monitoring Location							
	104	105	122	123	211	214	215	119
1974	1.3	1.2	NM	NM	81	17	8.2	0.19
1975	1.4	0.94	1.7	NM	21	6.7	3.8	<0.14
1976	<.79	<.21	3.8	16	8.7	9.1	3.3	<0.05
1977	0.37	<.15	2.1	2.9	5.1	3.1	1.3	<0.10
1978	0.27	0.15	0.94	3.0	2.7	3.3	1.3	0.16
1979	0.40	0.14	0.42	3.6	2.2	1.4	3.8	0.69
1980	0.25	0.09	0.28	1.4	3.8	0.69	0.57	0.02
1981	0.26	0.10	0.17	1.66	36.4	2.08	0.61	0.01
1982	0.17	0.09	0.28	1.74	8.83	2.42	0.55	0.03
1983	0.43	0.07	0.20	1.24	2.96	1.34	0.29	0.02
1984	0.23	0.08	0.21	1.5	4.19	2.32	0.50	0.0002
1985	0.19	0.26	0.86	4.03	18.2	12.6	1.66	0.015
1986	0.61	0.72	1.01	2.68	12.5	9.36	2.25	0.016
1987	0.24	0.08	0.53	1.07	7.9	4.35	0.84	0.007
1988	0.24	0.03	0.75	0.80	8.0	5.8	0.6	0.02

NM - Indicates that no measurements were performed.

[a] The DOE-derived concentration guide for plutonium-238 in air in unrestricted areas is 3,000 x 10^{-17} μCi/mL (DOE 1990). The NRC reference level concentration for plutonium-238 in air in unrestricted areas is 2,000 x 10^{-17} μCi/mL (NRC 1986).

Reference: MRC 1975-1989.

Table 3.6. SUMMARY OF GROUNDWATER MONITORING OF THE PRIVATE WELLS DOWNGRADIENT FROM THE MIAMI-ERIE CANAL FROM 1976 TO 1988

Average Plutonium-238 Concentration (10^{-10} μCi/mL)[a,b]

Year	Environmental Level (EL)[c]	Private Well B1	Private Well B2	Private Well B3	Private Well J1
1976	0.007[d]	0.038	0.033	0.022	0.036
1977	0.007[d]	<0.1	<0.1	1.5	<0.5
1978	0.007[d]	<0.12	<0.1	<0.1	<0.1
1979	0.013[d]	0.017	0.020	0.024	0.055
1980	0.004[e]	0.006	0.024	0.006	0.004
1981	Not detected	0.0039	0.25	0.079	0.0013
1982	0.008[e]	0.027	NM	0.016	EL
1983	0.025[e]	EL	NM	EL	EL
1984	0.006[e]	EL	0.007	EL	EL
1985	0.011[e]	EL	0.029	EL	EL
1986	0.031[f]	EL	EL	EL	EL
1987	0.0024[f]	0.001	EL	EL	EL
1988	0.001[f]	0.01	0.007	0.009	0.069

EL - Indicates that the concentrations were no greater than the environmental (background) levels in well water.

NM - Indicates that no measurements were performed.

μCi/mL may be converted to pCi/L by multiplying by 10^9.

[a] The DOE-derived concentration guide for plutonium-238 in water for unrestricted areas is 400 x 10^{-10} μCi/mL (DOE 1990). The NRC reference level concentration for plutonium-238 in water for unrestricted areas is 2000 x 10^{-10} μCi/mL (NRC 1986). (Note: The final NRC rule was issued in 1991 and the effluent concentration limit was revised to 2 x 10^{-8} [NRC 1991].)

[b] Environmental levels, if available, are not subtracted.

[c] Unless noted, environmental levels are for well water.

[d] Concentration given is for background levels in surface water; well water background levels not available.

[e] Measured 30 miles west of Mound Plant.

[f] Measured 36 miles southeast of Mound Plant.

Reference: MRC 1977-1989.

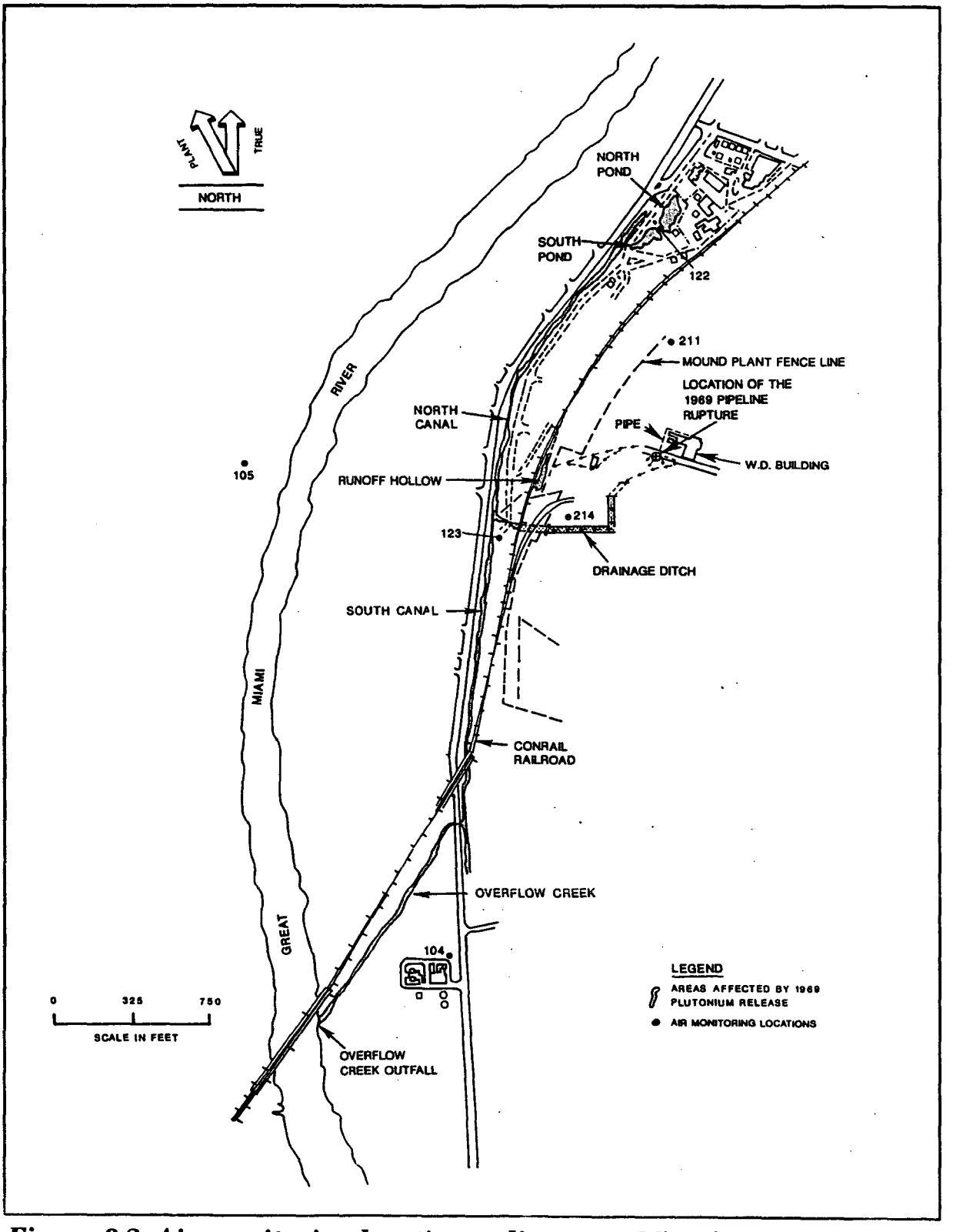

Figure 3.2. Air monitoring locations adjacent to Miami-Erie Canal.

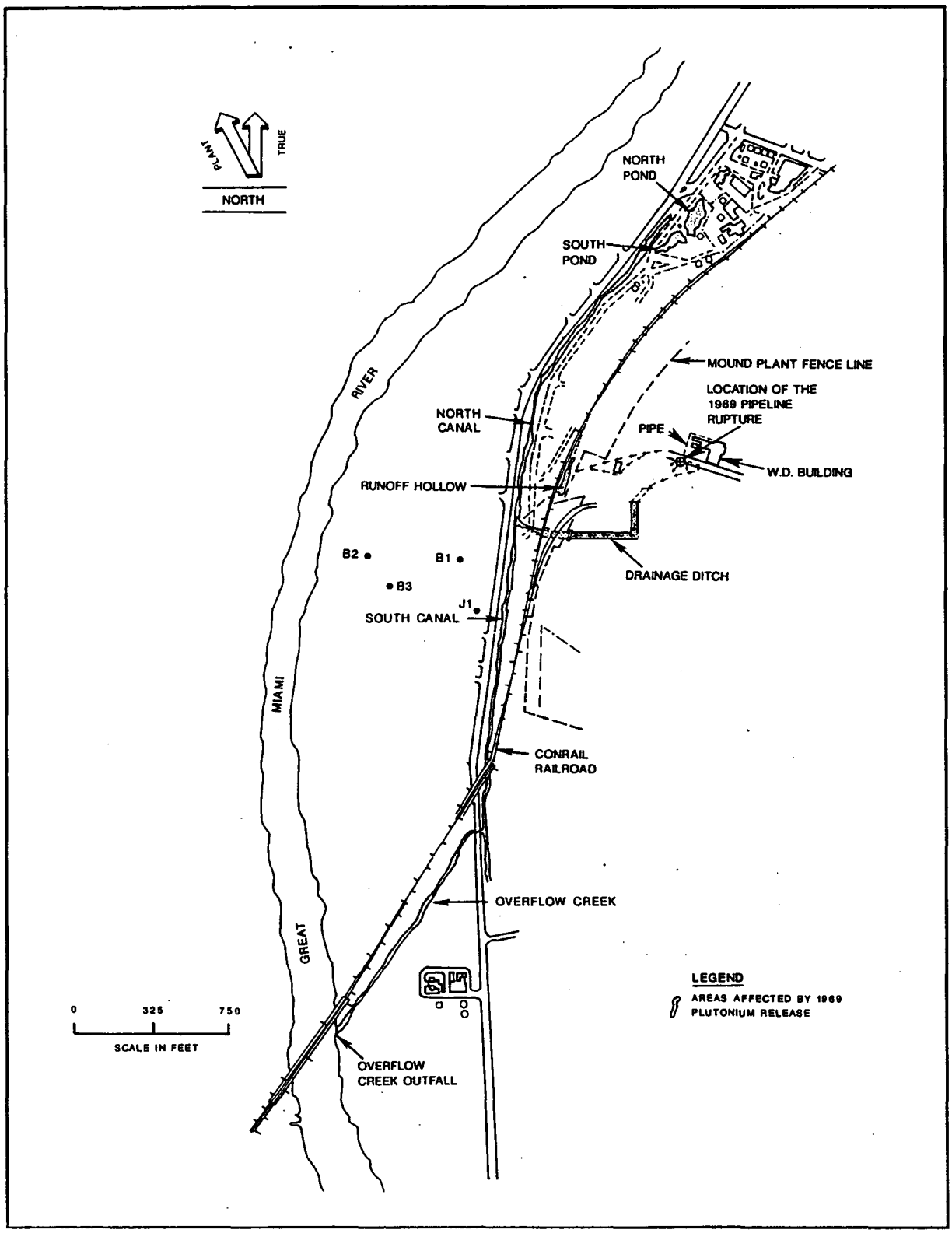

Figure 3.3. Private well locations downgradient from the Miami-Erie Canal.

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3.3. Identification of Exposed Populations and Exposure Scenarios

3.3.1. Exposed Populations

The contaminated area is outside the Mound Plant boundary and is readily accessible by the public. The municipal park adjacent to the north canal was expanded in 1977. Park facilities include tennis courts, a fishing pond, and other recreational facilities. The land adjacent to the canal and the overflow creek is owned by the city, the Miami Conservancy District, and Conrail Railroad and is not restricted from public access or use.

This risk assessment focuses on exposure scenarios typical of recreational land use for current site conditions only. Future land use patterns are likely to continue along current trends, with possible expansion of public park facilities in the area.

Because the land is used only for recreational purposes, park visitors (adults and children), park maintenance personnel, and to a lesser extent Mound Plant employees and nearby residents are assumed to be the only populations who, under current conditions, may be potentially exposed to contaminants at, or emanating from, the abandoned Miami-Erie Canal area adjacent to Mound Plant. The contamination is essentially confined to the actual beds of the drainage ditch, north canal, south canal, overflow creek, south pond, and runoff hollow. There is no drinking water in the area that comes from the canal or other surface waterways.

The residences nearest to the Miami-Erie Canal site are located approximately 0.1 mile west from the site. The nearest downgradient residential groundwater wells are also located 0.1 mile west from the site (Figure 3.3; wells B1, B2, B3, and J1). Any plutonium-238 leaching from contaminated soils into groundwater would be subject to dilution in the Buried Valley Aquifer. The ninety-fifth percentile plutonium-238 concentration measured in these wells downgradient from the canal site during 1976-1988 was approximately 0.02 pCi/L, and most measurements during 1983-1988 showed no elevation above ambient environmental concentrations. Similarly, because of the large dilution of any contaminated influent in the Great Miami River and the absence of downstream drinking water intakes, no significant exposures are expected to populations outside the immediate canal area from the surface water pathway. The river is also monitored as part of the environmental program and, as discussed in Section 3.2, shows negligible concentrations of plutonium-238.

3.3.2. Exposure Scenario

The exposure scenario for this focused risk assessment considers only those exposure pathways associated with recreational use of the Miamisburg Municipal Park and surrounding areas and assumes plutonium-238 concentrations in environmental media based on analysis of the 1974 survey data (see Section 3.2 and Appendix A for a review of these data) and Mound Plant environmental monitoring data. Only plutonium-238 is considered as a contaminant of concern; the presence of additional radionuclides and chemical contaminants is currently under investigation. This risk assessment may be revised in the future to incorporate additional contaminants of concern, if appropriate. Potential exposures to children and adults are considered.

Exposure point concentrations and estimated plutonium-238 intakes are based on the ninety-fifth percentile concentration in the near surface (0- to 1-ft) soils for the contaminated areas. As shown in Table 3.4 the ninety-fifth percentile plutonium-238 concentration in the 0- to 1-ft soils in the south canal was 1798 pCi/g, with much lower concentrations on the banks of the canal. The ninety-fifth percentile concentration observed in the top foot of soil in the main channel of the north canal was 985 pCi/g, and all other waterways had significantly lower concentrations. An area-weighted average of the ninety-fifth percentile concentrations in the various segments of the contaminated waterways is taken as a conservative estimate of the plutonium-238 concentration in soils potentially available for uptake. This value is considered to be highly conservative because the concentrations received in the bed of each canal are taken to represent the entire canal area.

The exposure pathways considered include incidental ingestion of soil, ingestion of drinking water, ingestion of fish caught from the fishing pond in the park, and inhalation of resuspended soils. Estimates of potential intake through each of these pathways are discussed in Section 3.4.

3.4. Estimation of Contaminant Intakes

Exposure pathways for which intakes are evaluated in this analysis are depicted in Figure 3.1. They are:

- ingestion of
  - contaminated soil,
  - contaminated drinking water,
  - fish from contaminated waterways; and
- inhalation of resuspended soils/sediments.

Plutonium intakes are evaluated for adults and children. Children are considered to be a potentially sensitive subpopulation because they may be more vulnerable than adults to the toxic effects of radionuclides. This

vulnerability is attributable to differences in their ability to absorb, metabolize, and excrete these substances and in behavioral patterns that may result in increased exposure. Children may also exhibit increased radiosensitivity and have a longer remaining lifetime for manifestation of radiogenic cancers. The primary exposure route of potentially greater concern in children than in adults is soil ingestion. Children may consume greater quantities of outdoor soil than adults because of their tendency to place their fingers and other objects that have come into contact with soil into their mouths. Contaminant intakes for children were based on exposure factors estimated for a child aged 1 through 6 years. This age group is most likely to exhibit pica (ingestion of nonfood materials) and, therefore, is the most likely to be subject to exposure by direct soil ingestion.

Additional exposure pathways that have been evaluated and determined to be negligible contributors to total dose and risk in this assessment include direct external radiation from radioactivity on ground surfaces or resuspended in the atmosphere, dermal absorption from contact with contaminated soil or water, ingestion of contaminated meat and milk, non-ingestion water usage (for example, showering), and transfer of contaminated soils to the home for subsequent resuspension and inhalation. External radiation is not a significant hazard because of the low energy and intensity (13.6 keV x 11.6%) of the x-rays emitted by plutonium-238.

Because of the low transfer coefficients for plutonium (and because there are no livestock in the contaminated areas), ingestion of meat or milk from animals grazing in contaminated areas is not an important exposure pathway. The transfer of contaminated soils deposited on clothing, and then to the home for subsequent inhalation, is not explicitly considered; but because the land use is assumed to be recreational rather than residential, the dose from this pathway is expected to be significantly less than the dose from the analyzed inhalation pathway. Dermal absorption, either from direct contact with contaminated soil or with contaminated water while swimming or bathing, is not considered to be an important exposure pathway because plutonium has a very low dermal absorption rate. Also, because of its low volatility, volatilization of plutonium-238 from contaminated water for non-ingestion uses (for example, showering or laundry) is not considered to be a significant exposure pathway.

In the event that additional radionuclides or chemical contaminants are identified at this site in significantly elevated concentrations, or that changes in the chemical form of the plutonium-238 have occurred to enhance mobilization, these assumptions will require reevaluation for use in the baseline risk assessment.

3.4.1. Ingestion

3.4.1.1. Ingestion of Contaminated Soil

Soil ingestion may be a potentially significant route of contaminant exposure, particularly for preschool children (age 1 to 6 years). Ingestion can occur directly by placing dirt-covered hands or objects into the mouth or, in some cases, by deliberately eating the soil. Some children habitually ingest nonfood items such as soil. This condition (pica) may occur in up to half of all children of age 1 through 3 years (LaGoy 1987). The potential for the oral intake of contaminants through soil ingestion is much lower for adults than for children because hand-to-mouth contact occurs less frequently and pica is rare.

For the young child, contact with soil is assumed to occur primarily during play in the warmer months of the year. A soil ingestion rate of 100 mg/day was assumed for children in this age group. This value is based on the EPA default value of 200 mg/day (EPA 1989c) for children, adjusted by a factor of 0.5 to account for the heavy ground cover at the site. Children with severe pica could potentially ingest much greater quantities of soil, up to 5000 mg/day (LaGoy 1987), but such individuals are expected to constitute a very small percentage of the population and need not be considered in this risk assessment (EPA 1989a). No soil ingestion is assumed for adults under the current scenario.

Children of age one to six years were assumed to have contact with contaminated soils in the park area approximately three days per week during April through October (3 days/week x 30 weeks/year = 90 days/year), over a three-year period. Because the contaminated waterways occupy approximately 10% of the park area, 10% of the soil ingested from hand-to-mouth contact is assumed to be from the contaminated area, while 90% is assumed to come from uncontaminated areas.

The plutonium-238 concentration in the near-surface soil and sediment in the contaminated area is estimated as the area-weighted average of the ninety-fifth percentile concentrations measured in each of the waterway segments. As discussed in Section 3.2, this concentration is approximately 1200 pCi/g.

The total plutonium-238 intake through the soil ingestion pathway is estimated as:

$$I_s = C_s \times IR_s \times FI \times EF_s \times ED_s$$

where I_s = plutonium-238 intake through soil ingestion (pCi)

C_s = plutonium-238 concentration in soil (pCi/g)
= 1200 pCi/g

IR_s = soil ingestion rate (g/day)
= 0.1 g/day for children age 1-6 years

FI = fraction of soil ingested from contaminated source (unitless)
= 0.1 (approximate location of park area occupied by contaminated waterways)

EF_s = exposure frequency
= 90 days/year

ED_s = exposure duration
= 3 years (EPA 1989c)

3.4.1.2. Ingestion of Contaminated Drinking Water

The two potential sources of drinking water in the local area are surface water from the Great Miami River and groundwater from the Buried Valley Aquifer. No drinking water intakes currently exist along the river downstream from the Mound Plant. Given this apparent absence of receptors, the very large dilution of influent from the canal within the river, and the low measured concentrations of plutonium-238 in the river, ingestion of surface water is not considered to be a significant exposure pathway.

Groundwater (well water) is a principal source of drinking water in the immediate area. Leaching of plutonium-contaminated soils may result in the contamination of groundwater and potential exposure of populations using groundwater as a source of drinking water. The municipal wells for the city of Miamisburg are on the west side of the river opposite the canal. Because the river acts as a hydraulic barrier to groundwater migration, no plutonium-238 from the canal should reach the municipal wells. However, private wells adjacent to the offsite waterways might potentially be influenced by plutonium migration. The nearest private wells are small,

single-dwelling wells located 0.1 mile west of the canal (wells B1, B2, B3, J1 in Figure 3.3). Based on the monitoring data for these wells, presented in Table 3.6, a concentration of 0.02 pCi/L plutonium-238 in drinking water is assumed for this analysis. This value represents the ninety-fifth percentile concentration observed in these wells during the period of 1976 to 1988.

For the purposes of this analysis, average drinking water consumption is assumed to be 1.4 liters/day for adults and 1 liter/day for children (EPA 1989c). The fraction of drinking water consumption from this well is assumed to be 0.75 (EPA 1989c), with 0.25 consumed away from home with uncontaminated sources. The exposure duration is assumed to be 30 years for adults (national maximum time at one residence [EPA 1989c]) and 3 years for children. Exposure frequency is assumed to be 365 days per year.

The plutonium-238 intake through the ingestion of contaminated drinking water is estimated as:

$$I_w = C_w \times IR_w \times F_w \times EF_w \times ED_w$$

where I_w = plutonium-238 intake through drinking water ingestion (pCi)

C_w = plutonium-238 concentration in drinking water (pCi/L)
= 0.02 pCi/L

IR_w = drinking water ingestion rate
= 1.0 liter/day for children (EPA 1989c)
= 1.4 liters/day for adults (EPA 1989c)

F_w = fraction of drinking water from contaminated area (per exposure day)
= 0.75 (EPA 1989c)

EF_w = exposure frequency
= 365 days/year

ED_w = exposure duration
= 30 years for adults (national maximum time at one residence) (EPA 1989c)
= 3 years for children

3.4.1.3. Ingestion of Contaminated Fish

Fish living in the contaminated waterways may accumulate plutonium and subsequently may be ingested by humans. Most of the canal area waterway typically does not contain sufficient water to sustain a significant fish population at present. However, the south pond has been developed into a small fishing pond for the municipal park, and fishing in the overflow ditch, near the river outfall, has been observed.

An average estimate of the freshwater fish consumption rate for adults was taken as 2400 g/yr (113 g/meal times 21 fish meals/year) (EPA 1989c). Consumption rates for children were taken as one-half of the adult rates (Pao et al. 1982). The south pond is very small (<500 ft^2) and is fished mainly by children for bluegill and carp. The consumption rate for bluegill and carp is approximately 40 g/yr (EPA 1989c). From these considerations, approximately 2% of the 2400 g/yr freshwater fish diet is assumed to come from the contaminated area. A water/sediment concentration ratio of 1×10^{-5} pCi/mL in water, per pCi/g in soil, was measured during the previous investigations at Mound Plant (Rogers 1975). The corresponding estimate of the *in situ* distribution coefficient in the canal system, 1×10^{5} mL/g, is at the upper end of the observed range of values of 11 to 300,000 mL/g for plutonium-238 (Baes et al. 1984). The distribution coefficient in the Miami-Erie Canal was later confirmed during studies by Kennedy and Bartelt (1978) who found the value to be 300,000 μL/g in the north canal. A bioconcentration factor of 4 L/kg (wet weight) was assumed for plutonium accumulation in fish muscle (Miller 1984). Exposure durations for children and adults are as described in Section 3.4.1.2.

For the fish ingestion pathway, the plutonium-238 concentrations used for estimating the potential intakes are the ninety-fifth percentile values from the surface 1-ft layer in the south pond, because this is the only area that regularly supports a fish population. The estimated activity concentration in fish tissue, based on these assumptions (that is, 41 pCi/g x 10^{-5} g/mL x 4 mL/g), is 0.0016 pCi/g, which is comparable to the maximum activity concentrations of 0.00079 and 0.0051 pCi/g in bluegill and carp, respectively, measured in area waterways in 1974. No monitoring data are available, however, for fish from the south pond.

The plutonium-238 intake from ingestion of contaminated fish is estimated as

$$I_f = C_{sediment} \times D_{w/s} \times B_f \times IR_f \times F_f \times EF_f \times ED_f$$

where

I_f	=	plutonium-238 intake from fish ingestion (pCi)
$C_{sediment}$	=	plutonium-238 concentrations in sediment (pCi/g)
	=	41 pCi/g (ninety-fifth percentile for south pond)
$D_{w/s}$	=	water/sediment concentration ratio
	=	1×10^{-5} pCi/mL in water, per pCi/g in sediment (Rogers 1975)
B_f	=	water-to-fish bioaccumulation factor (Miller 1984)
	=	4 mL/g (wet weight)
IR_f	=	fish ingestion rate
	=	113 g/meal for adults (median for fin fish) (EPA 1989a)
	=	57 g/meal for children
F_f	=	fraction of fish in diet grown in contaminated area
	=	0.02 (assumed)
EF_f	=	exposure frequency
	=	21 meals/year (average per capita for fish and shellfish) (EPA 1989a)
ED_f	=	exposure duration
	=	30 years for adults (national maximum time at one residence) (EPA 1989c)
	=	3 years for children

3.4.2. Inhalation of Resuspended Soils/Sediments (Recreational and Residential Scenarios)

Contaminated soils and sediments may be resuspended in the atmosphere and subsequently inhaled by humans. Resuspension of soils and sediments in the canal area is expected to be quite limited because of the heavy vegetation, surface topology, and generally moist conditions in the canal and surrounding areas.

The airborne plutonium-238 concentrations in the area of the Miami-Erie Canal have been monitored continuously with six permanent, high-volume air sampling stations since 1974 . The ninety-fifth percentile concentration of 1.6 x 10^{-4} pCi/m^3, computed from this data, is taken to represent the reasonable worst-case, long-term air concentration at the site. A breathing rate of 1.4 m^3/hr is assumed for adults and children (EPA 1989c). Children and adults are assumed to spend three hours per week throughout the year in the contaminated area (EPA 1989c). This is a generic value for time spent outdoors at home and is also used for time spent in the park under the recreational scenarios.

The estimated plutonium-238 intake from the inhalation of resuspended soil and sediment is

$$I_a = C_a \times IR_a \times EF_a \times ED_a$$

where I_a = plutonium-238 intake from inhalation of resuspended particulates (pCi)

C_a = plutonium-238 concentration in air (pCi/m^3)
= 1.6 x 10^{-4} pCi/m^3

IR_a = intake rate of air
= 1.4 m^3/hr average (EPA 1989c)

EF_a = exposure frequency
= 3 hr/week x 52 weeks/yr (EPA 1989c)

ED_a = exposure duration
= 30 years for adults (national maximum time at one residence) (EPA 1989c)
= 3 years for children

3.4.3. Summary of Estimated Contaminant Intakes

Estimated intakes of plutonium-238 through all exposure pathways, to the child and adult, are summarized in Table 3.7 for the current-use scenario. Estimates of committed dose equivalent and potential incremental health risks from these intakes are presented in Section 5.

Table 3.7. ESTIMATE OF LIFETIME PLUTONIUM-238 INTAKEs (pCi)

	Lifetime Intake (pCi)	
Exposure Pathway	Child	Adult
Ingestion		
Soil	3,200	---
Drinking water	16	230
Fish	0.12	2.3
Inhalation	0.10	1.0
TOTAL	3,200	230

4. Toxicity Assessment

This section provides a summary of the metabolism and dosimetry of plutonium in the human body and a review of the potential adverse health effects from plutonium exposure. The principal health risk associated with human exposure to plutonium is the induction of cancer in various internal organs. Mutagenic and teratogenic effects are estimated to be less significant (EPA 1989a). Acute toxic effects may be induced only at radiation doses well above those considered in this assessment.

4.1. Routes of Uptake and Systemic Distribution

Plutonium-238 undergoes radioactive decay to uranium-234 with the emission of alpha particles. Low energy x-rays are also emitted from the electron shells of the uranium-234 daughter. Because it is an alpha emitter, plutonium-238 represents a hazard to man primarily from internal deposition. The alpha particles from plutonium-238 cannot penetrate the external dead layer of the skin and do not represent an external radiation hazard. Plutonium may be taken into the body by inhalation of airborne particles; ingestion of contaminated food, water, or soil; and through absorption through the skin or wounds. Once inside the body, the alpha radiation from plutonium-238 may deposit energy in specific organs causing cellular damage, some of which could result in the development of cancer.

The fraction of plutonium that, upon ingestion, will be systematically distributed is dependent on the chemical form of the plutonium. The ICRP has suggested absorption fractions of 10^{-5} for plutonium dioxides and hydroxides, 10^{-4} for nitrates, and 10^{-3} for all other compounds of plutonium. The latter value (10^{-3}) is recommended for evaluating population exposures via food chains for all compounds (ICRP 1986). The ICRP has also noted that uptake from the gastrointestinal tract may be greatly increased in the very young and has recommended that an absorption fraction of 10^{-2} be used for the first year of life. These uptake factors are based upon studies with laboratory animals and a limited amount of epidemiological data.

The distribution of inhaled plutonium is determined by the chemical form of the nuclide, as well as the physical properties of the inhaled aerosol. The rate of removal of plutonium compounds from the lung is highly dependent upon the pattern of deposition in the lung and the particle size distribution of the aerosol. Particles deposited in the nasal and upper bronchial regions are cleared relatively quickly by the mucociliary and phagocytic mechanisms in the lung. The plutonium deposited in the deep alveolar regions of the lung is cleared from the lungs by transfer into the bloodstream and lymphatic systems at a much lower rate. Also, insoluble forms of plutonium will have

long residence times in the lungs, whereas soluble forms will undergo more rapid systemic distribution. For insoluble forms of plutonium, the pulmonary lymph nodes receive the greatest concentration of any tissue.

For the material that is systematically distributed from the lungs, the gastrointestinal tract, or the skin, the primary locations of final deposition are the liver and the skeleton. After review of all available animal experiments and limited human epidemiological data from workers exposed to plutonium, the ICRP has determined distribution fractions from the blood to the liver and skeleton of 30% and 50%, respectively (ICRP 1986). The remaining 20% is distributed throughout the other tissues of the body and eliminated through early excretion. For radiation protection purposes, however, the ICRP recommends continued use of the former distribution fractions of 45% each to the liver and skeleton, with 10% eliminated by early excretion (ICRP 1979). The fractional amount of plutonium taken into the human gonads is very small: 3.5×10^{-4} for males and 1.0×10^{-4} for females (ICRP 1979). Plutonium is retained in the body for long time periods and will continue to irradiate tissue in the liver and skeleton long after intake. The biological half-lives for the liver and skeleton are estimated as 20 and 50 years, respectively (ICRP 1986). Plutonium has been assumed to remain in the gonads indefinitely (ICRP 1986).

4.2. Internal Dosimetry

The ICRP has developed a detailed system of radiation dosimetry for radiation protection purposes, based upon the concept of committed effective dose equivalent (ICRP 1979). The committed dose equivalent is defined as the total integrated dose equivalent that would be received over a 50-year period following an intake of a radionuclide. The total dose equivalent to each of the most critical organs is then weighted according to the radiobiological sensitivity for that organ. Finally, the weighted organ doses are summed to obtain an effective whole-body dose that may be compared to whole-body doses from uniform external gamma exposure. The committed effective dose conversion factors (DCF) for plutonium-238 from inhalation and ingestion are presented in Table 4.1.

Knowledge of the chemical form of plutonium at the site has been used to select the most appropriate DCFs for inhalation (respiratory Class Y) and ingestion ($f_1 = 10^{-5}$ for soil ingestion, $f_1 = 10^{-3}$ for water ingestion and fish ingestion). In this assessment we have assumed that the contaminated sediment and soil are insoluble, like plutonium hydroxide. Therefore, DCFs for Class Y have been used for inhalation of soil/sediment. We also assumed that the absorption factor for ingestion of soil or sediment would follow the same logic (that is, soil is insoluble like plutonium hydroxide and, therefore,

would have a GI absorption factor of $f_1 = 1 \times 10^{-5}$). Plutonium ingested in water and fish is assumed to be in soluble form ($f_1 = 1 \times 10^{-3}$).

As Table 4.1 indicates, the largest doses occur in the skeletal system (that is, bone surface) for both inhalation and ingestion. A large remainder contribution exists for both routes of intake because of the large transfer fraction of plutonium to the liver which produces a high liver dose equivalent.

Studies by Cristy et al. (1984), Leggett (1985), and the National Radiological Protection Board (1985) have indicated that the committed dose equivalent to children from internal exposures to plutonium-238 may be greater than that for adults, but that such increases should be within a factor of two.

Table 4.1. DOSE CONVERSION FACTORS (COMMITTED DOSE EQUIVALENT PER UNIT INTAKE) FOR INGESTION OF PLUTONIUM-238

Organ	Inhalation (Y) (mrem/pCi)	Ingestion (mrem/pCi) $f_1 = 10^{-3}$	Ingestion (mrem/pCi) $f_1 = 10^{-5}$
Gonad	---	8.5×10^{-4}	8.5×10^{-6}
Lung	1.2×10^{-0}	----	----
Red Marrow	2.4×10^{-1}	5.6×10^{-3}	5.6×10^{-5}
Bone Surface	$3.1 \times 10^{+0}$	6.7×10^{-2}	6.7×10^{-4}
Liver	6.7×10^{-1}	1.5×10^{-2}	1.5×10^{-4}
Effective	3.0×10^{-1}	3.8×10^{-3}	5.2×10^{-5}

Reference: DOE 1988c.

4.3. Carcinogenic Risk

The extensive body of literature on radiation carcinogenesis has been recently reviewed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) (UNSCEAR 1982, 1988; NAS1980, 1988). Radiation-induced cancers in humans in the thyroid, female breast, lung, bone marrow (leukemia), bone, stomach, liver, large intestine, small intestine, brain, salivary glands, esophagus, bladder, pancreas, rectum, lymphatic tissues, skin, pharynx, uterus, ovary, mucosa of

the cranial sinuses, and kidney have been reported in these studies. Estimates in these studies of the average risk of fatal cancer from low-LET (linear energy transfer) radiation range from approximately 100 to 700 cancer deaths/million-person-rad, with total radiogenic cancer incidence risk approximately twice as great (cancer mortality rates ranging from approximately 10% for the thyroid to nearly 100% for liver cancer). The principal risks associated with plutonium-238 exposure are from cancers of the lung, bone, bone marrow (leukemia), and liver, because of the preferential distribution of plutonium to these tissues.

The EPA has recently proposed a lifetime risk factor range of 1.2×10^{-4} to 1.2×10^{-3} fatal cancers per rad of low-LET radiation (1.9×10^{-4} to 1.9×10^{-3} total cancers per rad) and 9.6×10^{-4} to 9.6×10^{-3} fatal cancers per rad of high-LET radiation (1.5×10^{-3} to 1.5×10^{-2} total cancers per rad) (EPA 1989d). Slope factors (cancer potency factors) have been derived to represent the age-averaged lifetime excess cancer incidence per unit intake of a given radionuclide, and are presented in Table 4.2 (EPA 1989a, 1990). These values are used in Section 5 to estimate the potential health risk from radiation doses estimated for plutonium-238 contamination in the Miami-Erie Canal area.

Table 4.2. SLOPE FACTORS AND PATHWAY-SPECIFIC UNIT RISK FACTORS FOR PLUTONIUM-238

Exposure Pathway	Slope Factor[a]
Inhalation	4.2×10^{-8} pCi^{-1}
Ingestion	2.8×10^{-10} pCi^{-1}

[a] Slope Factor = age-averaged lifetime excess total cancer risk per unit intake or exposure. (Note added in proof: Slope factors for ingestion and inhalation have been subsequently revised. The most recent values are 2.2×10^{-10} pCi^{-1} for ingestion and 3.9×10^{-8} pCi^{-1} for inhalation [EPA 1992].)

Reference: EPA 1990.

5. Health Risk Evaluation

Estimates of the potential health risks, committed effective dose equivalent, and committed dose equivalent to critical organs from potential exposures to plutonium-238 from the Miami-Erie Canal area, through each of the exposure pathways described in Section 3, have been computed. These values may be compared with risk ranges, dose limits, and criteria established by DOE, EPA, NRC, and other radiological protection authorities and advisory groups.

5.1. Dose Equivalent From Potential Exposure Pathways

Exposure pathways evaluated in this assessment include ingestion of contaminated materials and inhalation of resuspended soils or sediments. Potential ingestion pathways considered include ingestion of contaminated soil, contaminated drinking water, and fish from contaminated waterways.

Estimates are presented in Table 5.1 for the committed effective dose equivalent and the maximum organ committed dose equivalent for children and adults from the maximum one-year exposure, by way of each of the relevant exposure pathways. For purposes of estimating committed dose equivalent, the equations for estimating plutonium-238 intake by way of each exposure pathway, presented in Section 3.4, have been modified by

Table 5.1. ESTIMATES OF COMMITTED DOSE EQUIVALENT TO THE MAXIMALLY EXPOSED INDIVIDUAL FROM A ONE-YEAR EXPOSURE TO PLUTONIUM-238 CONTAMINATION AT THE MIAMI-ERIE CANAL (mrem/yr)

	Committed Dose Equivalent (mrem/year)			
	Children		Adults	
Pathway	Effective	Bone Surface	Effective	Bone Surface
Ingestion				
Soil	1.1×10^{-1}	7.2×10^{-1}	---	---
Drinking water	4.2×10^{-2}	7.3×10^{-1}	2.9×10^{-2}	5.1×10^{-1}
Fish	3.7×10^{-4}	6.6×10^{-3}	3.7×10^{-4}	6.6×10^{-3}
Inhalation	2.1×10^{-2}	2.2×10^{-1}	1.0×10^{-2}	1.1×10^{-1}
TOTAL	1.7×10^{-1}	1.7×10^{0}	3.9×10^{-2}	6.3×10^{-1}

elimination of the exposure duration (ED) term, since current limits on dose equivalents are based on a one-year intake. Dose conversion factors used in this analysis for adults are taken from DOE/EH-0071 (DOE 1988c) as presented in Table 4.1. The organ receiving the highest committed dose equivalent for all exposure pathways considered for plutonium-238 is the bone surface, or endosteum. Dose conversion factors (both committed effective dose equivalent and committed dose equivalent to bone surface) used in this analysis for children are taken to be greater than the corresponding value for adults by a factor of 2, as discussed in Section 4.2.

The committed effective dose equivalents for all pathways combined are estimated to be 0.17 and 0.039 mrem/yr for children and adults, respectively. Important exposure pathways include drinking water ingestion, soil ingestion, and inhalation of resuspended soils and sediments. The maximum organ dose equivalent (bone surface) is estimated at 0.63 mrem/yr for adults and 1.7 mrem/yr for children.

5.2. Health Risk from Potential Exposure Pathways

Estimates of lifetime health risk have been computed for each of the potential exposure pathways identified in Section 3. For each exposure pathway, the estimated plutonium-238 intake (Table 3.7) has been multiplied by the appropriate slope factors (cancer potency factors) from Table 4.2. These slope factors represent age-averaged lifetime excess total cancer risk (fatal and nonfatal) per unit intake. Estimates of the predicted lifetime health risks are presented in Table 5.2.

Table 5.2. ESTIMATES OF LIFETIME CANCER RISK FROM EXPOSURE TO PLUTONIUM-238 CONTAMINATION IN THE MIAMI-ERIE CANAL (TOTAL CANCERS)

	Predicted Lifetime Risk of Cancer Incidence		
Pathway	Child	Adult	Total
Ingestion			
Soil	9.1×10^{-7}	---	9.1×10^{-7}
Drinking water	4.5×10^{-9}	6.4×10^{-8}	6.9×10^{-8}
Fish	3.3×10^{-11}	6.4×10^{-10}	6.7×10^{-10}
Inhalation	4.4×10^{-9}	4.4×10^{-8}	4.8×10^{-8}
TOTAL	9.2×10^{-7}	1.1×10^{-7}	1.0×10^{-6}

The incremental lifetime cancer risk is estimated as 1.0×10^{-6}. Incidental soil ingestion by children (age 1 to 6) is the dominant exposure pathway, with a predicted lifetime cancer risk of 9.1×10^{-7}. It should be noted that the EPA's slope factor for ingestion of plutonium-238 is based on the assumption of a soluble chemical form ($f_1 = 1 \times 10^{-3}$), so that the actual risk from the soil ingestion pathway may be considerably lower than this estimate. All other exposure pathways are predicted to produce lifetime cancer risks below 10^{-6}.

The National Contingency Plan (NCP) (EPA 1990) currently specifies that the target for acceptable total carcinogenic risk to maximally exposed individuals from exposures at a Superfund site may range from 10^{-4} to 10^{-6}. The predicted lifetime cancer risk to the maximally exposed individual, from exposure to plutonium-238 at the Miami-Erie Canal site, is within the 10^{-6} NCP guidelines.

5.3. Uncertainties and Limitations

This analysis represents a preliminary evaluation of the potential radiation doses and health impacts that may result from exposures of the public to plutonium-238 contamination in the Miami-Erie Canal and adjacent waterways. The evaluation has been structured to rely entirely upon currently available data and to use the simplest appropriate models for each exposure pathway. Numerous assumptions have been made throughout the analysis to characterize potential exposures, doses, and health risks.

Input parameters for each model have been selected to represent conservative yet reasonable conditions. Values for parameters which were not considered to be extensively controlled by site-specific conditions such as intake rates for foodstuffs and water, breathing rates, and occupancy or usage factors, were selected from those recommended by EPA assessment guidance. However, other parameters such as the measured concentrations of plutonium-238 in air and groundwater and site-specific distribution coefficients, have been selected to more accurately reflect site conditions for the Miami-Erie Canal area where possible. Potential changes in land use and demography are uncertain and are not considered in this assessment; however, such changes are not expected to significantly alter the conclusions, since the dominant exposure pathway (soil ingestion) would be modeled very similarly for either a residential or recreational scenario.

The use of the 1974 data in this study is thought to be conservative, relative to current conditions. Limited data, available from the 1988 DOE Environmental Survey Sampling Program at Mound Plant, seem to indicate relative consistency with the 1974 data. Based on analysis of the 1974 data, conservative estimates of the concentrations of plutonium-238 in soil have been developed for use in this analysis. The area-averaged, ninety-fifth percentile

concentration measured in the contaminated waterways, has been used as a conservative estimate of site-wide conditions. Similarly, plutonium-238 concentrations in air and groundwater are estimated as the ninety-fifth percentile value of site environmental monitoring data from the period of 1974 to 1988.

As previously discussed, plutonium-238 is the only contaminant of concern considered in this focused risk assessment. Data to characterize levels of other radionuclides or chemical contaminants which may be present at the site are not yet available. While plutonium-238 is thought to be the major contaminant at the site, other contaminants of concern would be added to develop a comprehensive baseline risk assessment at some future date, if appropriate.[7]

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[7]*Note added in proof: A special canal sampling program conducted by Science Application International Corp. demonstrated that there are no significant hazardous chemicals or radioactive concentrations in the canal sediments. (Science Applications International Corp. "Special Canal Sampling Report, Miami-Erie Canal Operable Unit 4," Final, revision 1, July 1993.)*

6. Conclusions

This study presents an analysis of potential radiation doses and health risks to the public from exposures to plutonium-238 contamination in the Miami-Erie Canal near the Mound Plant. Plutonium-238 entered the waterway as a result of the rupture of an underground waste line in 1969 and a subsequent rainstorm that occurred during initial remediation activities.

Exposure pathways evaluated in this analysis include ingestion of contaminated soil, water, and fish and inhalation of resuspended soils and sediments. The total lifetime cancer risk from the assumed exposure scenarios is estimated as 1.0×10^{-6}, which is within the EPA acceptable risk range of 10^{-4} to 10^{-6} and the proposed target risk of 10^{-6}. Similarly, estimates of committed effective dose equivalent are 0.17 mrem/yr for children and 0.039 mrem/yr for adults, well below all relevant dose limits. Important exposure pathways include incidental ingestion of contaminated soil (for children only), drinking water ingestion, and inhalation of resuspended soils and sediment. As a point of comparison, the annual dose equivalent from natural background radiation in the United States is approximately 40 to 300 mrem/yr, with fluctuations of 5 to 30 mrem/yr in any specific location.

This analysis is preliminary in nature and is based on numerous assumptions. Consequently, uncertainties are associated with the results and predictions. Only plutonium-238 has been considered as a contaminant of concern; additional data are required to evaluate levels of other radionuclides or hazardous chemical contaminants that may be present. For each potential exposure pathway, a simplified conceptual model has been used to develop a conservative estimate of potential radiation dose equivalent and health risk. Each of these models uses parameters with large uncertainties. Parameter values have been selected to be consistent with values typically used in radiological assessment applications and EPA Superfund guidance, as well as available site-specific data.

Another limitation is the lack of recent data to characterize environmental concentrations of plutonium-238 in the contaminated area; however, preliminary review of more recent sampling data from the canal area (DOE Environmental Survey) seems to indicate the continued presence of plutonium-238 in canal soils at levels similar to those in the 1974 data. For the purposes of this focused assessment, soil concentration data collected in 1974 have been used, along with site-specific environmental monitoring data for air and groundwater, to represent current site conditions.

The results of this focused risk assessment indicate that plutonium-238 concentrations at the site do not present a significant threat to human health at the current time.

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Appendix A: Average and Ninety-Fifth Percentile Concentrations

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Table A.1. AVERAGE AND SAMPLE STANDARD DEVIATION FOR THE PLUTONIUM-238 CONCENTRATIONS IN ONE-FOOT BOREHOLE SOIL SAMPLES FROM THE MIAMI-ERIE CANAL WATERWAYS (pCi/g)

Area	Depth (ft)				
	0-1 (N)	1-2 (N)	2-3 (N)	3-4 (N)	4-5 (N)
South Canal					
East Bank	392 ± 381	378 ± 420	12.4 ± 13.8	9.5 ± 5.3	4.4 ± 4.0
Canal	832 ± 542	555 ± 562	45.6 ± 68.6	12.2 ± 21.9	4.9 ± 5.0
West Bank	252 ± 228	117 ± 230	15.0 ± 12.8	9.4 ± 8.4	5.2 ± 6.7
North Canal					
East Bank	19.4 ± 23.0	1.4 ± 1.1	1.1 ± 1.3	1.1 ± 1.2	0.7 ± 0.7
Canal	418 ± 326	396 ± 370	208 ± 361	70.3 ± 191	50.0 ± 141
West Bank	19.2 ± 22.7	3.6 ± 3.2	3.3 ± 4.8	0.8 ± 1.0	2.7 ± 4.4
Drainage Ditch					
South Bank	332 ± 210	81.5 ± 100	28.5 ± 47.1	8.9 ± 12.1	8.4 ± 11.0
Ditch	84.0 ± 59.2	92.0 ± 77.4	8.6 ± 12.3	0.8 ± 0.4	4.8 ± 6.4
North Bank	149 ± 223	55.3 ± 94.6	2.0 ± 2.6	10.4 ± 17.2	13.6 ± 12.1
Overflow Ditch					
East Bank	14.6 ± 5.7	0.4 ± 0.1	0.4 ± 0.2	0.3 ± 0.3	0.8 ± 1.0
Ditch	31.8 ± 37.1	24.5 ± 40.3	0.8 ± 0.2	0.9 ± 0.8	0.5 ± 0.4
West Bank	1.8 ± 0.2	<0.1 (NA)	<0.1 (NA)	0.1 (NA)	0.1 (NA)
Runoff Hollow	14.7 ± 9.6	2.5 ± 2.4	0.4 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
South Pond	16.3 ± 12.7	0.7 ± 0.4	0.3 ± 0.2	0.1 ± 0	1.3 ± 2.1
North Pond	2.7 ± 2.3	0.1 (NA)	0.2 (NA)	0.6 ± 0.6	0.6 (NA)

NA - Sample standard deviation is not applicable because only one measurement was made ≥0.1 pCi/g, or the average concentration was <0.1 pCi/g.

Table A.2. AVERAGE PLUTONIUM-238 CONCENTRATIONS FOR ALL LOCATIONS IN THE NORTH CANAL

Average Plutonium-238 Concentration (nCi/g)
Location V

Depth (ft)	West Bank	Canal	East Bank
0-1	0.0542	NM	NM
1-2	0.0076	NM	NM
2-3	NM	NM	NM
3-4	NM	NM	NM
4-5	NM	NM	NM

Average Plutonium-238 Concentration (nCi/g)
Location YB

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.2460	NM
1-2	NM	0.0626	NM
2-3	NM	0.0029	NM
3-4	NM	0.0009	NM
4-5	NM	0.0008	NM

Average Plutonium-238 Concentration (nCi/g)
Location YA

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.1595	NM
1-2	NM	0.3640	NM
2-3	NM	0.1793	NM
3-4	NM	0.0076	NM
4-5	NM	0.0006	NM

Average Plutonium-238 Concentration (nCi/g)
Location D

Depth (ft)	West Bank	Canal	East Bank
0-1	0.0050	0.1683	0.0106
1-2	0.0001	0.1191	0.0004
2-3	0.0002	1.1584	0.0002
3-4	0.0001	0.7165	0.0003
4-5	0.0002	0.5622	0.0002

NM - Indicates no measurements were performed.

Table A.2. (continued)

Average Plutonium-238 Concentration (nCi/g)
Location U

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.1570	NM
1-2	NM	0.3440	NM
2-3	NM	0.3810	NM
3-4	NM	NM	NM
4-5	NM	0.2950	NM

Average Plutonium-238 Concentration (nCi/g)
Location YYN

Depth (ft)	West Bank	Canal	East Bank
0-1	0.0298	0.5182	0.0530
1-2	0.0025	1.0301	0.0026
2-3	0.0009	1.1568	0.0026
3-4	0.0006	0.0085	0.0024
4-5	0.0012	0.0048	0.0016

Average Plutonium-238 Concentration (nCi/g)
Location YN

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.2630	NM
1-2	NM	0.7460	NM
2-3	NM	0.2150	NM
3-4	NM	0.0145	NM
4-5	NM	0.0045	NM

Average Plutonium-238 Concentration (nCi/g)
Location YC

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.6130	NM
1-2	NM	0.6950	NM
2-3	NM	0.0118	NM
3-4	NM	0.0017	NM
4-5	NM	0.0004	NM

Table A.2. (continued)

Average Plutonium-238 Concentration (nCi/g)
Location YD

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.7580	NM
1-2	NM	0.2130	NM
2-3	NM	0.0270	NM
3-4	NM	NM	NM
4-5	NM	0.0008	NM

Average Plutonium-238 Concentration (nCi/g)
Location YF

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.0517	NM
1-2	NM	0.1149	NM
2-3	NM	0.0225	NM
3-4	NM	0.0125	NM
4-5	NM	0.0051	NM

Average Plutonium-238 Concentration (nCi/g)
Location YE

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.8180	NM
1-2	NM	NM	NM
2-3	NM	0.2160	NM
3-4	NM	0.0062	NM
4-5	NM	0.0009	NM

Average Plutonium-238 Concentration (nCi/g)
Location YG

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.6550	NM
1-2	NM	0.7620	NM
2-3	NM	0.0154	NM
3-4	NM	0.0023	NM
4-5	NM	0.0223	NM

Table A.2. (continued)

Average Plutonium-238 Concentration (nCi/g)
Location YH

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.1652	NM
1-2	NM	0.0582	NM
2-3	NM	0.0080	NM
3-4	NM	0.0027	NM
4-5	NM	0.0018	NM

Average Plutonium-238 Concentration (nCi/g)
Location YI

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	1.1400	NM
1-2	NM	0.8280	NM
2-3	NM	0.0189	NM
3-4	NM	0.0029	NM
4-5	NM	0.0029	NM

Average Plutonium-238 Concentration (nCi/g)
Location YJ

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	NM	NM
1-2	NM	0.0366	NM
2-3	NM	0.0022	NM
3-4	NM	0.3930	NM
4-5	NM	0.0029	NM

Average Plutonium-238 Concentration (nCi/g)
Location YK

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.4190	NM
1-2	NM	0.8380	NM
2-3	NM	0.4720	NM
3-4	NM	0.0110	NM
4-5	NM	0.0099	NM

Table A.2. (continued)

Average Plutonium-238 Concentration (nCi/g)
Location YL

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.2326	NM
1-2	NM	0.8514	NM
2-3	NM	0.0621	NM
3-4	NM	0.0085	NM
4-5	NM	0.0294	NM

Average Plutonium-238 Concentration (nCi/g)
Location YM

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.8990	NM
1-2	NM	0.0340	NM
2-3	NM	0.0074	NM
3-4	NM	0.0021	NM
4-5	NM	0.0028	NM

Average Plutonium-238 Concentration (nCi/g)
Location E

Depth (ft)	West Bank	Canal	East Bank
0-1	0.0001	0.2487	0.0010
1-2	<0.0001	0.0182	<0.0001
2-3	<0.0001	0.0052	<0.0001
3-4	0.0001	0.0037	<0.0001
4-5	0.0003	0.0009	<0.0001

Average Plutonium-238 Concentration (nCi/g)
Location F

Depth (ft)	West Bank	Canal	East Bank
0-1	0.0068	0.0102	0.0131
1-2	0.0045	0.0252	0.0014
2-3	0.0088	0.0017	0.0005
3-4	0.0022	0.0007	0.0005
4-5	0.0094	0.0020	0.0010

Table A.3. - AVERAGE PLUTONIUM-238 CONCENTRATIONS FOR ALL LOCATIONS IN THE SOUTH CANAL

Average Plutonium-238 Concentration (nCi/g)
Location YO

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.8150	NM
1-2	NM	0.4390	NM
2-3	NM	0.0098	NM
3-4	NM	0.0015	NM
4-5	NM	0.0016	NM

Average Plutonium-238 Concentration (nCi/g)
Location YP

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.7910	
1-2	NM	0.1000	NM
2-3	NM	0.0060	NM
3-4	NM	0.0035	NM
4-5	NM	0.0021	NM

Average Plutonium-238 Concentration (nCi/g)
Location YQ

Depth (ft)	West Bank	Canal	East Bank
0-1	0.5400	1.2850	0.3360
1-2	0.0842	0.9160	0.8950
2-3	0.0294	0.0925	0.0175
3-4	0.0132	0.0820	0.0077
4-5	0.0201	0.0027	0.0028

Average Plutonium-238 Concentration (nCi/g)
Location Z

Depth (ft)	West Bank	Canal	East Bank
0-1	0.3320	0.5807	NM
1-2	0.0207	1.5237	NM
2-3	0.0375	0.1358	0.0096
3-4	0.0178	0.0156	NM
4-5	0.0033	0.0070	NM

NM - Indicates no measurements were performed

Table A.3. (continued)

Average Plutonium-238 Concentration (nCi/g)
Location P

Depth (ft)	West Bank	Canal	East Bank
0-1	0.2355	1.1797	1.0840
1-2	0.0356	0.8697	0.6115
2-3	0.0163	0.0312	0.0152
3-4	0.0165	0.0076	0.0191
4-5	0.0064	0.0060	0.0034

Average Plutonium-238 Concentration (nCi/g)
Location YYS

Depth (ft)	West Bank	Canal	East Bank
0-1	0.6220	2.1538	0.6170
1-2	0.6360	1.5044	0.7520
2-3	0.0101	0.2319	0.0397
3-4	0.0032	0.0090	0.0133
4-5	0.0004	0.0104	0.0054

Average Plutonium-238 Concentration (nCi/g)
Location YR

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.9690	NM
1-2	NM	NM	NM
2-3	NM	0.0182	NM
3-4	NM	0.0068	NM
4-5	NM	0.0018	NM

Average Plutonium-238 Concentration (nCi/g)
Location YU

Depth (ft)	West Bank	Canal	East Bank
0-1	0.1110	0.9433	0.2200
1-2	0.0222	0.1561	NM
2-3	0.0144	0.0226	NM
3-4	0.0202	0.0223	0.0039
4-5	0.0024	0.0187	0.0125

Table A.3. (continued)

Average Plutonium-238 Concentration (nCi/g)
Location YS

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.8360	NM
1-2	NM	0.8280	NM
2-3	NM	0.0170	NM
3-4	NM	0.0016	NM
4-5	NM	0.0054	NM

Average Plutonium-238 Concentration (nCi/g)
Location YT

Depth (ft)	West Bank	Canal	East Bank
0-1	NM	0.4330	NM
1-2	NM	0.0105	NM
2-3	NM	0.0019	NM
3-4	NM	0.0013	NM
4-5	NM	0.0024	NM

Average Plutonium-238 Concentration (nCi/g)
Location Q

Depth (ft)	West Bank	Canal	East Bank
0-1	0.1134	0.7028	0.4795
1-2	0.0179	0.2750	0.0114
2-3	0.0097	0.0208	0.0043
3-4	0.0032	0.0018	0.0057
4-5	0.0083	0.0019	0.0053

Average Plutonium-238 Concentration (nCi/g)
Location R

Depth (ft)	West Bank	Canal	East Bank
0-1	0.0612	0.0999	0.0061
1-2	0.0027	0.0313	0.0001
2-3	0.0028	0.0045	0.0001
3-4	0.0006	0.0032	0.0058
4-5	0.0005	0.0031	0.0006

Table A.3. (continued)

Average Plutonium-238 Concentration (nCi/g)
Location W

Depth (ft)	West Bank	Canal	East Bank
0-1	0.0006	0.0272	0.0015
1-2	NM	0.0033	0.0012
2-3	0.0001	0.0012	0.0003
3-4	0.0003	0.0019	0.0110
4-5	0.0003	0.0009	0.0008

Table A.4. - AVERAGE PLUTONIUM-238 CONCENTRATIONS FOR ALL LOCATIONS IN THE OVERFLOW DITCH

Average Plutonium-238 Concentration (nCi/g)
Location S

Depth (ft)	East Bank	Ditch	West Bank
0-1	0.0187	0.0063	0.0020
1-2	0.0004	0.0011	<0.0001
2-3	0.0003	0.0010	<0.0001
3-4	0.0002	0.0015	0.0001
4-5	0.0001	0.0008	<0.0001

Average Plutonium-238 Concentration (nCi/g)
Location T

Depth (ft)	East Bank	Ditch	West Bank
0-1	0.0106	0.0147	0.0016
0-2	0.0005	0.0013	<0.0001
2-3	0.0006	0.0007	<0.0001
3-4	0.0005	0.0004	<0.0001
4-5	0.0015	0.0002	0.0001

Average Plutonium-238 Concentration (nCi/g)
Location X

Depth (ft)	East Bank	Ditch	West Bank
0-1	NM	0.0744	NM
1-2	NM	0.0711	NM
2-3	NM	NM	NM
3-4	NM	NM	NM
4-5	NM	NM	NM

NM - Indicates no measurements were performed.

Table A.5. - AVERAGE PLUTONIUM-238 CONCENTRATIONS FOR ALL LOCATIONS IN THE DRAINAGE DITCH

Average Plutonium-238 Concentration (nCi/g)
Location A

Depth (ft)	South Bank	Ditch	North Bank
0-1	0.4715	0.0596	0.4060
1-2	0.0486	0.1440	0.1645
2-3	0.0004	0.0006	0.0050
3-4	0.0004	0.0070	0.0002
4-5	0.0004	<0.0001	0.0020

Average Plutonium-238 Concentration (nCi/g)
Location B

Depth (ft)	South Bank	Ditch	North Bank
0-1	0.0902	0.0410	0.0038
0-2	0.0020	0.0030	0.0006
2-3	0.0022	0.0228	0.0006
3-4	0.0036	0.0004	0.0008
4-5	0.0039	0.0003	0.0008

Average Plutonium-238 Concentration (nCi/g)
Location C

Depth (ft)	South Bank	Ditch	North Bank
0-1	0.4350	0.1515	0.0374
1-2	0.1940	0.1290	0.0008
2-3	0.0828	0.0026	0.0004
3-4	0.0228	0.0012	0.0303
4-5	0.0210	0.0094	0.0379

Table A.6. - CALCULATION OF AVERAGE PLUTONIUM-238 CONCENTRATION FOR THE NORTH POND

Mound Plutonium Sample Analysis in the Miami-Erie Canal
North Pond
Location I

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0020	0.0021
1-2	<0.0001	<0.0001
2-3	<0.0001	<0.0001
3-4	0.0013	<0.0001
4-5	<0.0001	<0.0001

Mound Plutonium Sample Analysis in the Miami-Erie Canal
North Pond
Location H

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0047	0.0062
1-2	<0.0001	0.0001
2-3	<0.0001	<0.0001
3-4	<0.0001	0.0003
4-5	0.0006	<0.0001

Mound Plutonium Sample Analysis in the Miami-Erie Canal
North Pond
Location G

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0004	0.0005
1-2	<0.0001	<0.0001
2-3	<0.0001	0.0002
3-4	ND	0.0003
4-5	NM	NM

ND - Indicates not detectable.
NM - Indicates no measurements were performed.

Table A.6. (continued)

Average Plutonium Concentration in the Miami-Erie Canal (North Pond)
Average Concentrations for All Locations

Depth (ft)	Average Plutonium-238 Concentration (nCi/g)
0-1	0.0027
1-2	0.0001
2-3	0.0002
3-4	0.0006
4-5	0.0006

Table A.7. - CALCULATION OF AVERAGE PLUTONIUM-238 CONCENTRATION FOR THE SOUTH POND

Mound Plutonium Sample Analysis in the Miami-Erie Canal South Pond Location L

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0096	0.0053
1-2	0.0005	0.0003
2-3	0.0002	0.0002
3-4	<0.0001	0.0001
4-5	0.0004	0.0001

Mound Plutonium Sample Analysis in the Miami-Erie Canal South Pond Location K

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0309	0.0271
1-2	0.0007	0.0011
2-3	0.0006	0.0001
3-4	<0.0001	NM
4-5	0.0051	0.0006

Mound Plutonium Sample Analysis in the Miami-Erie Canal South Pond Location J

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0007	0.0243
1-2	0.0002	0.0012
2-3	<0.0001	<0.0001
3-4	0.0001	<0.0001
4-5	0.0005	<0.0001

NM - Indicates no measurements were performed.

Table A.7. - (continued)

Average Plutonium Concentration in the Miami-Erie Canal (South Pond)
Average Concentrations for All Locations

Depth (ft)	Average Plutonium-238 Concentration (nCi/g)
0-1	0.0163
1-2	0.0007
2-3	0.0003
3-4	0.0001
4-5	0.0013

Table A.8. - CALCULATION OF AVERAGE PLUTONIUM-238 CONCENTRATION FOR THE RUNOFF HOLLOW

Mound Plutonium Sample Analysis in the Miami-Erie Canal Runoff Hollow Location M

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0123	0.0314
1-2	0.0027	0.0058
2-3	0.0005	0.0007
3-4	0.0002	0.0002
4-5	0.0002	0.0002

Mound Plutonium Sample Analysis in the Miami-Erie Canal Runoff Hollow Location N

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0173	0.0149
1-2	0.0007	0.0006
2-3	0.0003	0.0003
3-4	ND	0.0002
4-5	ND	<0.0001

Mound Plutonium Sample Analysis in the Miami-Erie Canal Runoff Hollow Location O

Depth (ft)	West Plutonium-238 Concentration (nCi/g)	Center Plutonium-238 Concentration (nCi/g)	East Plutonium-238 Concentration (nCi/g)
0-1	0.0028	0.0097	<0.0001
1-2	<0.0001	0.0002	0.0051
2-3	<0.0001	<0.0001	
3-4	0.000042	0.000067	
4-5	0.000043	0.000064	

ND - Indicates not detectable.

Table A.8. - (continued)

Average Plutonium Concentration in the Miami-Erie Canal (Runoff Hollow)
Average Concentrations for All Locations

Depth (ft)	Average Plutonium-238 Concentration (nCi/g)
0-1	0.0147
1-2	0.0025
2-3	0.0004
3-4	0.0001
4-5	0.0001

Table A.9. - Ninety-fifth Percentile Values of the Plutonium-238 Distributions in One-Foot Borehole Soil Samples from the Miami-Erie Canal Waterways (pCi/g)[a]

Area	Depth (ft)				
	0-1 (N)	1-2 (N)	2-3 (N)	3-4 (N)	4-5 (N)
South Canal					
East Bank	1,132 (7)	1,224 (6)	39.2 (7)	19.8 (7)	12.2 (7)
Canal	1,798 (13)	1,564 (12)	168 (13)	23.7 (13)	13.8 (13)
West Bank	684 (8)	564 (7)	39.3 (8)	25.3 (8)	17.9 (8)
North Canal					
East Bank	73.5 (4)	4.6 (3)	4.9 (3)	4.6 (3)	2.7 (3)
Canal	985 (18)	1,040 (18)	834 (19)	404 (17)	294 (19)
West Bank	67.6 (5)	11.1 (4)	17.3 (3)	3.2 (4)	13.1 (4)
Drainage Ditch					
South Bank	945 (3)	373 (3)	166 (3)	44.2 (3)	40.5 (3)
Ditch	257 (3)	318 (3)	44.5 (3)	2.0 (3)	45.2 (2)
North Bank	800 (3)	331 (3)	9.6 (3)	60.6 (3)	75.2 (3)
Overflow Ditch					
East Bank	50.6 (2)	1.0 (2)	1.7 (2)	2.2 (2)	7.1 (2)
Ditch	140 (3)	142 (3)	2.1 (2)	6.0 (2)	3.0 (2)
West Bank	3.1 (2)	NA (1)	NA (1)	NA (1)	NA (1)
Runoff Hollow	34.0 (6)	7.3 (6)	0.9 (4)	0.3 (5)	0.3 (4)
South Pond	41.9 (6)	1.5 (6)	0.8 (4)	0.1 (2)	5.8 (5)
North Pond	7.3 (6)	NA (1)	NA (1)	2.4 (3)	NA (1)

[a] Ninety-fifth percentile calculated according to

$$x_{0.95} = \bar{x} + s\,(t_{N-1,\,1-\alpha/2}) \quad \text{(Gilbert 1987)}$$

(N) - Number of measurements ≥0.1 contributing to the associated ninety-fifth percentile. Where N<3, the calculated value is highly uncertain.

NA - Not applicable because only one measurement was made ≥0.1 pCi/g, or the average concentration was <0.1 pCi/g.

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