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REMEDIAL INVESTIGATION REPORT FOR OPERABLE UNIT 4 VOLUME 3 OF 3 APRIL 1993 DRAFT

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REPORT

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FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

REMEDIAL INVESTIGATION and FEASIBILITY STUDY

VOLUME 3 OF 3

APRIL 1993

U.S. DEPARTMENT OF ENERGY
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APPENDIX D BASELINE RISK ASSESSMENT

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D.3 EXPOSURE ASSESSMENT

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LIST OF ACRONYMS

AEC	U.S. Atomic Energy Commission
BEIR	Biological Effects of Ionizing Radiation
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CERCLIS	Comprehensive Environmental Response Compensation and Liability Information System
CI	confidence interval
CIS	Characterization Investigation Study
CLP	Contract Laboratory Program
CNS	central nervous system
COC	contaminant of concern
CRQL	Contract Required Quantitation Limit
CT	central tendency
DL	detection limit
DOE	U.S. Department of Energy
ECG	electrocardiograph
EPA	U.S. Environmental Protection Agency
FEMP	Fernald Environmental Management Project
FIDLER	Field Instrument for Detection of Low Energy Radiation
FMPC	Feed Materials Production Center
FS	Feasibility Study
FY	Fiscal Year
GC/MS	gas chromatograph/mass spectrometer
GI	gastrointestinal
GM	Geiger-Mueller
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HQ	Hazard Quotient
ICP	inductively coupled plasma
ICRP	International Commission on Radiological Protection
IRIS	Integrated Risk Information System
ISCLT	Industrial Source Complex-Long Term
LOAEL	lowest observed adverse effect level
MAGLC	maximum acceptable ground-level concentration
MCLG	maximum contaminant level goal
MSL	mean sea level
MUSLE	Modified Universal Soil Loss Equation
NAAQS	National Ambient Air Quality Standard

LIST OF ACRONYMS
(Continued)

NAS	National Academy of Sciences
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection
NESHAP	National Emission Standards for Hazardous Air Pollutants
NLO	National Lead Company of Ohio
NOAEL	no observed adverse effect level
NOEL	no observed effect level
NRC	Nuclear Regulatory Commission
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
PCDF	polychlorinated dibenzofurans
ppm	parts per million
OEPA	Ohio Environmental Protection Agency
OU	operable unit
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RDA	recommended dietary allowance
RfC	reference concentration
RfD	reference dose
RI	Remedial Investigation
RME	reasonable maximum exposure
SAS	Statistical Analysis Software
SQL	sample quantitation unit
TCLP	Toxicity Characteristic Leaching Procedure
UCL	upper confidence limit
URF	unit risk factor
UTF	unit toxicity factor
UTL	upper tolerance limit
VOC	volatile organic compound
WEMCO	Westinghouse Environmental Management Company of Ohio
WLM	working level month
WM	working month
WMCO	Westinghouse Materials Company of Ohio
WPA	Risk Assessment Work Plan Addendum

LIST OF DEFINITIONS

AQUIFER - An underground geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

BASELINE RISK ASSESSMENT - The studies undertaken for Operable Units (OUs) 1-5 to characterize the current and potential threats to human health and the environment that may be posed by contaminants within those operable units. Each Baseline Risk Assessment shall provide a framework for developing risk information necessary to assist in developing remedial alternatives, and shall consider the risks that currently exist at the site, if no further response actions or institutional controls are applied. There are four steps in the baseline risk assessment process: data collection and analysis; exposure assessment; toxicity assessment; and risk characterization. The baseline risk assessment contributes to the site characterization and subsequent development, evaluation, and selection of appropriate response alternatives.

CHRONIC REFERENCE DOSE (RfD) - An estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic RfDs are specifically developed to be protective for long-term exposure to a compound (as a Superfund program guideline, seven years to lifetime).

CONSENT AGREEMENT - An Agreement between the U.S. EPA and the U.S. DOE for the cleanup of the FEMP under authorities of Sections 106 and 120 of Superfund Amendments and Reauthorization Act of 1986 (SARA). The Consent Agreement signed in April 1990, amends the July 1986 Federal Facility Compliance Agreement (FFCA), which established the original framework for the FMPC environmental investigation and cleanup. A modified Consent Agreement, signed in September 1991, including renegotiated framework and schedules for developing, implementing, and monitoring appropriate response actions at the site and to facilitate cooperation, exchange of information and participation of the Parties in such actions.

CONTAMINANTS OF POTENTIAL CONCERN - Chemicals and radionuclides that are potentially site-related and whose data are of sufficient quality for use in the quantitative risk assessment.

CURRENT LAND USE - One of the general categories of use of real property at a site that realistically describes the current use of the property for purposes of assessing potential human health risks. These categories include: residential, agricultural, commercial/industrial; and recreational.

LIST OF DEFINITIONS
(Continued)

EXPOSURE ASSESSMENT - The determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure.

EXPOSURE PATHWAY - The course a chemical or physical agent takes from a source to a receptor organism. Each exposure pathway includes a source or release from a source, an exposure point, an exposure route, and a receptor. If the exposure point differs from the source, a transport medium (e.g., air) or media (in cases of intermedia transfer) also is included.

EXPOSURE SCENARIO - A chain of events and conditions defining a combination of exposure pathways and processes that are used to estimate reasonable maximum exposure of individuals or groups.

FATE AND TRANSPORT MODELING - Modeling used to assess contaminant movement from source areas to receptor locations through various media (e.g., groundwater, air). Used in conjunction with monitoring data, these models estimate contaminant concentrations at exposure point locations where measured contaminant concentration data is not available, such as off-property locations, or contaminant distribution in the future.

FEMP - The Fernald Environmental Management Project, the present name for the former Feed Materials Production Center in Fernald, Ohio, starting August 23, 1991.

FMPC - The former Feed Materials Production Center in Fernald, Ohio, which is now renamed the Fernald Environmental Management Project on August 23, 1991 to reflect the change in its mission from that of a production facility to an environmental restoration project.

FUTURE POTENTIAL LAND USE - The hypothesized use of property at a site that describes plausible use of the property in the future for purposes of assessing potential human health risks. These categories may include: residential; agricultural; commercial/industrial; and recreational.

GROUNDWATER - Water in a saturated zone or stratum beneath the surface of land or water.

INSTITUTIONAL CONTROLS - Measures that generally limit human activities at or near facilities where hazardous substances, pollutants, or contaminants exist or will remain on site. Active institutional controls include engineering controls and an active security program. Passive institutional controls include monuments, land and resource restrictions, deed restrictions, permitting programs, zoning, government ownership, and deed notices. Institutional controls may supplement engineering controls (e.g., treatment and/or containment of source material) to provide protection of human health.

LIST OF DEFINITIONS
(Continued)

INTAKE - A measure of exposure. For chemicals, it is expressed as the mass of a chemical in contact with the exchange boundary of a receptor per unit body weight per unit time (e.g., mg chemical/kg body weight-day). For radionuclides, it is expressed as the activity of a radionuclide (e.g., Bq or Ci) taken into an organism. Intake by inhalation, ingestion and dermal absorption are the three most important exposure routes for both chemicals and radionuclides.

ON SITE - The areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action.

OPERABLE UNIT - A discrete action that comprises an incremental step toward comprehensively addressing Site problems.

REASONABLE MAXIMUM EXPOSURE (RME) - The exposure that is reasonably expected to occur at a site under both current and future land-use conditions and defined by conservative exposure parameters. The intent of the RME is to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures. It does not embrace all hypothetical possibilities, but rather is limited to situations and conditions that "are likely to occur". RMEs are estimated for individual pathways. If a population is potentially exposed via more than one pathway, an RME must be estimated for the combination of pathways.

RECEPTOR - A member of human, animal, or plant populations that may be exposed to radioactive or hazardous materials.

REMEDIAL INVESTIGATION (RI) - The investigation conducted to fully determine the nature and extent of the release or threat of release of hazardous substances, pollutants, contaminants, or hazardous constituents. The RI emphasizes data collection and site characterization. The RI includes sampling and monitoring, as necessary, and includes the gathering of sufficient information to support the Feasibility Studies and the risk assessments.

RISK CHARACTERIZATION - The part of the risk assessment that summarizes and combines outputs of the exposure and toxicity assessments to characterize baseline risk, both in quantitative expressions and qualitative statements. During risk characterization, chemical-specific toxicity information is compared against both measured contaminant exposure levels and those levels predicted through fate and transport modeling to determine whether current or future risk levels at or near the site are of potential concern.

LIST OF DEFINITIONS
(Continued)

SEDIMENT - The unconsolidated inorganic and organic material that is suspended in and is transported by surface water, or has settled out and has deposited into beds.

SITE - Areas within the property boundary of FEMP and any other areas that received or potentially received released hazardous substances, pollutants, contaminants, or hazardous constituents. The term shall have the same meaning as "facility" as defined by Section 101(9) of CERCLA, 42 U.S.C. § 9601(9).

SLOPE FACTOR - A plausible upper-bound estimate of the probability of a response per unit intake of a chemical or radionuclide over a lifetime. The slope factor is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular level of a potential carcinogen.

SOIL - All unconsolidated materials normally found on or near the surface of the earth including, but not limited to, silts, clays, sands, gravel, and small rocks.

SURFACE WATER - All water that is open to the atmosphere and subject to surface runoff.

TOXICITY ASSESSMENT - The part of the baseline risk assessment that considers: 1) the types of adverse health effects associated with chemical exposures; 2) the relationship between magnitude of exposure and adverse effects; and 3) related uncertainties such as the weight of evidence of a particular chemical's carcinogenicity in humans.

UNIT RISK FACTOR (URF) - The risk of one unit concentration (e.g., 1 pCi/g soil) calculated for a set of specified pathways, models, and parameters.

UNIT TOXICITY FACTOR (UTF) - The toxicity factor (hazard index) associated with one unit concentration (e.g., 1 mg/kg soil) calculated for a set of specified pathways, models, and parameters.

WORK PLAN ADDENDUM - A supplement to the RI/FS Work Plan that established the scope and specific methodology for risk assessment and risk management activities in the RI and FS.

D.1.0 INTRODUCTION

D.1.1 OBJECTIVES

This risk assessment is prepared in support of the Operable Unit 4 Remedial Investigation (RI) Report. The objectives of this risk assessment are to:

- Characterize the constituent sources and determine constituents of concern (COCs) for Operable Unit 4
- Assess constituent transport from the source to potential exposure points
- Quantify potential exposures under current and future land use scenarios
- Characterize the potential baseline risks associated with Operable Unit 4 under current and future land use scenarios

This baseline risk assessment is an appendix to the Operable Unit 4 RI Report. A summary of this assessment is presented in Section 6.0 of the RI Report.

D.1.2 OVERVIEW

The baseline risk is that risk to hypothetical receptors, due to sources in Operable Unit 4, which may occur under various scenarios if no remedial actions are taken to correct environmental deficiencies. The baseline is a measure of risk against which the reduced risk associated with various remedial action alternatives may be compared, thereby providing a measure of relative effectiveness of the different proposed alternatives.

This baseline risk assessment follows the methodology described in the Risk Assessment Work Plan Addendum (DOE 1992a), with a few exceptions identified herein. Baseline risks are calculated under a number of constituent release mechanisms, for transport to hypothetical receptors under three separate land use scenarios. The two primary source terms include the contents of Silos 1, 2, and 3, and the surface soil, berm soil, and subsurface soil within the Operable Unit 4 Study Area.

Land use scenarios include (1) current land use without access controls, (2) current land use with access controls, and (3) future land use without access controls. Under the first scenario, current land use without access controls, the Fernald Environmental Management Project (FEMP) is assumed to have been turned over to an industrial concern other than the U.S. Department of Energy (DOE). Access restrictions currently provided by the DOE are assumed to be discontinued. In addition, no remedial actions are assumed to have been taken. The scenario further assumes that no members of the public establish residence within the boundaries of Operable Unit 4. Thus, potential receptors include an off-property farmer, a trespassing child, an on-site worker (groundskeeper), and an off-site user of surface water from the Great Miami River.

Under the second scenario, current land use with access controls, the site access restrictions historically provided by the DOE are assumed to be maintained. No remedial actions are assumed to have been taken. Any scenario assumes that no members of the public have established residence in the Operable Unit 4 Study Area. Further, the scenario assumes that the DOE maintains a site-specific health and safety programs to ensure that nonremediation workers and visitors are properly protected. Potential receptors under this scenario include an off-property farmer, a trespassing child, and an off-property user of surface water from the Great Miami River.

The third land use scenario, future land use without access controls, includes exposure routes that require development time, such as establishing a home and farm within Operable Unit 4. Access controls are assumed to be absent and no remedial actions are assumed to have been taken. In addition, members of the public are assumed to have established a residence within the Operable Unit 4 boundaries. Hypothetical receptors under this scenario are a reasonable maximum exposure (RME) on-property resident farmer, a central tendency (CT) on-property resident farmer, an on-property resident child, an off-property farmer, and an off-property user of surface water from the Great Miami River.

Each of the above three land use scenarios considers two source-term scenarios. These include the current source-term scenario and the future source-term scenario. The current source-term scenario considers the silos as they exist today. The future source-term scenario considers complete structural failure of Silo 3 that would spread its contents to Operable Unit 4 surface soils, and dome collapse for Silos 1 and 2 that would expose their contents to the elements and increase leaching of the contents through the interception of rainwater.

The Operable Unit 4 baseline risk assessment is presented in four steps:

- COCs are identified. Section D.2.0 contains a discussion of the data sources used in the risk assessment, a presentation of the methods used to determine the COCs, and a listing of the COCs in tabular format.

- Results of the exposure assessment are presented. Section D.3.0 contains a listing of the sources for the COCs, a detailed description of the land use scenarios, a description of the constituent transport models employed, and a list of the exposure point concentrations calculated for each COC at the exposure locations assumed in the model. These exposure point concentrations are then used to estimate potential exposures to the hypothetical receptors used in the model and described in the overview.

- In Section D.4.0, a toxicity assessment contains information concerning the potential effects on the hypothetical receptors resulting from exposure to the COCs. For each COC, Section D.4.0 contains a quantitative estimate of the relationship between exposure and severity or probability of effect. The toxicity assessment includes a compilation of both toxic and carcinogenic effects of the constituents of "potential" concern and provides detailed evaluations of the major COCs.

- The data compiled in Sections D.2.0 through D.4.0 are used to calculate potential risks to the hypothetical receptors. The potential risks to humans following exposure to COCs are estimated using methods established by U.S. Environmental Protection Agency (EPA), when available. Section D.5.0 contains a description of the methods for calculating the risks and detailed risk tables for exposure of each of the hypothetical receptors under each of the three land use scenarios and each of the two source-term scenarios.

Section D.6.0 contains a summary of uncertainties in the risk assessment process for Operable Unit 4. This includes consideration of the impacts of limited data sets and how these limitations are overcome, and the potential magnitude and direction of bias that may be introduced by uncertainties in the risk assessment.

Section D.7.0 contains a summary of Operable Unit 4 baseline risk assessment.

Attachment D.I contains the unit risk factors (URFs) for radionuclides and carcinogenic chemicals and the unit toxicity factors (UTFs) for chemical toxicants. This attachment includes an example derivation of the URFs for a single COC for each potential exposure pathway that is quantitatively evaluated in the risk assessment.

Attachment D.II contains a tabulation of the risk characterization results by pathway for each receptor under current and potential future land use conditions.

D.1.3 BACKGROUND

Descriptive information regarding the site and Operable Unit 4 is contained in Section 1.0 of the RI Report for Operable Unit 4. The waste storage silos (Silos 1, 2, 3, and 4) are large concrete storage structures that were built in 1951 and 1952 at the Feed Materials Production Center (FMPC). The waste storage silos are located south of the waste pits on the west side of the FEMP property (Figure D.1-1). The silos are 80 feet in diameter, constructed with floors of 4-inch-thick concrete over an 8-inch layer of gravel containing an underdrain system of 2-inch-diameter slotted pipe that drains to a collection tank. Below the gravel is a 2-inch-thick layer of asphaltic concrete underlaid by approximately 18 inches of compacted clay. The silo walls are approximately 26 feet high and are constructed of 8-inch-thick concrete wrapped with steel post-tensioning wires. The exterior of the silo walls are covered with a 0.75-inch-thick layer of gunite. The domed roofs taper from 8 inches thick at the silo walls to 4 inches thick at the apex.

The silos were constructed to contain the waste residues generated from processing high grade uranium ores to extract the uranium. At present, Silo 1 contains 3280 cubic meter (m^3) (115,900 cubic feet [ft^3]) of waste residues and 360 m^3 (12,600 ft^3) of bentonite clay. Silo 2 contains 2840 m^3 (100,400

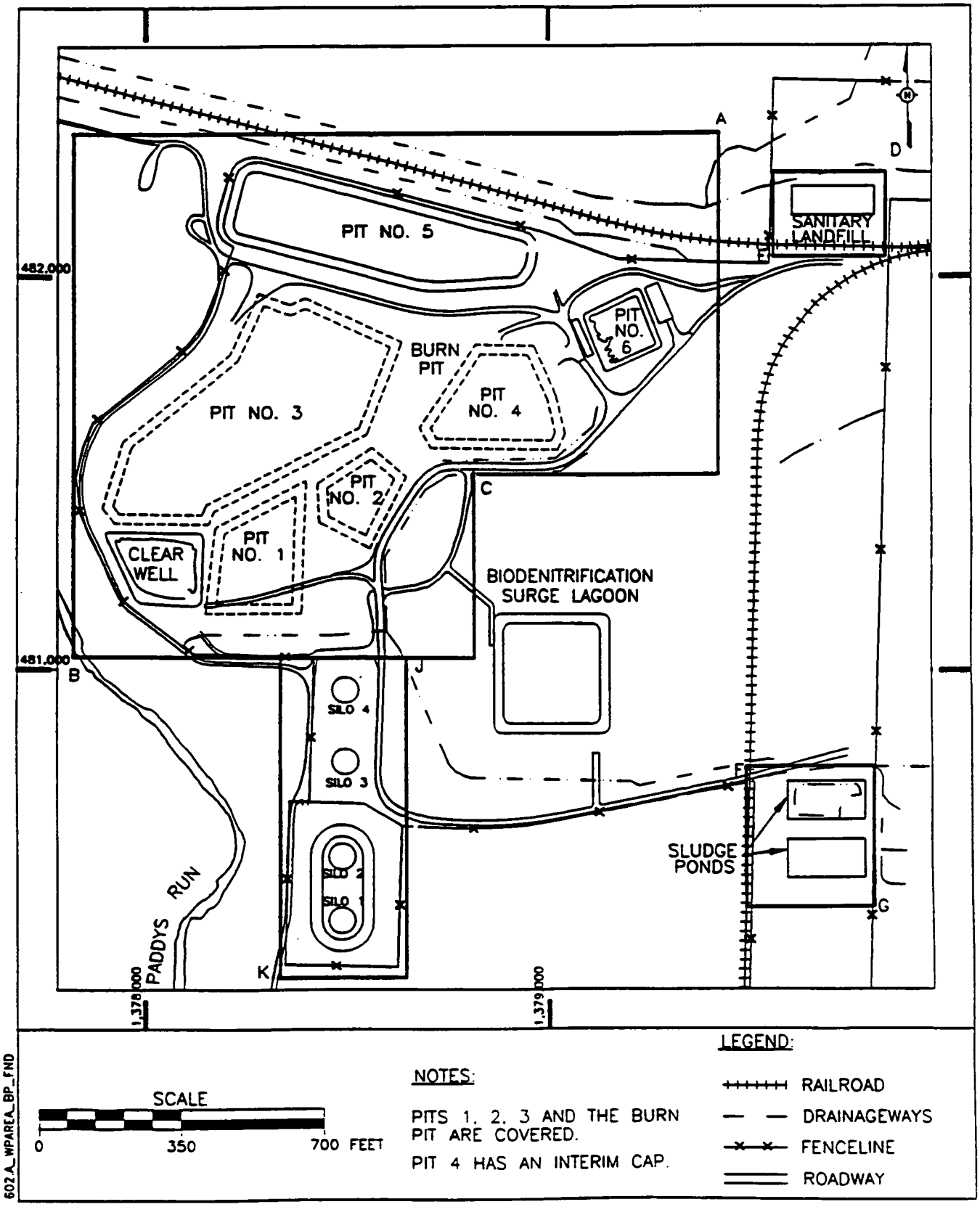

FIGURE D.1-1 WASTE STORAGE AREA

ft^3) of waste residues and 310 m^3 (11,100 ft^3) or bentonite clay. Silo 3 contains 3890 m^3 (137,500 ft^3) of waste residues. Silo 4 is empty.

D.1.4 COMPARISON WITH THE RISK ASSESSMENT WORK PLAN ADDENDUM METHODOLOGY

The baseline risk assessment is performed in accordance with the Risk Assessment Work Plan Addendum (DOE 1992a), with the following exceptions. These exceptions reflect deviations from the methodology in the Work Plan Addendum or incorporation of new information or guidance not covered in the Work Plan Addendum. The following are justifications for deviations from the Work Plan Addendum and their impacts on the baseline risk assessment:

- Constituent concentrations based on measurement data from small sample populations (less than seven samples) are calculated as the upper 95 percent confidence limit of the geometric mean.

  Justification: The geometric distribution cannot be determined confidently for data sets with small sample sizes. Lognormality is assumed as the default data distribution because environmental data are frequently found to be lognormally distributed (EPA 1992a). In addition, the statistical method for constructing the upper 95 percent confidence limit for the arithmetic mean described in the Work Plan Addendum becomes invalid for small sample sizes (Gilbert 1992). Thus, the upper 95 percent confidence limit for the mean of the log transformed data, which has been conventionally applied to a lognormally distributed data set, is used.

  Impact: Utilizing the geometric mean is expected to produce a more statistically stable estimate of the upper confidence limit.

- Airborne particulate concentrations of constiuents are calculated using an Industrial Source Complex - Long Term (ISCLT2) dispersion model (EPA 1987).

  Justification: The ISCLT2 dispersion model is one of the EPA's guideline models. It is a sector-averaged, Gaussian plume model capable of calculating seasonal or annual ground level constituent concentrations from deposition. The ISCLT model predicts concentrations at grid points set by the user and has the capability to model multiple release sources. The model contains a number of options, allowing the user to make the model more site-specific than might otherwise be the case.

  Impact: For a given set of input data, the ISCLT2 and AIRDOS dispersion models produce similar results. The ISCLT2 code was used because it provides the additional capabilities necessary to fully evaluate Operable Unit 4 airborne emissions.

- Slope factors are taken from Health Effects Assessment Summary Tables (HEAST) Annual Fiscal Year (FY) 1992 (EPA 1992b).

Justification: HEAST is updated regularly. The Operable Unit 4 risk assessment uses the most up-to-date HEAST as of March 1992.

Impact: Major changes in the slope factors from the 1991 version are made for radionuclides. Slope factors for radionuclides in this version are generally lower than previously presented. There is a 20 percent reduction in the slope factor for lead-210 (Pb-210) and neptunium-237 (Np-237) for the inhalation pathway. Slope factors for ingestion of most radionuclides are from 20 percent to a factor of 10 lower than previous values in HEAST. Slope factors for external exposure have the most significant changes with 50 percent of the radionuclides being reduced by a factor of approximately 100 to 1000. The range of the ratios of the slope factors from the FY 92 version to the FY 91 version for radionuclides found in the FEMP are presented as follows:

Route of Exposure	Range of ratios (FY 92/FY 91)
Inhalation	0.76 (for Pb-210) - 1.02 (For radium-228 Ra-228])
Ingestion	0.12 (uranium-isotopes) - 1.00 (fission products)
External Exposure	0.003 (for uranium-238 [U-238]) - 0.40 (for radon-220 [Rn-220])

Because the risk associated with a particular radionuclide is linearly proportional to its slope factor, the impact on the risk assessment corresponds linearly to the changes made for these slope factors.

- Risks to off-property receptors for future exposure scenarios are presented.

Justification: An off-property resident may be exposed to the site-related constituents via air transport, and water and recreational uses of the Great Miami River. The risk assessment for this exposure scenario was specifically requested by EPA in the comment resolution for the Site-Wide Characterization Report.

Impact: Additional RME location(s) will be identified for this scenario.

- Risks from average exposure conditions for a future resident farmer are included.

Justification: The new EPA guidance on risk assessment issued in February 1992 (a memorandum from EPA's Deputy Administrator F. H. Habicht to EPA's Assistant and Regional Administrators concerning guidance on risk characterization for risk managers) (EPA 1992c) urges risk assessors to address or provide descriptions of individual risk that include the "high end" portions and "central tendency" of the risk distribution. Because future resident farmers constitute the most

important subgroups for exposures, this receptor/scenario is selected to present a more realistic estimate of risk.

Impact: Because only a few of the exposure and modeling parameters use average or median values for this typical on-property resident scenario, and most of the parameters still use maximum or near-maximum values, the additional scenario does not present a "true" CT because the scenario is more conservative than the CT. However, this scenario is an attempt to investigate risks that are closer to the CT than risks to the RME on-property resident farmer.

- Intake calculations are incorporated in the "Unit Risk Factor" methodology described in Section D.5.0 and Attachment D.I.

Justification: In Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) risk assessment methodology, a linear relationship is assumed between the exposure point concentration of a constiuent in a medium and the calculated health risk from exposure to the constituent in the medium. The calculated health risk from exposure to one unit concentration of a given constiuent in a given environmental medium through a given exposure route is referred to as the "unit risk factor" for that constiuent. The unit risk factor is, therefore, constiuent-, scenario-, and medium-specific. Once the exposure models, parameters, and toxicity values are determined for a site, the unit risk factors can be prepared in parallel with the process of data collection and statistical analysis. This expedites the risk assessment process and simplifies the risk calculation.

Impact: Lifetime risks calculated from the "Unit Risk Factor" methodology are the same as risks based on using intake calculations and risk characterization methodology since the methods are mathematically equivalent. Thus, there is no impact on the calculated risk.

- Dermal contact models and parameters have been revised to reflect the most recent guidance from EPA.

Justification: DOE has agreed to employ the most recent dermal exposure assessment guidance from EPA in operable unit-specific risk assessments.

Impact: The risk estimates based on the most recent guidance for dermal exposure assessment are more conservative for the trespassing child and adult on-property resident receptors and are less conservative for the on-property resident child receptor.

D.2.0 IDENTIFICATION OF CONSTITUENTS OF POTENTIAL CONCERN

When performing a risk assessment, data for environmental media are compiled to determine potential site-related contaminants and exposures for each medium (EPA 1989a). The FEMP, like several other large CERCLA sites, is divided into operable units. Operable Units 1 through 4 are source units, and Operable Unit 5 is the surrounding environmental media. Because of this division, the Operable Unit 4 RI/Feasibility Study (FS) addresses only the potential risks associated with the contaminant sources, or waste storage areas within the boundaries of Operable Unit 4. Baseline risks associated with contaminants currently in the surrounding groundwater, surface water, and sediments are addressed during the Operable Unit 5 RI/FS. Thus, while the Operable Unit 4 RI report provides information on surrounding media, the baseline risk assessment addresses only the risks posed by contaminants in Operable Unit 4 to determine if remediation is required. With the use of fate and transport modeling, the risk assessment will include the potential for Operable Unit 4 to contribute to future contamination in the surrounding media.

D.2.1 DATA SOURCES

D.2.1.1 Site-Related Data

Sources of the environmental sampling data used in the baseline risk assessment are presented in Table D.2-1. The Work Plan Addendum (DOE 1992a) outlines the guidelines for use of data in FEMP risk assessments. Data generated in the RI/FS process are given first consideration in risk assessments because these data are the most current and most reliable, based on the RI/FS quality assurance/quality control (QA/QC) practices. Existing databases generated by Fernald Environmental Restoration Management Corporation (FERMCO) and its subcontractors in studies are used as secondary sources. If primary and secondary data do not corroborate each other, differences are addressed.

The Operable Unit 4 risk assessment used source term data based upon (1) waste material in Silos 1, 2, and 3, (2) radon concentration data from void space in the top of the silos, and (3) soil contaminant data from samples of surface soil, subsurface soil, and berm fill in the Operable Unit 4 Study Area. The concentration of contaminants in environmental media (e.g., groundwater, air, or surface water) were calculated, using fate and transport models, based on the source terms identified above.

The following subsections present the sources of data used to characterize source terms within Operable Unit 4.

D.2.1.1.1 Silo Contents

Analytical results for the contents of Silos 1, 2, and 3 sampled as part of the RI during May, June, and July 1989 are summarized for use in quantifying fate and transport modeling source terms. Additional data on silo content collected under the RI/FS after 1989 are available for radionuclides and chemicals

TABLE D.2-1

DATA USED FOR THE OPERABLE UNIT 4
RISK ASSESSMENT

Waste Unit	Medium	Data		Justification
		Radiological	Chemical	
K-65 Silos	Waste material inside silos	RI/FS borings collected in 1989 and 1991	RI/FS borings collected in 1989 and 1991	RI/FS data are available
	Air	Silo headspace radon concentration	Not applicable	Data are collected under routine environmental monitoring and are not available under the RI/FS
Silo 3	Waste material inside silo	RI/FS borings collected in 1989	RI/FS borings collected in 1989	RI/FS data are available
Operable Unit 4 Study Area	Soil	RI/FS surface soil	RI/FS surface soil	Limited surface soil data available from the RI/FS surface soil characterization program
		RI/FS subsurface soil borings	RI/FS subsurface soil borings	RI/FS data are available from the vertical berm and waste pit runoff sampling programs
		RI/FS berm fill borings	RI/FS berm fill borings	RI/FS data are available from the vertical berm sampling program

in Silos 1 and 2. The data are also incorporated into the modeling source terms. The sampling programs are discussed in detail in Section 2.0 of the Operable Unit 4 RI Report, including consideration of sampling objectives, sampling methodology and operations, and sample analytical parameters. The results of the sampling programs, as presented in Sections 3.0 and 4.0 of the RI Report, include sample recovery and physical characterization information, radioanalytical results, chemical analytical results, and available TCLP sample analytical results. Figure D.2-1 shows the layout of the silo sampling area, along with the locations of the silo manways through which sampling was performed.

D.2.1.1.2 Radon

Source terms for radon emission from Silos 1, 2, and 3 were calculated using radon concentration data in the headspace of the silos, and the concentrations of contaminants in Silos 1, 2, and 3.

Under the current source-term scenario, Silo 3 and the domes covering Silos 1 and 2 are assumed to remain intact. Under this scenario, the radon emissions from the silos were calculated as the product of the measured radon concentration inside the silo headspace and the calculated silo breathing rate (volume of air in the silo headspace released per unit time). Thus, the radon source term is based on radon concentration in the silo headspace. The radon concentration data were obtained from radon concentrations measured in Silos 1 and 2 for 31 consecutive days in December 1992. The radon concentrations for Silo 3 were obtained from the results of four grab samples collected on four separate days in September and October 1990. In all cases, the upper confidence limit concentrations from the measurements were used for estimating release rates.

The future source-term scenario considered that the domes on Silos 1 and 2 fail. Also, Silo 3 has failed structurally and spread its contents over the surface of Operable Unit 4. As a result, radon is released directly from the surface of the waste materials to the atmosphere. Under this scenario, the radon source term is calculated as the product of the radon flux (radon release per unit area per unit time) from the surface of the materials and the waste surface area. Thus, the radon source term is based on the waste contents of Silos 1, 2, and 3 and the quantity of radon generated by these wastes. Silo content data used to calculating radon emission are from the same data source discussed in Section D.2.1.1.1.

D.2.1.1.3 Soil

Soil sampling programs are discussed in detail in Section 2.0 and the results are presented in Section 4.0 of the Operable Unit 4 RI Report.

To evaluate exposure pathways involving transport via surface water runoff or air dispersion and direct exposure to a potential receptor, the analytical data for the surface soils were compiled separately. This includes chemical and/or radiological data from the following soil and berm samples:

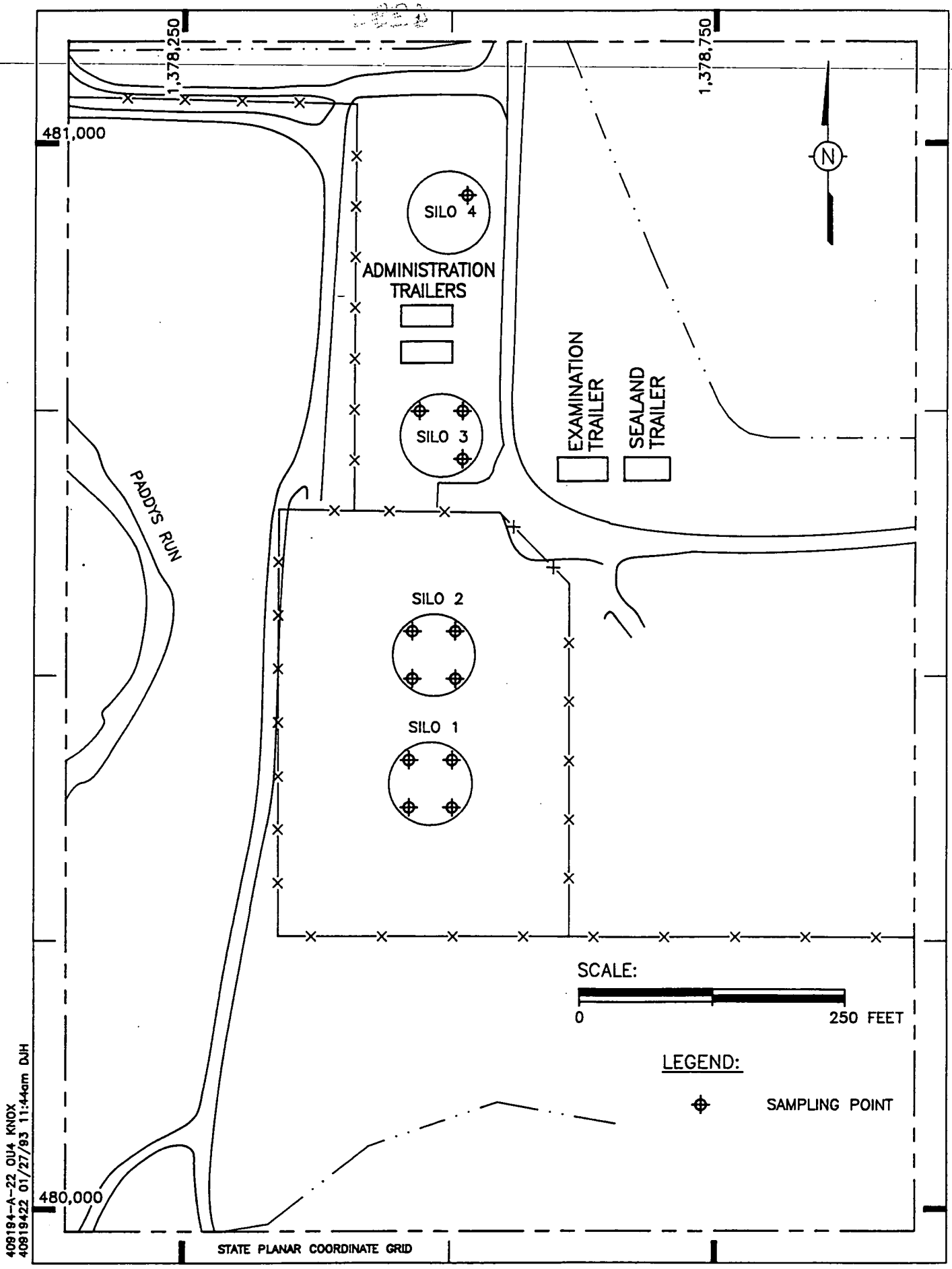

FIGURE D.2-1. LAYOUT OF SILO SAMPLING AREA

- RI/FS surface soil characterization samples within the Operable Unit boundary (state plane coordinates N480,000 to N481,033 and E1,378,125 to E1,378,750)
- Waste Pit Runoff Control Removal Action samples from depths between 0 and 2 feet within the Operable Unit 4 Study Area
- K-65 vertical boring samples from the berm fill (99,000-series samples) from depths between 0 and 5 feet
- RI/FS subsurface soil sample from 0 to 1.5 feet (sample number 8188)

Nonvalidated samples were excluded from the soil data set.

Because the berms consist of fill that has been moved into place rather than native soil, composite samples from depths up to 5 feet should adequately represent the surface material available for transport and direct exposure.

Figures D.2-2 and D.2-3 show the soil and berm sampling areas, including the sample number and locations.

D.2.1.2 Background Data

Background chemicals and radionuclides in soil include naturally-occurring levels and concentrations that are present in the environment due to human-made, nonsite sources.

In the spring of 1992, 89 background soil samples were collected at 30 locations in accordance with the "RCRA/CERCLA Background Soil Study Sampling and Analysis Plan" (DOE 1992c). A soil sample was collected at each of three different depths for each location: 0 to 6 inches; 36 to 42 inches; and 48 to 54 inches. The 30 surface soil (0 to 6 inches) sample analytical results were used to establish background concentrations for radionuclides and chemicals. These samples were analyzed for 17 radionuclides and 27 nonradioactive metals. These data have been validated and are used in the process of selecting COCs.

D.2.2 ANALYSIS OF DATA

D.2.2.1 Data Validation

Data validation is an after-the-fact, independent, systematic process of evaluating data and comparing them to pre-established criteria to confirm that the data are of the technical quality necessary to support the decisions made in the RI/FS process. Specific parameters associated with the data are reviewed to determine whether they meet the stipulated data quality objectives. The data quality objectives address five principal parameters: precision, accuracy, completeness, comparability, and

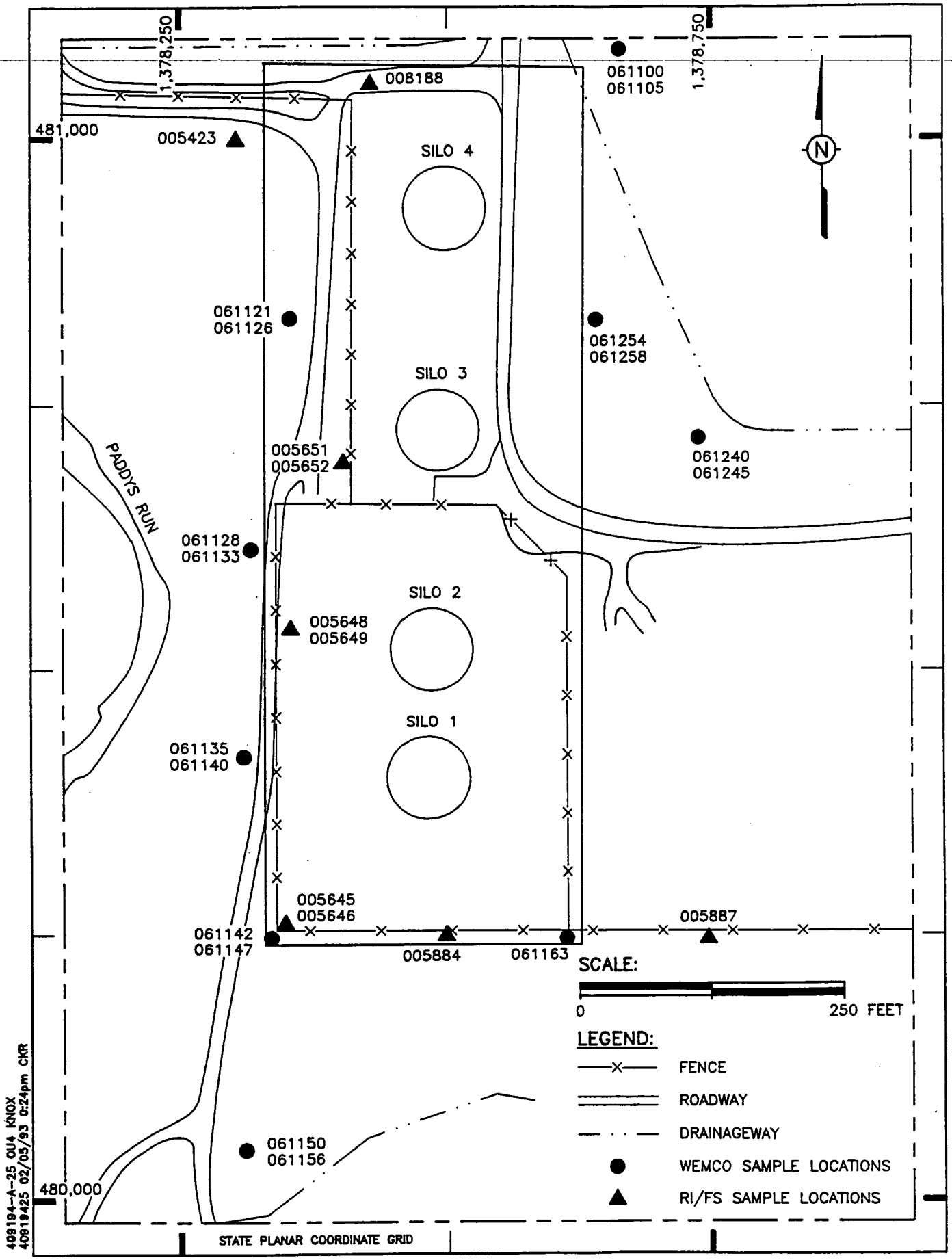

FIGURE D2-2. SURFACE SOIL AND BORING SAMPLING LOCATIONS AND SAMPLE IDENTIFICATION NUMBERS

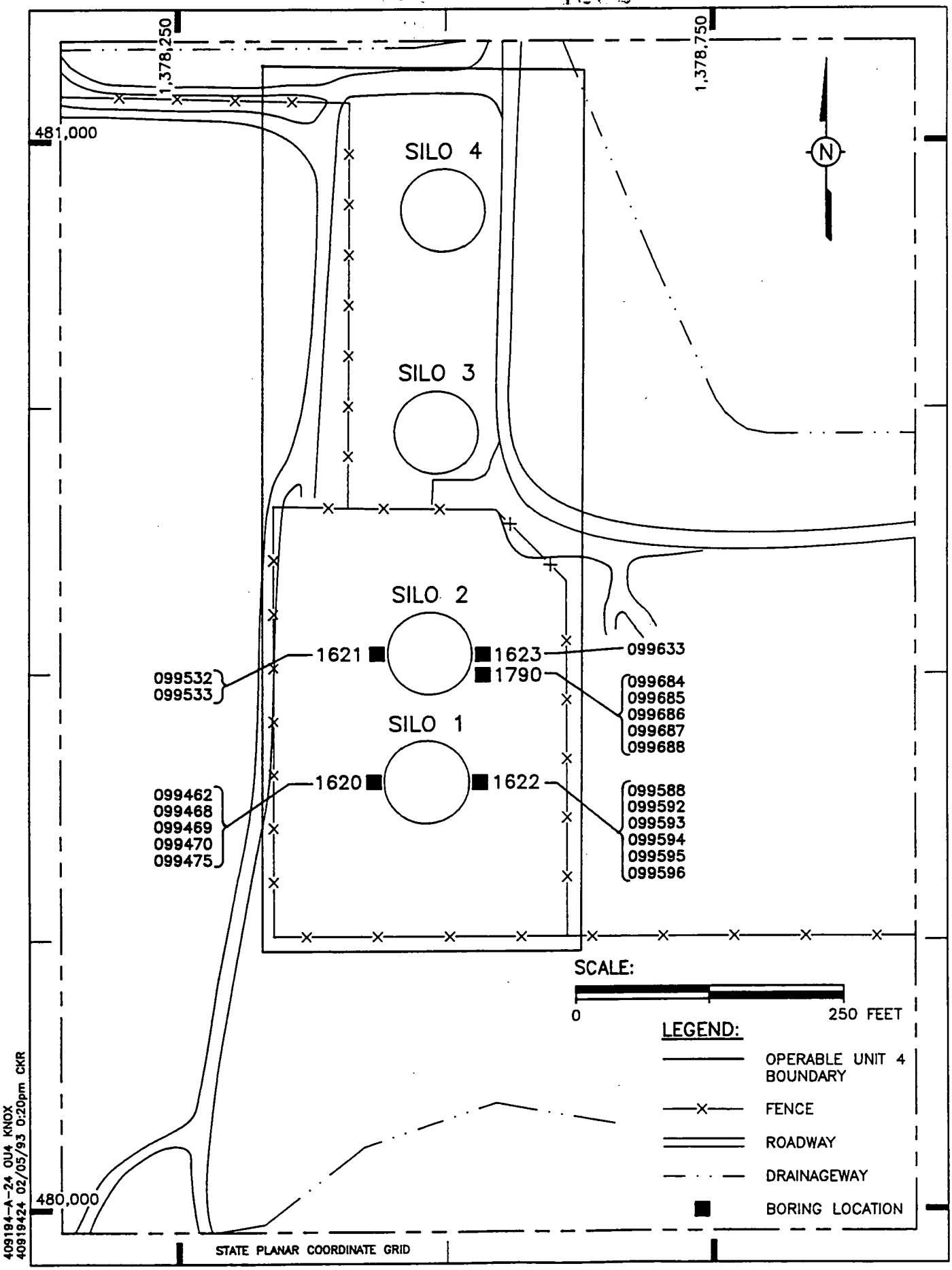

FIGURE D.2-3. VERTICAL BORING LOCATIONS AND SAMPLE IDENTIFICATION NUMBERS

representativeness. Quality assurance and quality control criteria are discussed in the Quality Assurance Project Plan (QAPP) (ASI/IT 1988). To verify that these objectives are met, field measurements, sampling and handling procedures, laboratory analysis and reporting, and nonconformances and discrepancies in the data are examined to determine compliance with appropriate and applicable procedures. The procedures and criteria for validation are defined in the RI/FS Data Validation Program Guidelines, which are based on the EPA National Functional Guidelines for Data Review (EPA 1988a; EPA 1988b).

A detailed description of the Operable Unit 4 data quality assessment and data validation procedures is presented in Section 2.12 of the RI report. Data that do not adequately meet the criteria addressed during data validation are flagged with an "R" qualifier. These data are not used in the quantitative risk assessment process. Data flagged with the "J" qualifier, meaning the values are "estimated," are used in the quantitative risk assessment, according to EPA guidance (EPA 1989a).

D.2.2.2 Analysis of Site-Related Data

Statistical methods are used to evaluate the analytical results from the Operable Unit 4 sampling program in order to (1) identify COCs in Operable Unit 4, (2) develop source term concentrations for fate and transport modeling, and (3) establish exposure point concentrations. The statistical methods used in data evaluation are discussed in this section. The rationale used to develop this methodology and the statistical techniques are based on the following sources:

- "Risk Assessment Guidance for Superfund: Human Health Evaluation Manual, Volume I, Part A, Interim Final" (EPA 1989a)
- "Statistical Methods for Evaluating the Attainment of Cleanup Standards, Volume 1 and Volume 3 (Draft)" (EPA 1989b, 1990a)
- "Statistical Methods for Environmental Pollution Monitoring" (Gilbert 1987)
- "Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance" (EPA 1989c)
- Personal communication with R. O. Gilbert (Gilbert 1992)
- EPA comments (December 1991 and March 1992) on the statistical methods used in the October 1991 Draft Risk Assessment Work Plan Addendum (Saric 1991 and 1992).
- "Risk Assessment Work Plan Addendum," (DOE 1992d)

The Statistical Analysis Software (SAS) is used to perform most of the statistical calculations. For each set of data that describes a medium in a waste area, the following information is tabulated: frequency of detection, range of detected values, distribution of the data (normal, lognormal or other), mean concentration, and upper 95 percent confidence limit on the mean concentration.

Because of the uncertainty associated with characterization of potentially inhomogeneous waste areas, the upper 95 percent confidence limit on the mean for either a normal or lognormal distribution is used to represent contaminant concentrations. The upper 95 percent confidence limit on the mean is generally referred to as the upper confidence limit (UCL).

To construct the UCL, the distribution type (normal, lognormal, or other) is determined. A histogram is constructed from the data set, which is visually inspected to determine if the distribution appears to be normal, lognormal, or other. In addition, a probability plot of the data set is constructed using a linear scale. If a straight line fits the plotted points reasonably well (highly correlated), a normal distribution is assumed. If the data do not follow a straight line on a linear probability plot, the data are replotted on a logarithmic probability plot. A quantitative determination of the "linearity" of the data is performed by calculating the correlation coefficient of the plotted points on the normal probability plot or on the lognormal probability plot. The type of distribution is selected from the plot with the higher correlation coefficient. The calculation of the UCL for both a normal distribution and lognormal distribution is presented in the Work Plan Addendum, Section 7.1 (DOE 1992a).

Analytical results are reported as "nondetects" whenever chemical concentrations in samples do not exceed the detection or quantitation limits for the analytical procedures for those samples. Generally, the detection limit is the lowest mass (or activity) of a chemical (or radionuclide) that can be "seen" above the normal, random noise of an analytical instrument or method. As suggested by EPA (1989a), to apply the above-mentioned statistical procedures to a data set with "nondetects," it is assumed that the chemical or radionuclide is present at one-half the detection limit. This is a reasonable compromise between the use of zero and the use of the detection limit to reduce the bias (positive or negative) in the calculated UCL.

D.2.2.3 Analysis of Background Data

Background soil sample analytical results for radionuclides and inorganic chemicals are obtained from the RCRA/CERCLA Background Soil Study (DOE 1993). Details concerning sampling for this study are briefly summarized in Section D.2.1.2.

As with the site-related data, the background data sets are evaluated to determine the distribution (normal, lognormal, or other) that best describes the data. As discussed in Section D.2.3.1, the selection of contaminants for evaluation in the risk assessment is based primarily on comparison of site-related data to background data. This comparison is made by determining whether the values of site-related data statistically exceed background data.

A t-test comparing the mean of the site-related data to the mean of the background data is performed to determine whether the values of site-related data statistically exceed those of background data. For

instances in which the t-test cannot be applied to the data, the Wilcoxon Rank Sum Test is performed. A standard procedure from SAS (Version 6.03) is used to perform the t-test. The method for performing the Wilcoxon Rank Sum Test is presented in the Work Plan Addendum, Section 4.3 (DOE 1992a). The SAS is also used to conduct the Wilcoxon Rank Sum Test.

The comparison between values of site-related data and background data is also made using the 95 percent upper tolerance limit (UTL) of the background data. This comparison is used because it is effective at revealing "hot spot" contamination in data sets. If the UTL test is the only test that can be conducted (i.e., both t-test and Wilcoxon Rank Sum Test are not suitable to use), the contaminant of interest is considered to be a contaminant if the UTL test suggests so. However, if the UTL test suggests that the site data are not different from the background data, visual comparison of the histograms for both data sets is performed.

The method for constructing the UTL is taken from EPA guidance, "Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities" (EPA 1989c). The UTL is calculated by one of two methods, depending on whether the background distribution is normal or lognormal. These calculation methods are presented in the Work Plan Addendum, Section 4.3 (DOE, 1992a).

Background soil values for radionuclides and inorganic chemicals are provided in Table D.2-2. Background levels of organic chemicals are assumed to be zero.

D.2.3 SELECTING CONSTITUENTS OF CONCERN

Radionuclide and chemical constituents of concern for Operable Unit 4 are identified using statistical methods outlined in the Risk Assessment Work Plan Addendum. Analysis of the data that characterize Operable Unit 4 includes consideration for those data that characterize the silo wastes, soil within the Operable Unit 4 Study Area, berm fill material, and background concentrations of radionuclides and chemicals not attributable to the site. The raw data sets on which the analyses are performed are presented in Section 4.0 of the RI and are tabulated in Section 4.0 and Appendices A, B, and C.

D.2.3.1 Comparison of Site-Related Data to Background Data

The mean of the site-related data for a contaminant and medium is compared to the mean of the background data for the same contaminant in the same medium. This comparison is made by a t-test (or Wilcoxon Rank Sum Test if a t-test cannot be applied). If the test reveals that the mean of the site-related data does not statistically exceed the mean of the background data ($\alpha = 0.05$), then the contaminant is not considered to be a COC unless comparison of the values of the site-related data to the background UTL indicates the contaminant is a COC. In cases where the quantity of background data is insufficient, that contaminant is retained as a COC. Because organic chemicals, some fission product radionuclides, and activation product radionuclides are not naturally occurring at measurable levels, their background concentrations are assumed to be zero. Consequently, if these organic

TABLE D.2-2

BACKGROUND DATA FOR RADIONUCLIDES AND CHEMICALS IN SOIL

Contaminants[a]	Frequency of Detection[a]	Range of Detections	Distribution[b]	Mean[c]	UTL for Background[d]
Radionuclides (pCi/g)					
Actinium-227[h]	1/30	0.09 - 0.09	N/A	0.066	0.197
Cesium-137	30/30	0.15 - 0.71	L	0.341	0.920
Lead-210	30/30	0.53 - 1.30	L	0.904	1.52
Potassium-40	30/30	13.1 - 21.4	L	16.1	21.1
Protactinium-231[h]	0/30	Avg SQL = 0.31	N/A	0.066	0.197
Radium-224	30/30	0.54-0.93	L[e]	0.798	1.06
Radium-226	30/30	0.85-1.48	L	1.17	1.56
Radium-228	30/30	0.80-1.27	L[e]	1.05	1.36
Thorium-228	29/30	0.68-1.43	N	1.05	1.56
Thorium-230	29/30	0.90-2.01	N	1.38	2.18
Thorium-232	30/30	0.64-1.52	L	0.998	1.52
Uranium-234	30/30	0.67-1.31	L	0.979	1.35
Uranium-235	27/30	0.03-0.20	L	0.066	0.197
Uranium-238	30/30	0.85-1.33	L	1.04	1.29
Chemicals (mg/kg)					
Aluminum	30/30	5350 - 15000	L	7863	13700
Antimony [f]	0/22	Avg SQL = 7.7	N/A	3.9	7.7
Arsenic	26/26	3.40 - 9.20	L	5.18	10.2

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TABLE D.2-2
(Continued)

Contaminants[a]	Frequency of Detection[a]	Range of Detections	Distribution[b]	Mean[c]	UTL for Background[d]
Barium	30/30	31.0 - 331	L[e]	62.0	162
Beryllium	1/30	0.60 - 0.60	N/A	0.26	0.60
Boron	12/30	12.6 - 1140	L[e]	9.11	26.4
Cadmium	6/29	0.52 -0.95	L[e]	0.32	0.82
Calcium	30/30	856 - 5340	L	1900	5790
Chromium	30/30	6.70 -17.70	L	10.4	17.8
Cobalt	30/30	4.30 - 16.5	L	9.66	17.8
Copper	27/30	3.20 - 17.3	N	7.33	16.4
Cyanide	12/30	0.14 - 0.29	L[e]	0.10	0.34
Iron	30/30	9370 - 24900	L	14500	26000
Lead	28/28	11.0 - 36.4	L	17.2	29.5
Magnesium	30/30	1020 - 3590	L[e]	1650	3330
Manganese	30/30	189 - 4850	L	650	2520
Mercury[g]	1/30	0.30 - 0.30	N/A	0.07	0.30
Molybdenum[f]	0/30	Avg SQL = 2.6	N/A	1.3	2.6
Nickel	29/30	5.80 - 22.7	L	9.66	27.33
Potassium	29/30	374 -1590	N	742	1400
Selenium[g]	1/30	0.72 - 0.72	N/A	0.39	0.72
Silicon	30/30	15.1 - 2230	N	1110	1980
Silver[f]	0/30	Avg SQL = 2.6	N/A	1.3	2.6

TABLE D.2-2
(Continued)

Contaminants[a]	Frequency of Detection[a]	Range of Detections	Distribution[b]	Mean[c]	UTL for Background[d]
Sodium	27/30	26.9 - 54.7	N	34.3	57.0
Thallium [g]	1/30	0.58 - 0.58	N/A	0.26	0.58
Vanadium	30/30	11.3 - 32.7	L	19.8	35.3
Zinc	30/30	29.4 - 70.0	L[e]	40.0	68.5

a The sample numbers used in this data set are presented in the CERCLA/RCRA Background Soil Study Report (DOE 1993).
b Determined from probability plots N = Normal, L = Lognormal
c If the distribution is normal, an arithmetic mean is given. If the distribution is lognormal or undefined, a geometric mean is given.
d Upper 95% tolerance level for background data with a 95% level of confidence
e The distribution could not be definitively determined. It is treated as lognormal.
f All of the values in the data set were not detectable. One-half of the SQL was substituted as the best representative value for the mean and the SQL was substituted as the best representative value for the UTL.
g Ten percent or fewer measured concentrations were above the SQL. The median was substituted as the best estimate of the mean and the maximum detected value was substituted as the UTL.
h Because of poor SQL values, this nuclide was assumed to be in secular equilibrium with its parent, U-235.

chemicals, fission products, or activation products are selected as constituents of concern, they are not based on comparison to background.

D.2.3.2 Other Criteria for Selecting Constituents of Concern

In accordance with EPA guidance (EPA 1989), other criteria are applied to determine nonradioactive COCs. Chemicals are omitted if they are essential human nutrients (dietary elements) and are toxic only at high doses (e.g., sodium, potassium, magnesium, calcium, and iron). Although several human epidemiologic studies associate high levels of sodium in drinking water with hypertension, equally as many studies found no association, and the connection between high sodium intake and hypertension remains unproved (EPA, 1985). General classes of compounds such as total organic carbon are eliminated as COCs because they are inappropriate for use in quantitative evaluation of risk. Contaminants that are ubiquitous and generally considered to be nontoxic except at very high doses (e.g., aluminum, chloride, and silicon) are not considered to be COCs. Organic and inorganic analytes found to be the result of possible blank contamination in the validation process were treated as nondetects and not selected as COCs.

D.2.3.3 Results of Selecting Constituents of Potential Concern

D.2.3.3.1 K-65 Silos

All radionuclides and organic compounds that were detected in samples from the K-65 silos were selected as constituents of potential concern. Of the inorganic contaminants, aluminum and silicon were not selected because they are ubiquitous elements in soil. Calcium, iron, magnesium, potassium, and sodium were not selected because they are common dietary elements. (Aluminum, calcium, magnesium, and potassium were also within soil background levels.) Manganese was not selected because sample concentrations were within background levels. All other inorganic contaminants detected in the K-65 silos were selected as COCs. A variety of organic chemicals including aroclors and phthalates are included as COCs. The reason for inclusion or exclusion of each contaminant is given in Table D.2-3.

D.2.3.3.2 Silo 3

All radionuclides that were detected in samples from Silo 3 were selected as COCs. Of the inorganic contaminants, aluminum was not selected because it is a ubiquitous element in soil. Calcium, iron, magnesium, potassium, and sodium were not selected because they are common dietary elements. (Calcium was also within soil background levels.) Antimony was excluded because the concentrations do not differ significantly from background. All other inorganic contaminants detected in Silo 3 were selected as constituents of potential concern. The organic chemicals 2-nitrophenol and 4-nitrophenol were detected and are included as COCs. The reason for inclusion or exclusion of each contaminant is given in Table D.2-4.

TABLE D.2-3

SELECTION OF CONSTITUENT OF POTENTIAL CONCERN FROM RI/FS SAMPLING OF THE K65 SILOS

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N- No	Reason for Inclusion or Exclusion
Radionuclides (pCi/g)							
Ac-227	24/34	2900 -17400	N	5610	6750	Y	Sample concentration above background (C)
Ac-227[d]	23/33	13.0 - 11100	N	5250	6260	Y	
Pa-231	1/33	4040 - 4040	L[e]	3490	4040[f]	Y	Sample concentration above background (C)
Pb-210	33/33	49000 -399000	L	150000	182000	Y	Sample concentration above background (A, C)
Po-210	21/21	55300 - 434000	N	203000	236000	Y	Sample concentration above background (C)
Po-210[d]	20/20	55300 - 296000	N	192000	219000	Y	
Ra-226	33/33	657 - 891000	L	459000	891000	Y	Sample concentration above background (B, C)
Th-228	7/34	411 - 7360	L[e]	503	641	Y	Sample concentration above background (C)
Th-230	33/33	8360 - 105000	L	50700	63800	Y	Sample concentration above background (B, C)
Th-232	11/34	661 - 1110	L[e]	415	502	Y	Sample concentration above background (C)
U-234	33/33	121 - 1550	N	861	963	Y	Sample concentration above background (A, C)
U-235/236	25/33	19.1 - 172	L	53.0	69.5	Y	Sample concentration above background (B, C)
U-238	34/34	46.0 - 1920	L	795	970	Y	Sample concentration above background (A, C)
Chemicals (mg/kg)							
2-Butanone	5/18	0.00200-0.0220	L[e]	0.00731	0.00942	Y	Positive detect with no reason for exclusion
2-Hexanone	6/18	0.00200-0.0170	L[e]	0.00862	0.0138	Y	Positive detect with no reason for exclusion
4,4'-DDE	2/33	0.0290-0.120	L[e]	0.203	0.120[f]	Y	Positive detect with no reason for exclusion
4,4'-DDT	2/33	0.0140-0.0680	L[e]	0.196	0.0680[f]	Y	Positive detect with no reason for exclusion
4-Methyl-2-pentanone	3/19	0.00200-0.00300	L[e]	0.00746	0.00300[f]	Y	Positive detect with no reason for exclusion

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TABLE D.2-3
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N- No	Reason for Inclusion or Exclusion
Acetone	9/18	0.0330-0.150	N	0.0544	0.0738	Y	Positive detect with no reason for exclusion
Aldrin	1/33^j	0.0560-0.0560	L[e]	0.0917	0.0560[f]	Y	Positive detect with no reason for exclusion
Aluminum	33/33	60.4-2570	N	1150	1340	N	Sample concentration within background (B', C')
Antimony	18/20	13.3-77.4	L	23.2	30.4	Y	Sample concentration above background (C)
Aroclor-1248	3/30	1.70-10.0	L[e]	1.09	1.59	Y	Positive detect with no reason for exclusion
Aroclor-1254	25/25	0.420-20.0	N	7.18	8.98	Y	Positive detect with no reason for exclusion
Aroclor-1260	3/33	0.340-3.50	L[e]	2.00	2.61	Y	Positive detect with no reason for exclusion
Arsenic	32/33	3.10-1960	L	197	671	Y	Sample concentration above background (B, C)
Barium	33/33	89.2-22100	N	9620	11600	Y	Sample concentration above background (B, C)
Benzoic Acid	7/21	0.0750-0.390	L[e]	0.551	0.390[f]	Y	Positive detect with no reason for exclusion
Beryllium	31/33	0.590-6.00	L	1.36	1.71	Y	Sample concentration above background (C)
Bis(2-ethylhexyl)phthalate	20/24	0.0700-6.00	L	0.666	0.960	Y	Positive detect with no reason for exclusion
Boron	20/20	18.4-81.2	N	47.2	53.0	Y	Sample concentration above background (C)
Cadmium	22/30	0.560-19.1	L	3.28	8.15	Y	Sample concentration above background (C)
Calcium	33/33	64.0-301000	L	11900	26000	N	Common dietary element
Carbon Tetrachloride	1/19	0.170-0.170	L[e]	0.00443	0.00631	Y	Positive detect with no reason for exclusion
Chromium	33/33	0.207-165	L	53.6	88.8	Y	Sample concentration above background (A, C)
Cobalt	33/33	6.20-2430	L	1230	1860	Y	Sample concentration above background (B, C)
Copper	32/32	122-1790	L	374	461	Y	Sample concentration above background (B, C)
Cyanide	32/32	0.520-7.10	L	2.73	3.39	Y	Sample concentration above background (C)
Di-n-butyl phthalate	2/32	0.0460-0.0570	L[e]	0.203	0.0570[f]	Y	Positive detect with no reason for exclusion
Di-n-octyl phthalate	8/32	0.0450-0.970	L[e]	0.239	0.281	Y	Positive detect with no reason for exclusion

TABLE D.2-3
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N- No	Reason for Inclusion or Exclusion
Dieldrin	1/33^j	0.0930-0.0930	L[e]	0.193	0.0930[f]	Y	Positive detect with no reason for exclusion
Diethyl phthalate	1/19	0.410-0.410	L[e]	0.261	0.288	Y	Positive detect with no reason for exclusion
Dimethyl phthalate	5/19	0.0680-0.160	L[e]	0.183	0.160[f]	Y	Positive detect with no reason for exclusion
Endosulfan II	2/33	0.0820-0.260	L[e]	0.215	0.260[f]	Y	Positive detect with no reason for exclusion
Endosulfan-I	2/33	0.0110-0.0920	L[e]	0.0988	0.0920[f]	Y	Positive detect with no reason for exclusion
Endrin	1/33^j	0.0890-0.0890	L[e]	0.202	0.0890[f]	Y	Positive detect with no reason for exclusion
Fluoranthene	1/32^j	0.0640-0.0640	L[e]	0.212	0.0640[f]	Y	Positive detect with no reason for exclusion
Heptachlor Epoxide	2/33	0.0220-0.200	L[e]	0.122	0.169	Y	Positive detect with no reason for exclusion
Iron	32/32	4010-75100	L	15000	20100	N	Common dietary element
Lead	33/33	153-299000	L	98500	195000	Y	Sample concentration above background (B, C)
Magnesium	33/33	805-8740	L	3290	3960	N	Common dietary element
Manganese	33/33	25.6-403	L	109	145	N	Sample concentration within background (A', C')
Mercury	31/32	0.150-2.80	L	0.733	1.06	Y	Sample concentration above background (C)
Methylene Chloride	4/19	0.0150-0.190	L[e]	0.0167	0.0276	Y	Positive detect with no reason for exclusion
Molybdenum	20/20	148-8600	L	3030	8600[f]	Y	Sample concentration above background (C)
N-nitroso-di-n-propylamine	4/19	0.0590-0.260	L[e]	0.214	0.260[f]	Y	Positive detect with no reason for exclusion
Nickel	33/33	14.6-3380	N	1620	1860	Y	Sample concentration above background (B, C)
Phenol	1/19	0.400-0.400	L[e]	0.256	0.280	Y	Positive detect with no reason for exclusion
Potassium	33/33	37.8-715	N	339	394	N	Common dietary element
Pyrene	1/32^j	0.0470-0.0470	L[e]	0.210	0.0470[f]	Y	Positive detect with no reason for exclusion
Selenium	32/32	49.6-2810	L	169	217	Y	Sample concentration above background (C)

TABLE D.2-3
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N- No	Reason for Inclusion or Exclusion
Silicon	20/20	359-1780	L	774	905	N	Ubiquitous element; Sample concentration within background (A', C')
Silver	32/32	5.00-34.9	L	13.4	15.5	Y	Sample concentration above background (C)
Sodium	33/33	226-16700	L	7150	12400	N	Common dietary element
Tetrachlorethene	1/19	0.140-0.140	L[e]	0.00438	0.00614	Y	Positive detect with no reason for exclusion
Thallium	17/30	0.0900-5.70	L	0.680	0.871	Y	Sample concentration above background (C)
Toluene	7/19	0.00200-0.190	L[e]	0.00805	0.0139	Y	Positive detect with no reason for exclusion
Total Xylenes	1/18	0.00300-0.00300	L[e]	0.00457	0.00300[f]	Y	Positive detect with no reason for exclusion
Tributyl phosphate	15/15	0.200-73.0	L	22.4	73.0[f]	Y	Positive detect with no reason for exclusion
Vanadium	33/33	21.9-535	L	182	228	Y	Sample concentration above background (A', C)
Zinc	33/33	7.70-212	L	36.8	52.3	Y	Sample concentration above background (A', C)

a Distribution: N = Normal; L = Lognormal

b If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and frequency of detection ≥ 50%, an arithmetic mean is given. If the distribution is lognormal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric mean is given.

c If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and the frequency of detection ≥ 50%, an arithmetic upper 95% confidence interval (CI) on the mean is given. If the distribution is lognormal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric upper 95% CI on the mean is given.

d Statistics for constituent with outliers rejected.

e Data set contains fewer than seven observations or more than 50% nondetects, therefore the distribution could not be definitively determined. It is treated as lognormal.

f If the upper 95% CI on the mean exceeds the maximum detected concentration or if the sample size ≤ 2, the maximum detected concentration is substituted.

Codes for statistical Test Results

A T-test suggests that site data exceed background data.

A' T-test suggests that site data do not exceed background data.

B WRS test suggests that site data exceed background data.

B' WRS test suggests that site data do not exceed background data.

TABLE D.2-3
(Continued)

C UTL test suggests that site data exceed background data.
C' UTL test suggests that site data do not exceed background data.
D Histogram comparison suggests that site data exceed background data.
D' Histogram comparison suggest that site data do not exceed background data.

TABLE D.2-4

SELECTION OF CONSTITUENTS OF POTENTIAL CONCERN FROM RI/FS SAMPLING OF SILO 3 CONTENTS

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Radionuclides (pCi/g)							
Ac-227	11/11	234 - 1360	L	581	793	Y	Sample concentration above background (C)
Ac-227[d]	10/10	234 - 773	N	503	593	Y	
Pa-231	9/11	266 - 931	L	487	931[e]	Y	Sample concentration above background (C)
Pb-210	11/11	454 - 6430	L	2620	4730	Y	Sample concentration above background (A, C)
Pb-210[d]	10/10	454 - 3670	N	2240	2810	Y	
Ra-224	11/11	64.0 - 453	N	290	367	Y	Sample concentration above background (B, C)
Ra-226	11/11	467 - 6440	N	2970	3870	Y	Sample concentration above background (A, C)
Ra-228	9/11	82.0 - 559	N	297	406	Y	Sample concentration above background (B, C)
Th-228	8/11	459 - 1340	N	686	875	Y	Sample concentration above background (B, C)
Th-230	11/11	21000 - 71600	N	51200	60200	Y	Sample concentration above background (B, C)
Th-232	8/11	411 - 1450	N	682	871	Y	Sample concentration above background (B, C)
U-234	11/11	348 - 1940	L	1480	1940[e]	Y	Sample concentration above background (B, C)
U-235/236	10/11	42.0 - 158	N	95.4	119	Y	Sample concentration above background (B, C)
U-238	11/11	320 - 2040	N	1500	1780	Y	Sample concentration above background (B, C)
Chemicals (mg/kg)							
2-Nitrophenol	1/1	0.0520 - 0.0520	f	f	0.0520[e]	Y	Positive detect with no reason for exclusion
4-Nitrophenol	1/1	0.0450 - 0.0450	f	f	0.0450[e]	Y	Positive detect with no reason for exclusion
Aluminum	11/11	10800 - 23700	N	17200	19300	N	Ubiquitous element
Antimony	1/1	5.50 - 5.50	f	f	5.50[e]	N	Sample concentration within background (C', D')
Arsenic	11/11	532 - 6380	L	1950	3170	Y	Sample concentration above background (B, C)

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TABLE D.2-4
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Arsenic[d]	10/10	532 - 2450	N	1510	1850	Y	
Barium	11/11	118 - 332	N	217	258	Y	Sample concentration above background (B, C)
Beryllium	11/11	10.0 - 39.9	N	24.2	29.1	Y	Sample concentration above background (C)
Cadmium	11/11	21.5 - 204	L	59.8	94.1	Y	Sample concentration above background (C)
Cadmium[d]	10/10	21.5 - 69.8	N	45.3	54.7	Y	
Calcium	11/11	21300 - 39900	L	29400	33400	N	Common dietary element
Chromium	11/11	139 - 560	L	288	395	Y	Sample concentration above background (A, C)
Cobalt	10/10	1100 - 3520	L	2100	2870	Y	Sample concentration above background (C)
Copper	11/11	1610 - 7060	L	2550	3340	Y	Sample concentration above background (B, C)
Copper[d]	10/10	1610 - 2760	N	2100	2320	Y	
Iron	11/11	13900 - 67600	L	37800	52200	N	Common dietary element
Lead	11/11	646 - 4430	L	1730	2380	Y	Sample concentration above background (B, C)
Lead[d]	10/10	646 - 1960	N	1460	1680	Y	
Magnesium	11/11	38200 - 80900	L	58600	68900	N	Common dietary element
Manganese	11/11	2420 - 6500	N	4380	5160	Y	Sample concentration above background (B, C)
Mercury	3/3	0.300 - 0.690	L[g]	0.396	0.690[e]	Y	Sample concentration above background (C)
Nickel	10/10	1760 - 6170	L	3150	4290	Y	Sample concentration above background (C)
Nickel[d]	9/9	1760 - 4230	N	2820	3380	Y	
Potassium	11/11	1300 - 22800	L	7260	14000	N	Common dietary element
Selenium	11/11	101 - 349	L	174	229	Y	Sample concentration above background (C)
Silver	11/11	9.20 - 23.8	N	15.9	18.4	Y	Sample concentration above background (C)
Sodium	11/11	22900 - 51700	L	36100	42000	N	Common dietary element

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TABLE D.2-4
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Thallium	10/10	4.00 - 73.9	L	20.6	56.1	Y	Sample concentration above background (C)
Vanadium	11/11	418 - 4550	L	1820	3490	Y	Sample concentration above background (A, C)
Vanadium[d]	10/10	418 - 3040	N	1550	2040	Y	
Zinc	11/11	301 - 672	L	450	535	Y	Sample concentration above background (A, C)

a Distribution: N = Normal; L = Lognormal

b If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and frequency of detection ≥ 50%, an arithmetic mean is given. If the distribution is log-normal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric mean is given.

c If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and the frequency of detection ≥ 50%, an arithmetic upper 95% confidence interval (CI) on the mean is given. If the distribution is lognormal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric upper 95% CI on the mean is given.

d Statistics for constituent with outliers rejected.

e If the upper 95% CI on the mean exceeds the maximum detected concentration or if the sample size ≤ 2, the maximum detected concentration is substituted.

f Not applicable if sample size ≤2.

g Data set contains fewer than seven observations or more than 50% non-detects, therefore the distribution could not be definitively determined. It is treated as lognormal.

Codes for statistical Test Results

A T-test suggests that site data exceed background data.
A' T-test suggests that site data do not exceed background data.
B WRS test suggests that site data exceed background data.
B' WRS test suggests that site data do not exceed background data.
C UTL test suggests that site data exceed background data.
C' UTL test suggests that site data do not exceed background data.
D Histogram comparison suggests that site data exceed background data.
D' Histogram comparison suggest that site data do not exceed background data.

D.2.3.3.3 Soil

Of the radionuclides detected in soil within the Operable Unit 4 Study Area, cesium-137 (Cs-137), thorium-228 (Th-228), radium-228 (Ra-228), and thorium-232 (Th-232) were not selected as COCs because sample concentrations were within soil background levels. All organic compounds detected in soil were selected as COCs. Of the inorganic contaminants, aluminum was not selected because it is a ubiquitous element in soil. Calcium, iron, magnesium, potassium, and sodium were not selected because they are common dietary elements. (Aluminum, calcium, iron, magnesium, potassium, and sodium were also all within soil background levels.)

Barium, cobalt, cyanide, lead, manganese, and selenium were not selected because sample concentrations were within background levels. All other inorganic contaminants detected in Operable Unit 4 soil were selected as COCs. The reason for inclusion or exclusion of each contaminant is given in Table D.2-5.

In addition to summarizing surface soil and berm fill data in a combined data set for the purpose of selecting COCs, the surface soil and berm fill data were summarized separately to provide two additional source terms for the surface water runoff model (Appendix E). Contaminants were selected for the model source term using the same criteria as for selecting COCs. The selection for the berm fill source term is presented in Table D.2-6, and for the surface soil term in Table D.2-7. Results and a discussion of the surface water runoff model are presented in Appendix E.

The chemicals for which there are no published toxicity data are not evaluated in the risk characterization portion of the risk assessment even though they may be selected as constituents of potential concern in this stage of the risk assessment.

TABLE D.2-5
SELECTION OF CONSTITUENTS OF POTENTIAL CONCERN FROM RI/FS SAMPLING OF SURFACE SOIL AND BERM FILL

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Radionuclides (pCi/g)							
Cs-137	2/8	0.200 - 0.230	L[d]	0.121	0.154	N	Sample concentration within background (C', D')
Pb-210	4/4	0.980 - 4.45	L[d]	1.86	3.98	Y	Sample concentration above background (C)
Po-210	3/3	1.68 - 4.02	L[d]	2.47	4.02[f]	Y	Sample concentration above background (C)
Ra-224	1/1	1.02 - 1.02	e	e	1.02[f]	Y	Sample concentration above background (C', D)
Ra-226	9/9	0.600 - 6.68	L	2.31	5.75	Y	Sample concentration above background (C)
Ra-228	9/9	0.500 - 1.30	N	0.961	1.12	N	Sample concentration within background (C', D')
Sr-90	1/4	1.80 - 1.80	L[d]	0.410	1.31	Y	Sample concentration above background (C)
Tc-99	2/12	1.20 - 3.60	L[d]	0.591	0.821	Y	Sample concentration above background (C)
Th-228	7/8	0.900 - 1.52	N	1.12	1.39	N	Sample concentration within background (C', D')
Th-230	8/8	1.40 - 4.80	N	3.14	4.03	Y	Sample concentration above background (C)
Th-232	7/8	0.860 - 1.45	L	0.904	1.40	N	Sample concentration within background (C', D')
U-234	8/8	1.26 - 3.62	N	2.58	3.17	Y	Sample concentration within background (A, C)
U-238	8/8	1.13 - 15.0	L	4.39	12.0	Y	Sample concentration within background (A, C)
U-238[g]	7/7	1.13 - 4.50	N	2.88	3.85	Y	
Chemicals (mg/kg)							
2-Butanone	4/11	0.00200 - 0.0110	L[d]	0.00445	0.00659	Y	Positive detect with no reason for exclusion
Acenaphthylene	1/10	1.30 - 1.30	L[d]	0.234	0.333	Y	Positive detect with no reason for exclusion
Acetone	4/11	0.00400 - 0.0790	L[d]	0.0110	0.0189	Y	Positive detect with no reason for exclusion

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TABLE D.2-5
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Aluminum	13/13	4690 - 12100	N	8690	9740	N	Ubiquitous element; sample concentration within background (B', C')
Anthracene	1/10	0.780 - 0.780	L[d]	0.223	0.288	Y	Positive detect with no reason for exclusion
Antimony	13/13	19.1 - 32.3	N	26.4	28.7	Y	Sample concentration above background (C)
Aroclor-1254	1/9	0.0300 - 0.0300	L[d]	0.0949	0.0300[f]	Y	Positive detect with no reason for exclusion
Arsenic	13/13	2.70 - 9.50	N	6.22	7.27	Y	Sample concentration above background (B, C')
Barium	13/13	44.7 - 113	L	67.4	78.8	N	Sample concentration within background (A', C')
Benzo(a)anthracene	2/10	0.0620 - 4.70	L[d]	0.238	0.453	Y	Positive detect with no reason for exclusion
Benzo(a)pyrene	1/10	5.20 - 5.20	L[d]	0.269	0.492	Y	Positive detect with no reason for exclusion
Benzo(b)fluoranthene	2/10	0.150 - 9.70	L[d]	0.280	0.577	Y	Positive detect with no reason for exclusion
Benzo(g,h,i)perylene	1/10	5.30 - 5.30	L[d]	0.270	0.495	Y	Positive detect with no reason for exclusion
Benzoic acid	1/6	0.0590 - 0.0590	L[d]	0.770	0.0590[f]	Y	Positive detect with no reason for exclusion
Beryllium	13/13	0.670 - 1.00	L	0.788	0.846	Y	Sample concentration above concentration (C)
Bis(2-ethylhexyl)phthalate	3/10	0.0750 - 1.60	L[d]	0.238	0.407	Y	Positive detect with no reason for exclusion
Cadmium	13/13	2.60 - 6.20	N	4.81	5.36	Y	Sample concentration above concentration (C)
Calcium	13/13	10000 - 131000	L	52500	112000	N	Common dietary element
Chromium	13/13	10.2 - 28.4	L	17.7	20.4	Y	Sample concentration above concentration (A, C)
Chromium[g]	12/12	10.2 - 22.6	N	16.8	18.6	Y	
Chrysene	2/10	0.0620 - 3.50	L[d]	0.231	0.418	Y	Positive detect with no reason for exclusion
Cobalt	13/13	7.80 - 14.8	L	11.0	12.1	N	Sample concentration within background (B', C')
Copper	13/13	16.2 - 23.8	L	19.8	21.0	Y	Sample concentration above background (B, C)

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TABLE D.2-5
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Cyanide	2/12	0.120 - 0.120	L[d]	0.0649	0.0755	N	Sample concentration within background (C', D')
Di-n-butylphthalate	2/10	0.0480 - 0.190	L[d]	0.168	0.190[f]	Y	Positive detect with no reason for exclusion
Dibenzo(a,h)anthracene	1/10	0.900 - 0.900	L[d]	0.226	0.300	Y	Positive detect with no reason for exclusion
Fluoranthene	3/10	0.0400 - 6.70	L[d]	0.216	0.465	Y	Positive detect with no reason for exclusion
Indeno(1,2,3-cd)pyrene	1/10	4.20 - 4.20	L[d]	0.263	0.463	Y	Positive detect with no reason for exclusion
Iron	13/13	11100 - 26300	N	18600	20700	N	Common dietary element
Lead	13/13	6.70 - 17.0	L	11.7	13.6	N	Sample concentration within background (B', C')
Magnesium	13/13	6390 - 26800	N	19200	22500	N	Common dietary element
Manganese	13/13	372 - 1130	L	526	608	N	Sample concentration within background (A', C')
Manganese[g]	12/12	372 - 530	N	476	505	N	
Methylene Chloride	1/11	0.0250 - 0.0250	L[d]	0.00634	0.00890	Y	Positive detect with no reason for exclusion
Molybdenum	13/13	2.40 - 13.3	L	4.73	5.88	Y	Sample concentration above background (C)
Molybdenum[g]	12/12	2.40 - 4.90	N	4.02	4.42	Y	
Nickel	13/13	21.7 - 38.9	L	28.0	30.8	Y	Sample concentration above background (B, C)
Phenanthrene	1/10	2.60 - 2.60	L[d]	0.251	0.405	Y	Positive detect with no reason for exclusion
Phenol	2/10	0.110 - 0.230	L[d]	0.217	0.230[f]	Y	Positive detect with no reason for exclusion
Potassium	13/13	530 - 1430	N	956	1080	N	Common dietary element
Pyrene	3/10	0.0450 - 8.20	L[d]	0.226	0.496	Y	Positive detect with no reason for exclusion
Selenium	1/13	0.540 - 0.540	L[d]	0.248	0.279	N	Sample concentration within background (C', D')
Silver	13/13	5.80 - 14.4	L	8.65	9.81	Y	Sample concentration above background (C)

TABLE D.2-5
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Silver[g]	12/12	5.80 - 9.70	N	8.17	8.85	Y	
Sodium	11/13	77.7 - 197	L	107	136	N	Common dietary element
Thallium	2/13	0.510 - 0.710	L[d]	0.267	0.321	Y	Sample concentration above background (C)
Toluene	5/11	0.0010 - 0.200	L[d]	0.00330	0.00718	Y	Positive detect with no reason for exclusion
Total Xylenes	1/11	0.0690 - 0.0690	L[d]	0.00380	0.00643	Y	Positive detect with no reason for exclusion
Vanadium	13/13	15.9 - 28.4	N	23.5	25.3	Y	Sample concentration above background (B, C')
Zinc	13/13	32.9 - 65.2	L	46.7	51.8	Y	Sample concentration above background (A, C')

a Distribution: N = Normal; L = Lognormal
b If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and frequency of detection ≥ 50%, an arithmetic mean is given. If the distribution is lognormal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric mean is given.
c If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and the frequency of detection ≥ 50%, an arithmetic upper 95% confidence interval (CI) on the mean is given. If the distribution is lognormal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric upper 95% CI on the mean is given.
d Data set contains fewer than seven observations or more than 50% nondetects; therefore the distribution could not be definitively determined. It is treated as log-normal.
e Not applicable if sample size ≤2.
f If the upper 95% CI on the mean exceeds the maximum detected concentration or if the sample size ≤ 2, the maximum detected concentration is substituted.
g Statistics for constituent with outliers rejected

Codes for statistical Test Results
A T-test suggests that site data exceed background data.
A' T-test suggests that site data do not exceed background data.
B WRS test suggests that site data exceed background data.
B' WRS test suggests that site data do not exceed background data.
C UTL test suggests that site data exceed background data.
C' UTL test suggests that site data do not exceed background data.
D Histogram comparison suggests that site data exceed background data.

TABLE D.2-5
(Continued)

D' Histogram comparison suggest that site data do not exceed background data.

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TABLE D.2-6

SELECTION OF CONSTITUENTS OF POTENTIAL CONCERN FROM RI/FS SAMPLING OF BERM FILL

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Radionuclides (pCi/g)							
Cs-137	1/2	0.230 - 0.230	d	d	0.230[e]	N	Sample concentration within background (C', D')
Pb-210	4/4	0.980 - 4.45	L[f]	1.86	3.98	Y	Sample concentration above background (C)
Po-210	3/3	1.68 - 4.02	L[f]	2.47	4.02[e]	Y	Sample concentration above background (C)
Ra-224	1/1	1.02 - 1.02	d	d	1.02[e]	Y	Sample concentration above background (C', D)
Ra-226	3/3	1.04 - 6.68	L[f]	2.94	6.68[e]	Y	Sample concentration above background (C)
Ra-228	3/3	0.800 - 0.980	L[f]	0.913	0.98[e]	N	d-Sample concentration within background (C', D')
Th-228	4/4	1.12 - 1.52	L[f]	1.36	1.52[e]	Y	Sample concentration above background (C', D)
Th-230	4/4	1.69 - 4.78	L[f]	3.09	4.78[e]	Y	Sample concentration above background (C)
Th-232	4/4	0.86 - 1.45	L[f]	1.01	1.35	N	Sample concentration within background (C', D')
U-234	4/4	1.26 - 3.62	L[f]	1.99	3.62	Y	Sample concentration above background (C)
U-238	4/4	1.13 - 4.17	L[f]	2.12	4.17[e]	Y	Sample concentration above background (C)
Chemicals (mg/kg)							
2-Butanone	1/3	0.0110 - 0.0110	L[f]	0.00734	0.0110[e]	Y	Positive detect with no reason for exclusion
Acetone	1/3	0.0640 - 0.0640	L[f]	0.0145	0.0640[e]	Y	Positive detect with no reason for exclusion
Aluminum	3/3	9040 - 12100	L[f]	10300	12100[e]	N	Ubiquitous element; sample concentration within background (C')
Antimony	3/3	19.1 - 24.9	L[f]	21.4	24.9[e]	Y	Sample concentration above background (C)
Arsenic	3/3	5.00 - 8.00	L[f]	6.07	8.00[e]	Y	Sample concentration above background (C', D)

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TABLE D.2-6
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Barium	3/3	47.1 - 89.4	L[f]	66.4	89.4[e]	N	Sample concentration within background (C', D')
Beryllium	3/3	0.670 - 0.850	L[f]	0.773	0.850[e]	Y	Sample concentration above background (C)
Cadmium	3/3	2.60 - 4.20	L[f]	3.27	4.20[e]	Y	Sample concentration above background (C)
Calcium	3/3	30000 - 95600	L[f]	48400	95600[e]	N	Common dietary element
Chromium	3/3	16.4 - 28.4	L[f]	21.0	28.4[e]	Y	Sample concentration above background (C)
Cobalt	3/3	11.0 - 13.3	L[f]	11.8	13.3[e]	N	Sample concentration within background (C', D')
Copper	3/3	19.3 - 23.8	L[f]	21.2	23.8[e]	Y	Sample concentration above background (C)
Cyanide	1/2	0.120 - 0.120	d	d	0.120[e]	N	Sample concentration within background (C', D')
Di-n-butylphthalate	1/2	0.0480 - 0.0480	d	d	0.0480[e]	Y	Positive detect with no reason for exclusion
Iron	3/3	18600 - 25400	L[f]	21500	25400[e]	N	Common dietary element
Lead	3/3	9.00 - 11.9	L[f]	10.8	11.9[e]	N	Sample concentration within background (C', D')
Magnesium	3/3	6390 - 23900	L[f]	12900	23900[e]	N	Common dietary element
Manganese	3/3	395 - 519	L[f]	438	519[e]	N	Sample concentration within background (C', D')
Molybdenum	3/3	2.40 - 13.3	L[f]	4.67	13.3[e]	Y	Sample concentration above background (C)
Nickel	3/3	21.7 - 32.4	L[f]	25.7	32.4[e]	Y	Sample concentration above background (C)
Phenol	1/2	0.110 - 0.110	d	d	0.110[e]	Y	Positive detect with no reason for exclusion
Potassium	3/3	711 - 1230	L[f]	981	1230[e]	N	Common dietary element
Silver	3/3	5.80 - 14.4	L[f]	8.44	14.4[e]	Y	Sample concentration above background (C)
Sodium	3/3	77.7 - 197	L[f]	107	197[e]	N	Common dietary element

TABLE D.2-6
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Thallium	1/3	0.710 - 0.710	L[f]	0.337	0.710[e]	Y	Sample concentration above background (C)
Toluene	3/3	0.00200 - 0.200	L[f]	0.0106	0.200[e]	Y	Positive detect with no reason for exclusion
Total Xylenes	1/3	0.0690 - 0.0690	L[f]	0.00853	0.0690[e]	Y	Positive detect with no reason for exclusion
Vanadium	3/3	24.6 - 28.4	L[f]	26.8	28.4[e]	Y	Sample concentration above background (C', D)
Zinc	3/3	44.2 - 59.6	L[f]	50.4	59.6[e]	Y	Sample concentration above background (C', D)

a Distribution: N = Normal; L = Lognormal

b If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and frequency of detection ≥ 50%, an arithmetic mean is given. If the distribution is lognormal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric mean is given.

c If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and the frequency of detection ≥ 50%, an arithmetic upper 95% confidence interval (CI) on the mean is given. If the distribution is lognormal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric upper 95% CI on the mean is given.

d Not applicable if sample size ≤2.

e If the upper 95% CI on the mean exceeds the maximum detected concentration or if the sample size ≤ 2, the maximum detected concentration is substituted.

f Data set contains fewer than seven observations or more than 50% nondetects, therefore the distribution could not be definitively determined. It is treated as log-normal.

Codes for statistical Test Results

A T-test suggests that site data exceed background data.
A' T-test suggests that site data do not exceed background data.
B WRS test suggests that site data exceed background data.
B' WRS test suggests that site data do not exceed background data.
C UTL test suggests that site data exceed background data.
C' UTL test suggests that site data do not exceed background data.
D Histogram comparison suggests that site data exceed background data.
D' Histogram comparison suggest that site data do not exceed background data.

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TABLE D.2-7

SELECTION OF CONSTITUENTS OF POTENTIAL CONCERN FROM RI/FS SAMPLING OF SURFACE SOIL

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Radionuclides (pCi/g)							
Cs-137	1/6	0.200 - 0.200	L[d]	0.112	0.142	N	Sample concentration within background (C', D')
Ra-226	6/6	0.600 - 4.20	L[d]	1.27	2.18	Y	Sample concentrations above background (C)
Ra-228	6/6	0.500 - 1.30	L[d]	0.937	1.26	N	Sample concentration within background (C', D')
Sr-90	1/3	1.80 - 1.80	L[d]	0.483	1.80[e]	Y	Sample concentrations above background (C)
Tc-99	2/10	1.20 - 3.60	L[d]	0.623	0.929	Y	Sample concentrations above background (C)
Th-228	3/4	0.900 - 1.20	L[d]	0.773	1.20[e]	N	Sample concentration within background (C', D')
Th-230	4/4	1.40 - 4.80	L[d]	2.66	4.80[e]	Y	Sample concentrations above background (C)
Th-232	3/4	0.900 - 1.00	L[d]	0.702	1.00[e]	N	Sample concentration within background (C', D')
U-234	4/4	2.40 - 3.40	L[d]	2.92	3.40[e]	Y	Sample concentration above background (C)
U-238	4/4	2.40 -15.0	L[d]	4.81	12.3	Y	Sample concentration above background (C)
Chemicals (mg/kg)							
2-Butanone	3/8	0.00200 - 0.00800	L[d]	0.00369	0.00607	Y	Positive detect with no reason for exclusion
Acenaphthylene	1/8	1.30 - 1.30	L[d]	0.243	0.383	Y	Positive detect with no reason for exclusion
Acetone	3/8	0.00400 - 0.0790	L[d]	0.00992	0.0185	Y	Positive detect with no reason for exclusion
Aluminum	10/10	4690 - 10900	N	8180	9370	N	Ubiquitous element; sample concentration within background (C')
Anthracene	1/8	0.780 - 0.780	L[d]	0.228	0.318	Y	Positive detect with no reason for exclusion
Antimony	10/10	20.6 - 32.3	N	27.9	30.1	Y	Sample concentrations above background (C)
Aroclor-1254	1/9	0.0300 - 0.0300	L[d]	0.0949	0.0300[e]	Y	Positive detect with no reason for exclusion

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TABLE D.2-7
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Arsenic	10/10	2.70 - 9.50	N	6.23	7.58	Y	Sample concentrations above background (C', D)
Barium	10/10	44.7 - 113	L	67.0	81.0	N	Sample concentrations within background (A', C')
Barium[f]	9/9	44.7 - 80.3	N	61.9	70.1	Y	
Benzo(a)anthracene	2/8	0.0620 - 4.70	L[d]	0.248	0.574	Y	Positive detect with no reason for exclusion
Benzo(a)pyrene	1/8	5.20 - 5.20	L[d]	0.289	0.632	Y	Positive detect with no reason for exclusion
Benzo(b)fluoranthene	2/8	0.150 - 9.70	L[d]	0.303	0.777	Y	Positive detect with no reason for exclusion
Benzo(g,h,i)perylene	1/8	5.30 - 5.30	L[d]	0.290	0.637	Y	Positive detect with no reason for exclusion
Benzoic acid	1/4	0.0590 - 0.0590	L[d]	0.684	0.0590[e]	Y	Positive detect with no reason for exclusion
Beryllium	10/10	0.670 - 1.00	L	0.792	0.866	Y	Sample concentrations above background (C)
Bis(2-ethylhexyl)phthalate	3/8	0.0750 - 1.60	L[d]	0.247	0.499	Y	Positive detect with no reason for exclusion
Cadmium	10/10	3.70 - 6.20	N	5.25	5.68	Y	Sample concentrations above background (C)
Calcium	10/10	10000 - 131000	L	51700	131000[e]	N	Common dietary element
Chromium	10/10	10.2 - 22.6	N	16.6	18.6	Y	Sample concentrations above background (C)
Chrysene	2/8	0.0620 - 3.50	L[d]	0.239	0.518	Y	Positive detect with no reason for exclusion
Cobalt	10/10	7.80 - 14.8	L	10.7	12.1	N	Sample concentration within background (C', D')
Copper	10/10	16.2 - 23.5	L	19.4	20.8	Y	Sample concentrations above background (C)
Cyanide	1/10	0.120 - 0.120	L[d]	0.0616	0.0707	N	Sample concentration within background (C', D')
Di-n-butylphthalate	1/8	0.190 - 0.190	L[d]	0.191	0.190[e]	Y	Positive detect with no reason for exclusion
Dibenzo(a,h)anthracene	1/8	0.900 - 0.900	L[d]	0.232	0.335	Y	Positive detect with no reason for exclusion
Fluoranthene	3/8	0.0400 - 6.70	L[d]	0.219	0.599	Y	Positive detect with no reason for exclusion

TABLE D.2-7
(Continued)

Constituent	Frequency of Detection	Range of Detection	Distribution[a]	Mean[b]	UCL on Mean[c]	Include? Y - Yes N - No	Reason for Inclusion or Exclusion
Indeno(1,2,3-cd)pyrene	1/8	4.20 - 4.20	L[d]	0.281	0.585	Y	Positive detect with no reason for exclusion
Iron	10/10	11100 - 26300	L	17700	20800	N	Common dietary element
Lead	10/10	6.70 - 17.0	L	11.9	14.8	N	Sample concentration within background (C', D')
Magnesium	10/10	10800 - 26800	N	20600	23800	N	Common dietary element
Manganese	10/10	372 - 1130	L	551	665	N	Sample concentration within background (A', C')
Methylene chloride	1/8	0.0250 - 0.0250	L[d]	0.00700	0.0105	Y	Positive detect with no reason for exclusion
Molybdenum	10/10	3.20 - 4.90	N	4.26	4.58	Y	Sample concentrations above background (C)
Nickel	10/10	22.8 - 38.9	L	28.5	32.0	Y	Sample concentrations above background (C)
Phenanthrene	1/8	2.60 - 2.60	L[d]	0.265	0.492	Y	Positive detect with no reason for exclusion
Phenol	1/8	0.230 - 0.230	L[d]	0.239	0.230[e]	Y	Positive detect with no reason for exclusion
Potassium	10/10	530 - 1430	N	940	1080	N	Common dietary element
Pyrene	3/8	0.0450 - 8.200	L[d]	0.233	0.650	Y	Positive detect with no reason for exclusion
Selenium	1/10	0.540 - 0.540	L[d]	0.252	0.295	N	Sample concentration within background (C', D')
Silver	10/10	6.60 - 9.70	N	8.50	9.15	Y	Sample concentrations above background (C)
Sodium	8/10	97.2 - 145	L	104	137	N	Common dietary element
Thallium	1/10	0.510 - 0.510	L[d]	0.249	0.289	N	Sample concentration within background (C', D')
Toluene	2/8	0.00100 - 0.00100	L[d]	0.00213	0.00100[e]	Y	Positive detect with no reason for exclusion
Vanadium	10/10	15.9 - 27.7	N	22.5	24.5	N	Sample concentration within background (C', D')
Zinc	10/10	32.9 - 65.2	L	45.5	52.1	N	Sample concentration within background (A', C')

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TABLE D.2-7
(Continued)

a Distribution: N = Normal; L = Lognormal.

b If the distribution is normal or if the distribution is log-normal, the number of detects ≥ 7, and frequency of detection ≥ 50%, an arithmetic mean is given. If the distribution is log-normal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric mean is given.

c If the distribution is normal or if the distribution is log-normal, the number of detects ≥ 7, and the frequency of detection ≥ 50%, an arithmetic upper 95% confidence interval (CI) on the mean is given. If the distribution is log-normal and either the number of detects < 7 or the frequency of detection is < 50%, a geometric upper 95% CI on the mean is given.

d Data set contains fewer than seven observations or more than 50% non-detects, therefore the distribution could not be definitively determined. It is treated as log-normal.

e If the upper 95% CI on the mean exceeds the maximum detected concentration or if the sample size ≤ 2, the maximum detected concentration is substituted.

f Statistics for constituent with outliers rejected.

Codes for statistical Test Results

A T-test suggests that site data exceed background data.
A' T-test suggests that site data do not exceed background data.
B WRS test suggests that site data exceed background data.
B' WRS test suggests that site data do not exceed background data.
C UTL test suggests that site data exceed background data.
C' UTL test suggests that site data do not exceed background data.
D Histogram comparison suggests that site data exceed background data.
D' Histogram comparison suggest that site data do not exceed background data.

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D.3.0 EXPOSURE ASSESSMENT

The exposure assessment is the determination of the magnitude of contact that a potential receptor may have with site-related COCs. The exposure assessment involves three stages:

- Characterization of the operable unit setting
- Identification of contaminant migration and exposure pathways
- Quantification of exposure pathways

The setting and physical characteristics of Operable Unit 4 are discussed in Section 3.0 of the Operable Unit 4 RI Report. A conceptual model for the risk assessment for Operable Unit 4 is developed in Section D.3.1. The conceptual model develops contaminant migration and exposure pathways from source terms in Operable Unit 4 through release mechanisms, secondary sources, exposure media, and exposure routes for each receptor applicable to the operable unit. The methodology used to quantify exposures is presented at the end of the exposure assessment.

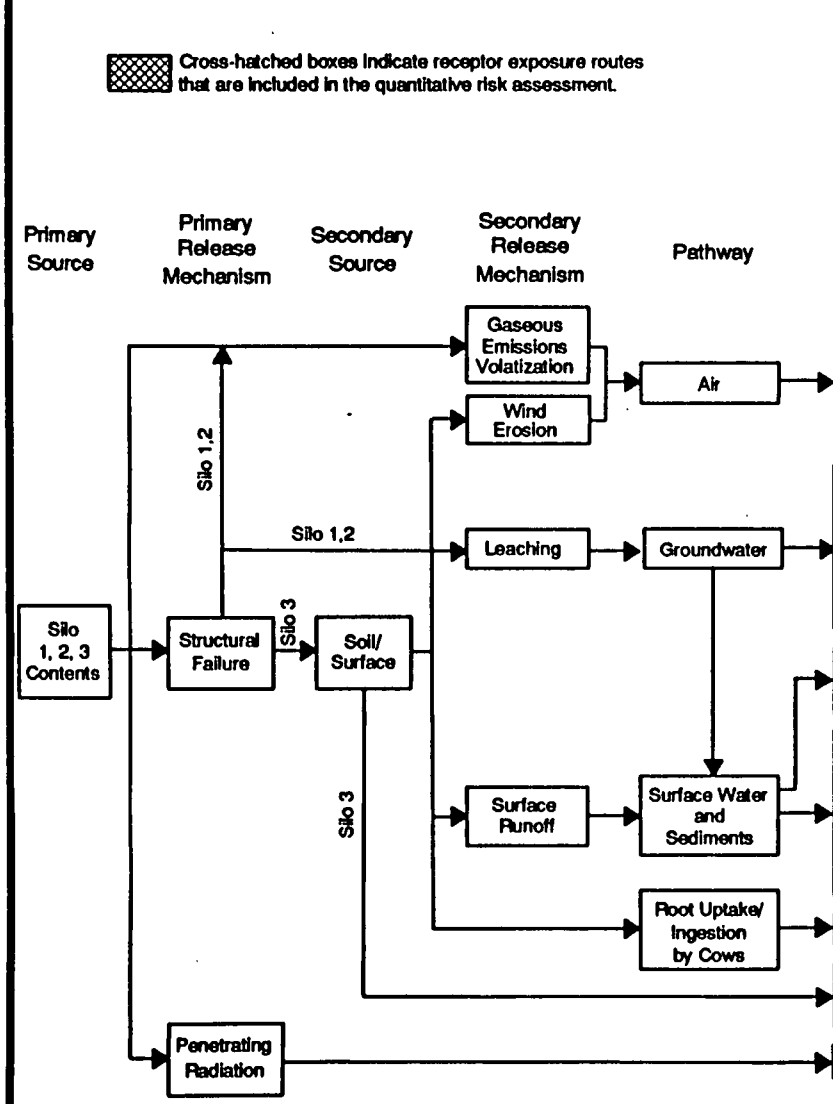
D.3.1 CONCEPTUAL MODEL FOR OPERABLE UNIT 4

A conceptual model for the risk assessment for Operable Unit 4 has been developed to provide the basis for identifying and evaluating the potential risks to human health in the baseline risk assessment. The conceptual model considers only the potential risks to human health. The potential impacts on environmental receptors are considered within the scope of Operable Unit 5.

The conceptual model facilitates consistent and comprehensive evaluation of risks to human health by creating a framework for identifying the paths by which human health may be impacted by Operable Unit 4. The elements necessary to construct a complete exposure pathway and develop the conceptual model include:

- Sources and potential constituents of concern
- Release mechanisms
- Transport pathways
- Exposure pathway scenarios
- Receptors

Figures D.3-1 and D.3-2 present the conceptual model for potential human exposure to the contents of the silos and the soil in Operable Unit 4. The conceptual model illustrated in these figures traces the exposure pathways and receptors for Operable Unit 4 from the source, through primary release mechanisms, secondary sources and release mechanisms, and exposure routes and receptors. The conceptual model also indicates which exposure routes are carried through the quantitative risk assessment for each receptor under three land use scenarios: current land use without access controls, current land use with access controls, and future land use without access controls. These three land use scenarios were explained in detail in Section D.1.2. Objectives of the development of the



Exposure Routes	Receptors: Current Land Use without Access Control				Current Land Use with Access Control			Future Land Use				
	Trespassing Child	Groundskeeper Worker	Off-Property Farmer	Off-Property User of Surface Water	Trespassing Child	Off-Property Farmer	Off-Property User of Surface Water	CT On-Property Farmer	RME On-Property Farmer	On-Property Resident Child	Off-Property Farmer	Off-Property User of Surface Water
Inhalation				1			1					1
Dermal Contact	2	2	2	1	2	2	1	2	2	2	2	1
Direct Radiation	2,3	2,3	2,3	1	2,3	2,3	1	2,3	2,3	2,3	2,3	1
Food Stuffs	4	4		1	4		1					1
Inhalation VOCs	4	4		1	4		1					1
Ingest Drinking Water	4	4		1	4		1		8			1
Food Stuffs	4	4		1	4		1					1
Dermal Contact	4	4		1	4		1					1
Direct Radiation	2,3	2,3	2,3	1	2,3	2,3	1	2,3	2,3	2,3	2,3	1
Incidental Ingestion	9	5	2	2	9	2	2	2	2	9	2	2
Dermal Contact	9	5	2	2	9	2	2	2	2	9	2	2
Inhalation VOCs	4	4	6		4	6		6	6	6	6	
Ingest Drinking Water	4	4	6		4	6		6	6	6	6	
Food Stuffs	4	4	6		4	6		6	6	6	6	
Dermal Contact	4	4	6		4	6		6	6	6	6	
Direct Radiation	4	4	6	2,3	4	6	2,3	6	6	6	6	2,3
Food Stuffs	4	4	7	1	4	7	1				7	1
Incidental Ingestion			7	1		7	1				7	1
Dermal Contact			7	1		7	1				7	1
Direct Radiation			2	1		2	1				2	1

1) The objective of quantifying exposure routes to the off-property user of surface water is to isolate and evaluate the impact of contamination from the Great Miami River through water pathways.
2) Potential impact of exposure route is minor compared to other exposure routes.
3) EPA risk assessment methodology for radionuclides does not address this exposure route.
4) Exposure route is not applicable to a transient, non-resident receptor.
5) Receptor is assumed to restrict activites at OU4 and not contact surface water via these exposure routes.
6) Receptor is assumed to obtain water for all needs from groundwater.
7) Off-property soil is within the scope of OU5. Impact on food stuff exposure routes from air deposition is included in the air exposure routes.
8) Evaluated using two different exposure point concentrations: modeled aquifer concentration and modeled sand lens concentration.
9) Evaluated for sediment ingestion and dermal contact with sediment using modeled concentration impacted by sand lens.

FIGURE D.3-1. OU4 CONCEPTUAL MODEL-SILO CONTENTS

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Cross-hatched boxes indicate receptor exposure routes that are included in the quantitative risk assessment.

Source: Soil: Surface, Subsurface, Berm Fill

Release Mechanism → Pathway → Exposure Routes

Release Mechanism	Pathway	Exposure Routes	Receptors: Current Land Use without Access Control				Current Land Use with Access Control			Future Land Use				
			Trespassing Child	Groundskeeper Worker	Off-Property Farmer	Off-Property User of Surface Water	Trespassing Child	Off-Property Farmer	Off-Property User of Surface Water	CT On-Property Farmer	RME On-Property Farmer	On-Property Resident Child	Off-Property Farmer	Off-Property User of Surface Water
Wind Erosion; Gaseous Emissions Volatization	Air	Inhalation				1			1					1
		Dermal Contact	2	2	2	1	2	2	1	2	2	2	2	1
		Direct Radiation	2,3	2,3	2,3	1	2,3	2,3	1	2,3	2,3	2,3	2,3	1
		Food Stuffs	4	4		1	4		1					1
Leaching	Groundwater	Ingest Drinking Water	4	4	5	1	4	5	1	5	5	5	5	1
		Inhalation VOCs	4	4	5	1	4	5	1	5	5	5	5	1
		Dermal Contact	4	4	5	1	4	5	1	5	5	5	5	1
		Food Stuffs	4	4	5	1	4	5	1	5	5	5	5	1
		Direct Radiation	2,3	2,3	2,3	1	2,3	2,3	1	2,3	2,3	2,3	2,3	1
Surface Runoff	Surface Water and Sediments	Ingest Drinking Water	4	4	7		4	7		7	7	7	7	
		Inhalation VOCs	4	4	7		4	7		7	7	7	7	
		Dermal Contact	4	4	7		4	7		7	7	7	7	
		Food Stuffs	4	4	7		4	7		7	7	7	7	
		Direct Radiation	4	4	7	2,3	4	7	2,3	7	7	7	7	2,3
		Incidental Ingestion		8	2	2		2	2	2	2		2	2
		Dermal Contact		8	2	2		2	2	2	2		2	2
	Root Uptake/Ingestion by Cows	Food Stuffs	4	4	6	1	4	6	1				6	1
Direct Contact		Incidental Ingestion			6	1		6	1				6	1
		Dermal Contact			6	1		6	1				6	1
Penetrating Radiation		Direct Radiation			2	1		2	1				2	1

1) The objective of quantifying exposure routes to the off-property user of surface water is to isolate and evaluate the impact of contamination from the Great Miami River through water pathways.
2) Potential impact of exposure route is minor compared to other exposure routes.
3) EPA risk assessment methodology for radionuclides does not address this exposure route.
4) Exposure route is not applicable to a transient, non-resident receptor.
5) Soil in Operable Unit 4 is not included as a source term to groundwater modeling.
6) Off-property soil is within the scope of OU5. Impact on food stuff exposure routes from air deposition is included in the air exposure routes.
7) Receptor is assumed to obtain water for all needs from groundwater.
8) Receptor is assumed to restrict activities to work at OU4 and not contact surface water via these exposure routes.

FIGURE D.3-2. OU4 CONCEPTUAL MODEL-SOIL AND BERM FILL MATERIAL

conceptual model and analysis of exposure routes and receptors are to focus on those pathways and sources that drive the potential impacts on human health risk, and to provide a rationale for screening other exposure pathways that are likely to pose minor risks.

Sections D.3.1.1 through D.3.1.4 describe the aforementioned elements in detail. At the end of Section D.3.1.4, a summary table presents a matrix of the conceptual model's exposure pathways and receptors that will be carried through the quantitative risk assessment. The matrix presents exposure pathways and receptors separately for each of the three land use scenarios. Quantitative risk results are presented in Section D.5.0 of the risk assessment.

D.3.1.1 Sources and COCs

Operable Unit 4 is divided into four subgroups in the FS process to facilitate dealing with the waste forms separately from the soil and silo structural materials. These four subgroups are:

- Subgroup A - the K-65 waste
- Subgroup B - the metal oxide waste
- Subgroup C - the berm fill material, surface and subsurface soil associated with the operable unit, Silos 1, 2, and 3 structures, and the decant system
- Subgroup D - Silo 4 and residual material in Silo 4

The conceptual model depicted in Figures D.3-1 and D.3-2 addresses the wastes within Silos 1, 2, and 3, the surface and subsurface soil, and the berm fill associated with Operable Unit 4. These materials represent the primary sources of concern in the operable unit.

The Silo 4 structure and residual material and the decant system for Silos 1 and 2 represent minor source terms in comparison to the silo wastes. Therefore, they are not included in the conceptual model for the risk assessment. The characterization data for the residual material in Silo 4 (water and sludge accumulation in the bottom of Silo 4) reveal low concentrations of uranium in comparison to the source term concentrations in the silo wastes themselves. In addition, the quantity of residual material in Silo 4 is limited, representing a minor source term. A removal action has been performed for the decant system associated with Silos 1 and 2 including removal of the water and sludge material that had accumulated in the decant sump tank. Completion of this removal action renders the decant system a minor potential source term.

The conceptual model does not consider existing contamination in groundwater, surface water, sediment, or soil not within the boundaries of Operable Unit 4, nor does it consider impacts on flora and fauna. These concerns are within the scope of Operable Unit 5, as specified in the Risk Assessment Work Plan Addendum (DOE 1992a).

D.3.1.1.1 Contents of Silos

The material inside Silos 1 and 2 is a residual product of the K-65 uranium ore processing activities performed at Fernald and other DOE facilities. The residues contain concentrates of radionuclides of the uranium, actinium, and thorium natural decay series that remain after processing to extract uranium isotopes.

The residual material inside Silo 3 is a metal oxide product of uranium ore processing that contains concentrates of radionuclides of the three natural decay series, but in proportions different from the residues in Silos 1 and 2.

As previously described, Silo 4 contains a relatively small accumulation of water in the bottom of the silo. Sample analytical results of this material reveal low concentrations of uranium or other contaminants. For the reasons stated previously, Silo 4 is not included in the conceptual model for the risk assessment.

D.3.1.1.2 Surface Soil, Berm Fill, and Subsurface Soil

The surface soil source term included in the conceptual model is defined by the coordinate boundaries of the Operable Unit 4 Study Area, as presented in the Risk Assessment Work Plan Addendum (DOE 1992a). This surface soil is contaminated, possibly by historical spills during silo filling operations, transport of contaminated soil from areas outside Operable Unit 4 by natural erosive forces, or movement of contaminated soil to Operable Unit 4 from other areas of the FEMP as a result of operational activities at the site. Surface soil is included risk assessment source term to air and surface water transport modeling when the surface soil is directly subject to the erosive forces of wind and water. However, surface soil is not included as a source term to groundwater modeling because, when compared to the potential impact of the silo contents, the potential for a significant impact on the aquifer is insignificant.

The berm fill source term included in the conceptual model represents fill material put in place after construction of Silos 1 and 2 to support the silo walls, thus eliminating the potential for wall collapse. The berm fill material represents a source term because it is a large quantity of lightly contaminated material that is in direct contact with the exterior of the silo walls. The fill could have become contaminated if it was obtained from other areas of the FEMP property, or if it was subject to historical spills, leaks, or contaminant deposition. The berm fill is included as a source term to air and surface water transport modeling because the berm is directly subject to the erosive forces of wind and water. However, it is not included as a source term to groundwater modeling because the potential for a significant impact on the aquifer is low when compared to the potential impact of the silo wastes.

The soil beneath the waste storage silos represents a large quantity of subsurface soil associated with the operable unit that is only slightly contaminated (based on sample analytical results from the slant

boring samples). This soil is considered in the conceptual model because of the potential for migration of contaminants from and through the soil from the silos and berms; however, the subsurface soil is not included in the groundwater modeling source term because the potential for a significant impact on the aquifer is low when compared to the potential impact of the silo contents.

D.3.1.1.3 Decant System and Silo Structures

The decant system comprises a series of gravity-fed drain lines beneath Silos 1 and 2 connecting to a decant sump tank. Accumulations of liquid have been removed from the decant sump tank, during implementation of the decant sump removal action, eliminating the potential source term from the decant sump tank itself. The tank is monitored regularly to estimate the quantity of material accumulating in the tank and to collect samples for radiological and chemical analyses. The liquid in the decant system represents a relatively small accumulation of contamination; therefore, it is not included as a source term in the conceptual model for the risk assessment.

The silo structures include the concrete walls, dome, and floor as well as the asphaltic-concrete base beneath the silos. The inner surfaces of the silo walls are contaminated because they are in direct contact with the stored waste material. Analyses of concrete wall cross sections of silos that contained K-65 residues at the Niagara Falls Storage Site reveal that radon decay product radionuclides can be deposited within the concrete. Again, in comparison to the quantity of waste within the silos, the contaminated silo structures represent a minor source term and are not included in the fate and transport modeling for the risk assessment.

D.3.1.1.4 Potential Constituents of Concern

The characterization data generated by the RI for Operable Unit 4 are used in contaminant fate and transport modeling and risk assessment to estimate transport modeling source terms and release estimates, as well as receptor exposure point concentrations. Before the data are used in these steps, the characterization data must be examined and evaluated. This evaluation results in statistical summaries of the data from which constituents of concern are selected.

The process of determining the constituents of concern is discussed in detail in Section D.2.0. The methodology for statistical analysis of the data is presented in the Risk Assessment Work Plan Addendum (DOE 1992a). The results of this selection process are presented in statistical summary tables in Section D.2.0.

Tables D.2-3 and D.2-4 present the statistical summaries of data that characterize the contents of the K-65 silos and Silo 3, respectively. All of the radionuclides detected in the K-65 silo waste and a variety of inorganic and organic chemicals are selected as constituents of concern (Table D.2-3). All of the radionuclides detected in the Silo 3 waste and a variety of metal constituents are selected as constituents of concern (Table D.2-4). The UCL concentrations of constituents of concern from both

of these tables (K-65 silos and Silo 3) are used to calculate the groundwater transport modeling source terms, and the UCL concentrations of constituents of concern from Table D.2-4 (Silo 3) are used to calculate air and surface water transport modeling source terms.

Tables D.2-5, D.2-6, and D.2-7 present the statistical summaries of data that characterize the soil and berm fill data in Operable Unit 4. Isotopes of radium, thorium, and uranium are the primary radionuclide constituents of concern in soil and berm fill; chemical constituents of concern include several inorganic and organic constituents. Generally, the concentrations of the radionuclides and chemical constituents in soil and berm fill are far lower than in the silo waste materials. The UCL concentrations of constituents of concern from Table D.2-5 (surface soil and berm fill data combined) are used to calculate the air transport modeling source term. The UCL concentrations from Tables D.2-5, D.2-6, and D.2-7 are used to calculate surface water transport modeling source terms.

D.3.1.2 Release Mechanisms

Table D.3-1 presents a summary of potential release mechanisms from sources in Operable Unit 4. These release mechanisms are consistent with the conceptual model presented in Figures D.3-1 and D.3-2. Individual receptor exposure routes are described in detail in Section D.3.1.4.

Two scenarios are defined with respect to release mechanisms and associated assumptions for the purpose of performing environmental fate and transport modeling:

- The current source-term scenario
- The future source-term scenario

These two source-term scenarios bound the range of what may reasonably be expected to happen to the silos in Operable Unit 4. The current source-term scenario assumes that the existing physical condition of the waste silos persists in the future. The future source-term scenario assumes that the physical condition of the waste silos has degraded to the degree that structural failure of the silos occurs. Silo structural failure implies collapse of the entire Silo 3 structure and collapse of the domes in Silos 1 and 2. Therefore, the metal oxide waste from Silo 3 is available to spread over an enlarged area; however, the K-65 waste remains within the walls of Silos 1 and 2 because the berm fill and silo walls remain sufficiently intact to keep the waste inside these silos.

The impact of these two source-term scenarios on fate and transport modeling assumptions is presented in the comments in Table D.3-1.

D.3.1.3 Transport and Exposure Pathways

Once released to the environment, constituents of concern can travel by several transport pathways to reach media to which receptors may be exposed. The following subsections briefly summarize

TABLE D.3-1

PRIMARY RELEASE MECHANISMS

Component Group	Release Mechanism	Comments
Silos 1, 2, and 3 Contents	Silo Structural Failure	Silo 3 failure will result in collapse of the entire silo structure permitting the metal oxide waste to leach into subsurface soil, and disperse over an enlarged area subject to the erosive forces of wind and water. The direct contact of a receptor with waste can result in ingestion and dermal contact, as well as impact food chain pathways for on-property resident farm receptors. Silo 1 and 2 failure will result in collapse of only the silo dome structure; the berm fill and silo walls remain sufficiently intact to prevent the spread of K-65 waste over the surface of the Operable Unit 4 area. The bentonite layer covering the waste is spared significant surface water and wind erosion because it is partially protected by the height of the silo walls and may retain moisture from rainwater. However, the waste is subject to leaching into subsurface soil. Direct contact with the K-65 waste can result in incidental ingestion and dermal contact exposure but not impact food chain pathways by root uptake because the waste remains within the K-65 silo walls.
	Penetrating Radiation Exposure	Gamma-emitting radionuclides are present in the silo wastes. Gamma radiation from the radionuclides is capable of causing direct radiation exposures to nearby receptors.
	Gaseous Emissions and Volatilization	The silos can release gaseous contaminants currently as well as after hypothetical silo structural failure.
Soil: Surface, Subsurface, Berm Fill	Direct Contact	The direct contact of a receptor with surface soil or berm fill can result in ingestion and dermal contact exposure.
	Penetrating Radiation Exposure	Gamma-emitting radionuclides are present in the surface soil and berm fill. Gamma radiation is capable of penetrating the surface and traveling in air to expose nearby receptors.

TABLE D.3-1
(Continued)

Component Group	Release Mechanism	Comments
	Water and Wind Erosion	Contaminated surface soil and berm fill are subject to some water and wind erosion, which can loosen contaminated soil to the point where it is available for transport. These mechanisms will not, however, remove enough materials to compromise the berm structure substantially, thus the K-65 silo walls remain supported.
	Water Leaching	Contaminated surface soil and berm fill are subject to leaching to the subsurface soil; however, this potential source term is minor in comparison to the corresponding source term from the Silos 1, 2 and 3 wastes. Therefore, the soil source term is not included in the transport modeling for groundwater.

transport and exposure pathways, which are discussed in more detail in the Risk Assessment Work Plan Addendum (DOE 1992a).

D.3.1.3.1 Air

The impact of sources within Operable Unit 4 on air is included in the scope of the conceptual model for Operable Unit 4. Contaminant source terms to air transport and dispersion include surface soil and berm fill within Operable Unit 4, and waste from Silo 3 assuming that silo structural failure occurs and the waste spreads over the surface of the Operable Unit 4 Study Area. Potential exposure pathways from contaminants in air following transport include inhalation of airborne contaminants, and ingestion of fruit and vegetable products, meat, and milk products impacted by plant and animal uptake following deposition of contaminants on soil. Irradiation of an individual immersed in a cloud of radioactive gas as a potential exposure pathway is considered to be an insignificant contributor to human health risk from the radionuclide present within Operable Unit 4, and is not quantitatively evaluated in the risk assessment.

D.3.1.3.2 Soil

Soil inside the Operable Unit 4 boundary is included in the conceptual model although existing contamination in soil outside Operable Unit 4 is within the scope of Operable Unit 5. Soil is a source of contaminants for air and surface water transport pathways (Sections D.3.1.3.1 and D.3.1.3.4) as well as receptor exposures from direct contact with soil and food chain pathways via root and animal uptake and foliar deposition on plant crops. Soil is less significant as a source of potential exposures than the contents of Silos 1, 2, and 3. Potential receptor exposure pathways from direct contact with soil include incidental ingestion of soil, dermal contact with soil, and external radiation exposure from contaminated soil. Potential receptor exposure, pathways for air and surface water impacted by transport of contaminants from soil are discussed in Sections D.3.1.3.1 and D.3.1.3.4, respectively.

D.3.1.3.3 Groundwater

The existing contamination in groundwater is within the scope of Operable Unit 5. However, the impact of sources within Operable Unit 4 on perched groundwater in the sand lens beneath the silos and a groundwater in the Great Miami Aquifer is included in the scope of the conceptual model for Operable Unit 4. Contaminant source terms that are predicted to leach to perched groundwater and the aquifer include the waste in the K-65 silos and the waste in Silo 3. Leaching from the surface and subsurface soil and berm fill material in Operable Unit 4 is not included in the groundwater transport modeling because these sources exhibit far lower contaminant concentrations and quantities of contaminants than the silo wastes. Potential exposure pathways from contaminants in groundwater in the aquifer following transport include ingestion of drinking water, ingestion of fruits and vegetables irrigated with groundwater, ingestion of animal products from cattle raised on groundwater and feed crops irrigated with groundwater, dermal contact with groundwater while bathing, and inhalation of VOCs from use of groundwater in the home. Potential exposure pathways from contaminants in

perched groundwater following transport include ingestion of drinking water evaluated for the RME on-property resident farmer.

D.3.1.3.4 Surface Water and Sediment

The existing contamination in surface water bodies such as Paddys Run, the outfall ditch, and the Great Miami River is within the scope of Operable Unit 5. However, the impact of sources within Operable Unit 4 on Paddys Run and the Great Miami River via surface water erosion is included in the scope of the conceptual model for Operable Unit 4. Among the source terms are the surface soil within the Operable Unit 4 boundaries, the berm fill material, and the waste from Silo 3. The waste from Silo 3 is included as a source term assuming silo structural failure occurs. The metal oxide waste from Silo 3 is assumed to be spread over the surface of the Operable Unit 4 Study Area. Potential exposure pathways from contaminants in surface water following transport to Paddys Run include incidental ingestion and dermal contact. Potential exposure pathways from contaminants in surface water following transport to the Great Miami River include all uses of water in the home and on a farm assuming that the receptor is an off-property user of surface water on a farm. This receptor specifically is assumed to use river water as a sole source for all water needs and does not use groundwater simultaneously.

Exposure pathways involving receptor exposures to sediments following transport via surface water runoff are not carried through the quantitative risk assessment. The transport modeling results for sediment logically produce receptor exposure point concentrations that are lower than the corresponding constituent concentrations in the source term. Because exposures are assumed to occur at any location, the risk characterization results for exposure to sediment transported from the site would be lower than the risks to the receptors for the same exposure pathways involving exposure to the source term itself.

D.3.1.4 Receptor Exposure Pathway Scenarios

The conceptual model for the Operable Unit 4 risk assessment considers three land use scenarios for the purpose of defining potential receptors and exposure pathways:

- Current land use without access controls
- Current land use with access controls
- Future land use without access controls

These land use scenarios define receptors and exposure pathways that are evaluated under the two source-term scenarios defined in Section D.3.1.2.

Detailed descriptions of potentially exposed receptors that are selected for the Operable Unit 4 risk assessment conceptual model are obtained from the Risk Assessment Work Plan Addendum (DOE 1992a) for the three aforementioned land use definitions.

D.3.1.4.1 Current Land Use Without Access Controls

Under the current land use scenario, the FEMP is currently defined as an operating industrial facility although no longer involved in production operations. In this scenario of no access controls, access restrictions at the FEMP historically provided by DOE are assumed to be discontinued by DOE, and the FEMP is operated by an industrial concern other than DOE. In addition, no remedial action is assumed to have been taken beyond that completed by DOE at the time the site is released by DOE. Under current land use, this represents the most conservative scenario for assessing baseline risks.

The risk assessment under the scenario without access controls assumes that members of the public do not establish residence on the Operable Unit 4 Study Area. A trespassing child receptor and a worker receptor are considered under this scenario. These receptors can be exposed to source term concentrations of constituents of concern at the operable unit on property. Also, off-property residential receptors are evaluated. The receptor exposure scenarios included in the Operable Unit 4 conceptual model include:

- Off-Property Farmer Receptor - This exposure assumes that a farm family lives immediately adjacent to the FEMP property boundary. Exposure routes include:

  - Ingestion of groundwater
  - Inhalation of fugitive dust, volatile organic compounds (VOCs), and gases
  - Consumption of farm-produced foodstuffs including vegetables, meat, and milk
  - Dermal contact and inhalation while using groundwater in the home

- Trespassing Child Receptor - This hypothetical exposure considers the risk incurred by a trespassing child. Exposure routes include:

  - Inhalation of fugitive dust, VOCs, and gases
  - Incidental ingestion of, direct radiation exposure from, and dermal contact with contaminated soils
  - Incidental ingestion of and dermal contact with surface water in Paddys Run
  - Incidental ingestion of sediment impacted by the sand lens

- Groundskeeper Worker Receptor - This exposure assumes that a non-DOE worker is present on the property. The worker conducts activities in the Operable Unit 4 Study Area including groundskeeping and maintenance. No groundwater from the Operable Unit 4 Study Area would be used. Exposure routes for this receptor include:

  - Inhalation of fugitive dust, VOCs, and radon
  - Incidental ingestion of soil
  - Dermal contact with chemicals in soil
  - External radiation exposure from contaminated soil

- Off-Property User of Surface Water from the Great Miami River - This exposure assumes that the user obtains water from the river for all water uses in the home and the farm. No groundwater is used. Exposure routes for this receptor include:

- Ingestion of surface water
- Inhalation of VOCs from use of water in the home
- Dermal contact with surface water used in the home
- Ingestion of farm-produced foodstuffs including vegetable, meat, and milk
- Ingestion of fish caught from the river

Receptors listed in the Risk Assessment Work Plan Addendum not evaluated under this exposure scenario include:

- Visitor - This scenario investigates the exposures incurred by the activities of a regular visitor to FEMP who is not covered by a health and safety or radiation protection program. An example of this receptor would be a delivery person making regular deliveries to the Administration Building in Operable Unit 3. This receptor was not considered applicable, since no visitor would consistently visit the Operable Unit 4 area.

- On-Property Grazing - This scenario considers the risks associated with off-property use of animal products produced by cattle currently grazing on FEMP property. For Operable Unit 4, exposures to this receptor are considered within the examination of the RME on-property farmer scenario.

- On-Property Building User - This scenario considers risks from occupancy of an existing building on-site by a hypothetical receptor. This receptor was not considered since no existing habitable structures exist in Operable Unit 4.

- Hunter - This scenario examines risks due to consumption of animal products from wild animals found on FEMP property. This receptor, as stated in the Risk Assessment Work Plan, will be evaluated in Operable Unit 5.

D.3.1.4.2 Current Land Use With Access Controls

Under the current land use scenario, the FEMP is defined as an industrial facility operated by DOE. With access controls, the site access restrictions historically provided by DOE are maintained by DOE. In addition, no remedial action has been taken beyond that completed to date.

This scenario assumes that DOE maintains a site-specific health and safety program to ensure that non-remediation workers and visitors on property are protected. Therefore, the risk assessment addresses workers subject to short exposure durations under administratively controlled conditions.

Under the scenario with access controls, members of the public do not establish residence on the Operable Unit 4 Study Area. A trespassing child receptor is considered under this scenario in accordance with EPA's conventional practice. Also, off-property residential receptors are evaluated for this scenario. The receptor exposure scenarios included in the Operable Unit 4 conceptual model include:

- Off-Property Farmer Receptor - This exposure assumes that a farm family lives immediately adjacent to the FEMP property boundary. Exposure routes for this receptor include those listed for the scenario without access controls (Section 3.1.4.1).

- Trespassing Child Receptor - This exposure assumes that a child trespasses on property in the Operable Unit 4 area and is subject to the same exposure routes as listed for this receptor for the scenario without access controls (Section 3.1.4.1).

- Off-Property User of Surface Water from the Great Miami River - This exposure assumes that the user obtains water from the river for all water uses in the home and for farm uses. No groundwater is used. Exposure routes for this receptor include those listed for the scenario without access controls (Section 3.1.4.1).

Receptors listed in the Risk Assessment Work Plan Addendum not evaluated under this exposure scenario include:

- Visitor - This receptor was not evaluated as it was not considered reasonable to have visitors to the Operable Unit 4 Study Area without consideration of health and safety and radiation protection program requirements.

- On-Property Grazing - This receptor was not examined for the reasons previously stated in D.3.1.4.1.

D.3.1.4.3 Future Land Use Without Access Controls

The future land use scenario assumes no access controls and includes exposure routes that require development time such as establishing a home and farm operations on property. The receptor exposure scenarios included in the Operable Unit 4 conceptual model include:

- The Reasonable Maximum Exposure (RME) On-Property Resident Farmer Receptor - This exposure assumes that a farmer resides on the property and conducts agricultural activities. Typical activities may include food and feed production, livestock production, and general farm work. Exposure routes include:

  - Inhalation of fugitive dust, VOCs, and gases
  - Ingestion of groundwater
  - Dermal contact and inhalation while using groundwater in the home
  - Consumption of foodstuff grown on the property, including vegetables, meat, and milk
  - Incidental ingestion of, external radiation from, and dermal contact with, soil
  - Direct radiation from and dermal contact with waste from the silos
  - Ingestion of perched groundwater trapped within the sand lens

- The Central Tendency (CT) On-Property Resident Farmer Receptor - This exposure assumes that a farmer resides on the property and conducts agricultural activities. This exposure is similar to the RME resident farmer with modifications of exposure parameter values to more closely reflect values typical of the CT of exposure. Exposure routes for this receptor include those listed for the RME resident farmer receptor.

- On-Property Resident Child Receptor - This exposure is similar to the RME resident farmer with modifications of exposure parameter values to reflect values typical of a child. The exposure routes for this receptor include those listed for the RME resident farmer in addition to incidental ingestion of and dermal contact with surface water in Paddys Run and incidental ingestion of sediment associated with the sand lens.

- Off-Property Farmer Receptor - This exposure assumes that a farmer lives immediately adjacent to the FEMP property boundary. Exposure routes for this receptor include those listed for the same receptor under current land use (Section 3.1.4.1).

- Off-Property User of Surface Water from the Great Miami River - This exposure assumes that the user obtains water from the river for all water uses in the home and for farm uses. No groundwater is used. Exposure routes for this receptor include those listed for the same receptor under current land use (Section 3.1.4.1).

The Construction Intruder Receptor was identified in the Risk Assessment Work Plan Addendum for considerations in the Future Land Use Scenario. This scenario involves exposures to workers building residences for the on-property farmer. This receptor was not individually evaluated as it was not considered reasonable to have significant construction activity within the limited area of Operable Unit 4, and exposure pathways are considered within the examination of the RME on-property resident farmer.

D.3.1.5 Summary of Selected Exposure Routes

Tables D.3-2 and D.3-3 present a summary of the potential exposure routes under current and future land use scenarios that will be carried through the quantitative risk assessment for each identified receptor. These exposure routes are discussed in greater detail in Section 5.3 of the Risk Assessment Work Plan Addendum (DOE 1992a). Tables D.3-2 and D.3-3 list exposure routes for each receptor presented in the conceptual model in Figures D.3-1 and D.3-2. The groundskeeper worker, the off-property resident farmer, and the off-property user of surface water from the Great Miami River are not repeated in Tables D.3-2 and D.3-3 under current land use with access controls in order to simplify the presentation in these tables. For completeness, the exposure routes for these receptors under current land use are included in the quantitative risk assessment, consistent with the exposure route selection presented in the conceptual model (Figures D.3-1 and D.3-2). Note that in Tables D.3-2 and D.3-3, the presence or absence of access controls has no quantitative impact on exposure parameter values or exposure point concentrations experienced by the groundskeeper worker, the off-property resident farmer, and the off-property user of surface water from the Great Miami River. The only current land use receptor for which exposure parameter values could vary with access controls is the trespassing child. However, in this risk assessment the exposure parameter values for the standard EPA trespassing child scenario are assumed for current land use both with and without access controls. Those exposure routes in Tables D.3-2 and D.3-3 that involve the assumption that the silos have experienced structural failure (future source-term scenario) are presented in bold and underline format for clarity. These exposure routes are also included in the conceptual model in Figures D.3-1 and D.3-2. The matrix of exposure routes and receptors presented in the conceptual model (Figures D.3-1 and D.3-2) includes cross references to explanatory footnotes for those exposure route-receptor combinations that are not selected for inclusion in the quantitative risk assessment.

TABLE D.3-2

SUMMARY OF POTENTIAL EXPOSURE PATHWAYS FOR SOIL AND SILO CONTENTS EVALUATED FOR OPERABLE UNIT 4

Receptor/ Scenario	Surface Soil	Silo Contents[a]
CURRENT LAND USE WITHOUT ACCESS CONTROLS		
Trespassing Child	• Incidental ingestion of soil • Dermal contact with chemicals in soil • External radiation exposures from soil	• External radiation exposures from silos • Incidental ingestion of silo contents • Dermal contact with silo contents
Groundskeeper Worker	• Incidental ingestion of soil • Dermal contact with chemicals in soil • External radiation exposures from soil	• External radiation exposures from silos • Incidental ingestion of silo contents • Dermal contact with silo contents
Off-Property Resident Farmer	NA[b]	NA[b]
Off-Property User of Surface Water	NA[b]	NA[b]
CURRENT LAND USE WITH ACCESS CONTROLS[c]		
Trespassing Child	• Incidental ingestion of soil • Dermal contact with chemicals in soil • External radiation exposures from soil	• External radiation exposures from silos • Incidental ingestion of silo contents • Dermal contact with silo contents
FUTURE LAND USE (ASSUMES NO ACCESS CONTROLS)		
CT On-Property Resident Farmer	• Incidental ingestion of soil • Dermal contact with chemicals in soil • External radiation exposures from soil • Ingestion of fruits and vegetables • Ingestion of meat, milk	• External radiation exposures from silos • Incidental ingestion of silo contents • Dermal contact with silo contents • Ingestion of fruits and vegetables • Ingestion of meat and milk

TABLE D.3-2
(Continued)

Receptor/ Scenario	Surface Soil	Silo Contents[a]
RME On-Property Resident Farmer	• Incidental ingestion of soil • Dermal contact with chemicals in soil • External radiation exposures from soil • Ingestion of fruits and vegetables • Ingestion of meat, milk	• External radiation exposures from silos • **Incidental ingestion of silo contents** • **Dermal contact with silo contents** • **Ingestion of fruits and vegetables** • **Ingestion of meat and milk**
On-Property Resident Child	• Incidental ingestion of soil • Dermal contact with chemicals in soil • External radiation exposures from soil • Ingestion of fruits and vegetables • Ingestion of meat, milk	• External radiation exposures from silos • **Incidental ingestion of silo contents** • **Dermal contact with silo contents** • **Ingestion of fruits and vegetables** • **Ingestion of meat and milk**
Off-Property Resident Farmer	NA[b]	NA[b]
Off-Property User of Surface Water	NA[b]	NA[b]

[a]Pathways that occur only in the case of silo structural failure are **bolded and underlined**.
[b]Medium does not apply to specific receptor.
[c]The presence or absence of access controls would have no effect on exposure times or exposure point concentrations experienced by the groundskeeper worker, the off-property resident farmer, or the off-property user of surface water; these receptors are not repeated in this section.

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TABLE D.3-3

SUMMARY OF POTENTIAL EXPOSURE PATHWAYS
FOR RECEIVING ENVIRONMENTAL MEDIA
EVALUATED FOR OPERABLE UNIT 4

Receptor/ Scenario	Groundwater[a,b]	Surface Water[b]	Sediment[a,b]	Air[b]
CURRENT LAND USE WITHOUT ACCESS CONTROLS				
Trespassing Child	NA[c]	• Incidental ingestion while swimming or playing • Dermal contact while swimming or playing	• Incidental ingestion of sediment • Dermal contact with chemicals in sediment	• Inhalation of VOCs, resuspended material, and radon
Groundskeeper Worker	NA[c]	NA[c]	NA[c]	• Inhalation of VOCs, resuspended material, and radon
Off-Property Resident Farmer	• Ingestion of drinking water • Ingestion of fruits and vegetables • Ingestion of meat and milk • Dermal contact while bathing • Inhalation of VOCs from home water use	NA[c]	NA[c]	• Inhalation of VOCs, resuspended material, and radon • Ingestion of fruits and vegetables • Ingestion of meat and milk

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TABLE D.3-3
(Continued)

Receptor/ Scenario	Groundwater[a,b]	Surface Water[b]	Sediment[a,b]	Air[b]
Off-Property User of Surface Water	NA[c]	• Ingestion of drinking water • Ingestion of fruits and vegetables • Ingestion of meat and milk • Ingestion of fish • Dermal contact while bathing • Inhalation of VOCs from home water use.	NA[c]	NA[c]
CURRENT LAND USE WITH ACCESS CONTROLS[d]				
Trespassing Child	NA[c]	• Incidental ingestion while swimming or playing • Dermal Contact while swimming or playing	• **Incidental ingestion of sediment** • **Dermal contact with chemicals in sediment**	• Inhalation of VOCs, resuspended material, and radon

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TABLE D.3-3
(Continued)

Receptor/ Scenario	Groundwater[a,b]	Surface Water[b]	Sediment[a,b]	Air[b]
FUTURE LAND USE (ASSUMES NO ACCESS CONTROLS)				
CT On-Property Resident Farmer	• Ingestion of drinking water • Ingestion of fruits and vegetables • Ingestion of meat and milk • Dermal contact while bathing • Inhalation of VOCs from home water use	NA[c]	NA[c]	• Inhalation of VOCs, resuspended material, and radon • Ingestion of fruits and vegetables • Ingestion of meat and milk
RME On-Property Resident Farmer	• Ingestion of drinking water • Ingestion of fruits and vegetables • Ingestion of meat and milk • Dermal contact while bathing • Inhalation of VOCs from home water use	NA[c]	NA[c]	• Inhalation of VOCs, resuspended material, and radon • Ingestion of fruits and vegetables • Ingestion of meat and milk

TABLE D.3-3
(Continued)

Receptor/ Scenario	Groundwater[a,b]	Surface Water[b]	Sediment[a,b]	Air[b]
On-Property Resident Child	• Ingestion of drinking water • Ingestion of fruits and vegetables • Ingestion of meat and milk • Dermal contact while bathing • Inhalation of VOCs from home water use	• Incidental ingestion while swimming or playing • Dermal Contact while swimming or playing	• Incidental ingestion of sediment • Dermal contact with chemicals in sediment	• Inhalation of VOCs, resuspended material, and radon • Ingestion of fruits and vegetables • Ingestion of meat and milk
Off-Property Resident Farmer	• Ingestion of drinking water • Ingestion of fruits and vegetables • Ingestion of meat and milk • Dermal contact while bathing • Inhalation of VOCs from home water use	NA[c]	NA[c]	• Inhalation of VOCs, resuspended material, and radon • Ingestion of fruits and vegetables • Ingestion of meat and milk

TABLE D.3-3
(Continued)

Receptor/ Scenario	Groundwater[a,b]	Surface Water[b]	Sediment[a,b]	Air[b]
Off-Property User of Surface Water	NA[c]	• Ingestion of drinking water • Ingestion of fruits and vegetables • Ingestion of meat and milk • Ingestion of fish • Dermal contact while bathing • Inhalation of VOCs from home water use.	NA[c]	NA[c]

[a]Pathways that occur only in the case of silo structural failure are **bolded and underlined**.
[b]Pathways for air, groundwater, sediment, and surface water under Current Land Use evaluate only constituents that are modeled to migrate from soil or silo contents; constituents currently present in these media will be evaluated under Operable Unit 5.
[c]Medium does not apply to specific receptor.
[d]The presence or absence of access controls would have no effect on exposure times or exposure point concentrations experienced by the groundskeeper worker, the off-property resident farmer, or the off-property user of surface water; these receptors are not repeated in this section.

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D.3.2 EXPOSURE POINT CONCENTRATIONS

The exposure concentration is the concentration of a contaminant in an exposure medium that will be contacted by a real or hypothetical receptor. Determination of the exposure concentration depends on factors such as:

- Availability of data
- Amount of data available to perform statistical analysis
- Background concentrations not attributed to the site
- Location of the potential receptor

Background concentrations of contaminants are not subtracted from UCL values when determining exposure point concentrations for chemicals and radionuclides. Chemical toxicants pose risks at threshold levels; therefore, total intakes must be compared to the intake level associated with toxic effects.

Exposure concentrations are determined from measured concentrations for silo exposure routes. Measured concentrations in the Silo 3 waste are used because the silo structure may deteriorate to the degree that waste material would be available for exposure routes analogous to those for soil. For air, groundwater, and surface water, fate and transport models are used to predict exposure point concentrations. The fate and transport models provide an estimate of the concentration of each contaminant that may migrate from the waste area to surrounding environmental media.

D.3.2.1 Exposure Point Concentrations for Soil and Silo 3 Contents and Sand Lens Sediment

The UCLs calculated from surface soil data are the exposure point concentrations for soil (Table D.3-4). Radiological soil sample analytical results from soil depths between 0 and 6 inches, and one sample between 0 and 18 inches, are used in the risk assessment. Chemical soil sample analytical results from soil depths between 0 and 2 feet from the waste pit runoff sampling effort and between 0 and 5 feet from the K-65 vertical berm boring sampling effort are used in the risk assessment. The selection of these data for use in the risk assessment is discussed in Section D.2.0 in which data sets are presented and constituents of concern are selected. Exposure point concentrations for the Silo 3 waste are the UCLs calculated from the Silo 3 characterization data. The Silo 3 exposure point concentrations are presented in Table D.3-5. Differences in UCL values in Table D.2-4 and Table D.3-5 reflect changes in data qualifiers for Silo 3 samples. Table D.3-5 values were not changed as the magnitude and direction of the change, and the overall impact on risk did not warrant recalculation of all risk factors. Sand lens sediment concentrations were determined from leachate B values presented in Appendix E of the Operable Unit 4 RI Report.

D.3.2.2 Exposure Point Concentrations for Air

Airborne concentrations of contaminants from the waste storage areas of Operable Unit 4 are modeled at on-property and off-property locations for current and future source-term scenarios. The calculation

TABLE D.3-4

EXPOSURE POINT CONCENTRATIONS FOR SOIL AND SAND LENS SEDIMENT

Constituent	UCL on Mean[a]	Sediment
Radionuclides (pCi/g)		
Actinium-227	ND	6.73×10^{1}
Lead-210	4.0×10^{0}	2.34×10^{7}
Polonium-210	4.0×10^{0} [b]	1.82×10^{2}
Protactinium-231	ND	5.38×10^{1}
Radium-224	1.0×10^{0} [b]	2.14×10^{1}
Radium-226	5.8×10^{0}	2.29×10^{2}
Radium-228	1.1×10^{0}	2.39×10^{1}
Strontium-90	1.3×10^{0}	ND
Technetium-99	8.2×10^{-1}	ND
Thorium-230	4.0×10^{0}	ND
Thorium-232	1.4×10^{0}	1.54×10^{-8}
Uranium-234	3.2×10^{0}	1.82×10^{-2}
Uranium-235	ND	7.98×10^{-4}
Uranium-238	1.2×10^{1}	1.71×10^{-2}
Chemicals (mg/kg)		
2-Butanone	6.6×10^{-3}	ND
2-Hexanone	5.0×10^{-3} [b]	ND
4-Methyl-2-pentanone	3.0×10^{-3} [b]	ND
Acenaphthylene	3.2×10^{-1}	ND
Acetone	5.9×10^{-2}	ND
Anthracene	2.8×10^{-1}	ND
Antimony	2.9×10^{1}	1.33×10^{-1}
Aroclor-1254	3.0×10^{-2} [b]	ND
Barium	ND	1.49×10^{-2}
Benzo(a)anthracene	4.2×10^{-1}	ND
Benzo(a)pyrene	4.9×10^{-1} [b]	ND
Benzo(b)fluoranthene	5.2×10^{-1}	ND
Benzo(g,h,i,)perylene	4.5×10^{-1}	ND
Benzoic acid	5.9×10^{-2} [b]	ND
Beryllium	8.5×10^{-1}	8.78×10^{-3}
bis(2-Ethylhexyl)phthalate	3.8×10^{-1}	ND
Boron	ND	6.03×10^{-3}

TABLE D.3-4
(Continued)

Constituent	UCL on Mean[a]	Sediment
Cadmium	5.4×10^{0}	1.78×10^{-1}
Chromium	2.0×10^{1}	2.67×10^{-3}
Chrysene	3.9×10^{-1}	ND
Cobalt	ND	2.02×10^{2}
Copper	2.1×10^{1}	4.56×10^{-1}
Di-n-butylphthalate	1.9×10^{-1} [b]	ND
Dibenzo(a,h)anthracene	2.9×10^{-1}	ND
Fluoranthene	4.2×10^{-1}	ND
Indeno(1,2,3-cd)pyrene	4.3×10^{-1}	ND
Lead	13.6×10^{0}	ND
Manganese	ND	1.56×10^{-2}
Mercury	ND	1.68×10^{-4}
Methylene chloride	2.0×10^{-2}	ND
Molybdenum	ND	3.38×10^{-2}
Nickel	3.1×10^{1}	1.20×10^{1}
Phenanthrene	3.8×10^{-1}	ND
Phenol	2.3×10^{-1} [b]	ND
Pyrene	4.5×10^{-1}	ND
Selenium	ND	4.89×10^{1}
Silver	9.8×10^{0}	6.97×10^{-2}
Thallium	3.2×10^{-1}	1.05×10^{1}
Toluene	8.2×10^{-3}	ND
Xylenes (total)	6.0×10^{-3}	ND
Vanadium	ND	4.31×10^{2}
Zinc	ND	9.91×10^{-1}

[a]If the distribution is normal or if the distribution is lognormal, the number of detects ≥ 7, and frequency of detection $\geq 50\%$, an arithmetic upper 95% confidence interval (CI) on the mean is given. If the distribution is lognormal and either the number of detects is <7 or the frequency of detection is < 50%, a geometric upper 95% CI on the mean is given.
[b]If the upper 95% CI on the mean exceeds the maximum detected concentration or if the sample size is ≤ 2, the maximum detected concentration is substituted.
ND - No data

TABLE D.3-5

EXPOSURE POINT CONCENTRATIONS FOR SILO 3 CONTENTS

Constituent	UCL on Mean[a]
Radionuclides (pCi/g)	
Actinium-227	7.9×10^{2}
Lead-210	4.7×10^{3}
Protactinium-231	9.3×10^{2} [b]
Radium-224	3.7×10^{2}
Radium-226	3.9×10^{3}
Radium-228	4.1×10^{2}
Thorium-228	1.3×10^{3} [b]
Thorium-230	5.7×10^{4} [b]
Thorium-232	9.9×10^{2}
Uranium-234	1.9×10^{3} [b]
Uranium-235/236	1.2×10^{2}
Uranium-238	1.8×10^{3}
Chemicals (mg/kg)	
Antimony	5.5×10^{0} [b]
Arsenic	3.2×10^{3}
Barium	2.6×10^{2}
Beryllium	2.9×10^{1}
Cadmium	9.4×10^{1}
Chromium	4.0×10^{2}
Cobalt	2.9×10^{3}
Copper	3.3×10^{3}
Lead	2.4×10^{3}
Manganese	5.2×10^{3}
Mercury	6.9×10^{-1} [b]
Nickel	4.3×10^{3}
Selenium	2.3×10^{2}
Silver	1.8×10^{1}

TABLE D.3-5
(Continued)

Constituent	UCL on Mean[a]
Thallium	5.6×10^1
Vanadium	3.5×10^3
Zinc	5.4×10^2

[a]If the distribution is normal or if the distribution is lognormal, the number of detects ≥7, and the frequency of detection ≥50%, an arithmetic upper 95% confidence interval (CI) on the mean is given. If the distribution is lognormal and either the number of detects is <7 or the frequency of detection is < 50%, a geometric upper 95% CI on the mean is given.
[b]If the upper 95% CI on the mean exceeds the maximum detected concentration or if the sample size is ≤2, the maximum detected concentration is substituted.

model assumes mass loading (fugitive dust emissions) of surface soil (current source-term scenario) and waste from Silo 3 (future source-term scenario) to the air and subsequent transport and dispersion of contaminants. The model and parameters for air dispersion are described in Section 5.0 and Appendix E of the Operable Unit 4 RI Report.

The highest annual average air concentrations (the annual average concentration in air at the locus having the highest concentrations) are used to evaluate potential exposures. For the current and future land use scenarios, on-property concentrations are used for on-property receptors. Off-property concentrations are used for off-property receptors under current and future land use. The air pathway is included in the risk characterization for radionuclides and chemicals. Modeled air concentrations are presented in Tables D.3-6 and D.3-7. A few values changed in Table D.3-7 for thorium and actinium radionuclide concentrations as a result of new airborne modeling assumptions. These changes were not reflected in the incremental lifetime cancer risk tables in subsection D.5 for airborne pathways as the affected radionuclides and the magnitude of the change did not affect the overall cancer risk. A detailed description of the model and results is presented in Section 5.0 and Appendix E of the Operable Unit 4 RI Report.

D.3.2.3 Exposure Point Concentrations for Groundwater

Exposures to existing contaminant concentrations in groundwater at the FEMP will be addressed as part of the Operable Unit 5 RI. Exposure to potential future concentrations of contaminants in groundwater from Operable Unit 4 sources (Silos 1, 2, and 3) are addressed in the Operable Unit 4 risk assessment. Future exposure point concentrations for groundwater are determined from the results of geochemical and groundwater transport modeling, as described in Section 5.0 and Appendix E of the RI Report, and are presented in Table D.3-8.

As part of the programmatic approach for performing groundwater modeling at the FEMP, screening values were developed to screen some of the contaminants that reach the aquifer (DOE 1992a). These screening values represent 10^{-7} lifetime cancer risk levels from the drinking water pathway for carcinogens and the equivalent of 20 percent of the allowable dose of each noncarcinogenic toxicant. Because these screening levels are applied to calculated leachate concentrations entering the top of the aquifer from the vadose zone, it is as if the assumption is made that a receptor uses this leachate as drinking water. In fact, a receptor would not use this leachate. Instead, water from the aquifer would be used as drinking water, which would likely be a factor of 10 or more less concentrated than the leachate. These levels ensure that any chemical that could contribute significantly to risk will be retained and modeled for the risk assessment.

D.3.2.4 Exposure Point Concentrations for Surface Water

As for groundwater, exposures to existing concentrations in surface water not within Operable Unit 4 are addressed in Operable Unit 5. Also, fate and transport modeling must be used to determine the

TABLE D.3-6

EXPOSURE POINT CONCENTRATIONS FOR RADIONUCLIDES, CHEMICALS, AND RADON IN AIR FROM CONTAMINATED SOIL UNDER THE CURRENT CONDITIONS SCENARIO

Constituent	Highest On-Property Annual Average Ground Level Concentration[a]	Highest Off-Property Annual Average Ground Level Concentration[a]
Radionuclides (pCi/m^3)		
Lead-210	1.3×10^{-4}	9.0×10^{-6}
Polonium-210	1.3×10^{-4}	9.0×10^{-6}
Radium-224	3.3×10^{-5}	2.0×10^{-6}
Radium-226	6.1×10^{-4}	4.6×10^{-5}
Radium-228	2.4×10^{-4}	1.9×10^{-5}
Radon-222[b]	1.6×10^{2}	2.6×10^{0}
Strontium-90	3.5×10^{-4}	2.7×10^{-5}
Technetium-99	1.8×10^{-4}	1.4×10^{-5}
Thorium-230	1.1×10^{-3}	8.1×10^{-5}
Thorium-232	4.3×10^{-5}	3.0×10^{-6}
Uranium-234	7.5×10^{-4}	5.8×10^{-5}
Uranium-238	2.5×10^{-3}	1.9×10^{-4}
Inorganics (μg/m^3)		
Beryllium	1.9×10^{-4}	1.5×10^{-5}
Cadmium	1.2×10^{-3}	9.3×10^{-5}
Chromium	4.4×10^{-3}	3.3×10^{-4}
Nickel	7.0×10^{-3}	5.4×10^{-4}
Organics (μg/m^3)		
2-Butanone	1.0×10^{-6}	c
Benzo(a)anthracene	1.1×10^{-4}	8.0×10^{-6}
Benzo(a)pyrene	1.0×10^{-3}	7.7×10^{-5}
Benzo(b)fluoranthene	1.5×10^{-4}	1.1×10^{-5}
Chrysene	1.0×10^{-4}	8.0×10^{-6}
Dibenzo(a,h)anthracene	6.4×10^{-5}	5.0×10^{-6}
Indeno(1,2,3,c,d)pyrene	1.1×10^{-4}	9.0×10^{-6}
Methylene chloride	4.0×10^{-6}	c
Toluene	5.0×10^{-6}	c

[a]The annual average constituent concentration in air at the location having the highest modeled concentration in air.
[b]Radon emissions are from Silos 1, 2, and 3.
[c]Concentration is less than one microgram per cubic meter ($<1 \times 10^{-6}$ μg/m^3).

TABLE D.3-7

EXPOSURE POINT CONCENTRATIONS FOR RADIONUCLIDES, CHEMICALS, AND RADON IN AIR FROM SOIL AND SILO 3 UNDER THE FUTURE CONDITIONS SCENARIO

Constituent	Highest On-Property Annual Average Ground Level Concentration[a]	Highest Off-Property Annual Average Ground Level Concentration[a]
Radionuclides (pCi/m^3)		
Actinium-227	1.0×10^{-1}	5.0×10^{-3}
Lead-210	7.7×10^{-1}	3.7×10^{-2}
Polonium-210	1.3×10^{-4}	9.0×10^{-6}
Protactinium-231	1.5×10^{-1}	7.2×10^{-3}
Radium-224	6.0×10^{-2}	2.9×10^{-3}
Radium-226	6.3×10^{-1}	3.0×10^{-2}
Radium-228	6.6×10^{-2}	3.2×10^{-3}
Radon-222[b]	5.4×10^{3}	2.6×10^{2}
Strontium-90	3.2×10^{-4}	1.9×10^{-5}
Technetium-99	1.6×10^{-4}	1.0×10^{-5}
Thorium-228	1.4×10^{-1}	6.8×10^{-3}
Thorium-230	9.8×10^{0}	4.7×10^{-1}
Thorium-232	1.4×10^{-1}	6.8×10^{-3}
Uranium-234	3.2×10^{-1}	1.5×10^{-2}
Uranium-235	1.9×10^{-2}	9.1×10^{-4}
Uranium-238	2.9×10^{-1}	1.4×10^{-2}
Inorganics (μg/m^3)		
Antimony	8.9×10^{-4}	4.3×10^{-5}
Arsenic	5.1×10^{-1}	2.5×10^{-2}
Barium	4.2×10^{-2}	2.0×10^{-3}
Beryllium	4.9×10^{-3}	2.4×10^{-4}
Cadmium	1.6×10^{-2}	8.0×10^{-4}
Chromium	6.7×10^{-2}	3.3×10^{-3}
Cobalt	4.7×10^{-1}	2.2×10^{-2}
Copper	5.4×10^{-1}	2.6×10^{-2}
Lead	3.9×10^{-1}	1.8×10^{-2}
Manganese	8.4×10^{-1}	4.0×10^{-2}
Mercury	1.1×10^{-4}	5.0×10^{-6}
Nickel	7.0×10^{-1}	3.4×10^{-2}
Selenium	3.7×10^{-2}	1.8×10^{-3}
Silver	3.0×10^{-3}	1.4×10^{-4}

TABLE D.3-7
(Continued)

Constituent	Highest On-Property Annual Average Ground Level Concentration[a]	Highest Off-Property Annual Average Ground Level Concentration[a]
Thallium	9.1×10^{-3}	4.4×10^{-4}
Vanadium	5.7×10^{-1}	2.7×10^{-2}
Zinc	8.7×10^{-2}	4.1×10^{-3}
Organics ($\mu g/m^3$)		
2-Butanone	1.0×10^{-6}	c
Benzo(a)anthracene	1.0×10^{-4}	6.0×10^{-6}
Benzo(a)pyrene	9.2×10^{-4}	5.6×10^{-5}
Benzo(b)fluoranthene	1.4×10^{-4}	8.0×10^{-6}
Chrysene	9.1×10^{-5}	6.0×10^{-6}
Dibenzo(a,h)anthracene	5.9×10^{-5}	4.0×10^{-6}
Indeno(1,2,3,c,d)pyrene	1.0×10^{-4}	6.0×10^{-6}
Methylene chloride	4.0×10^{-6}	c
Toluene	5.0×10^{-6}	c

[a]The annual average constituent concentration in air at the location having the highest modeled concentration in air.
[b]Radon emissions are from Silos 1, 2, and 3.
[c]Concentration is less than one picogram per cubic meter ($<1 \times 10^{-6}$ [$\mu g/m^3$]).

TABLE D-3-8

EXPOSURE POINT CONCENTRATIONS FOR GROUNDWATER UNDER THE FUTURE SOURCE-TERM SCENARIO

Constituent	Highest On-Property Concentration	Highest Property Boundary Concentration
	Aquifer	
Radionuclides (pCi/L)		
Uranium-234	2.55×10^{1}	3.72×10^{0}
Uranium-235/236	2.19×10^{0}	3.21×10^{-1}
Uranium-238	2.27×10^{1}	3.32×10^{0}
Chemicals (mg/L)		
Uranium	6.80×10^{-2}	1.00×10^{-2}
	Perched Water	
Radionuclides (pCi/L)		
Actinium-227	2.80×10^{1}	NA
Lead-210	7.79×10^{6}	NA
Polonium-210	4.53×10^{2}	NA
Protactinum-231	1.98×10^{1}	NA
Radium-224	3.06×10^{1}	NA
Radium-226	3.28×10^{2}	NA
Radium-228	3.42×10^{1}	NA
Thorium-232	2.65×10^{-9}	NA
Uranium-234	1.01×10^{1}	NA
Uranium-235	4.43×10^{-1}	NA
Uranium-238	9.51×10^{0}	NA
Chemicals (mg/L)		
Antimony	5.32×10^{-4}	NA
Arsenic	2.64×10^{-1}	NA
Barium	1.30×10^{-5}	NA
Beryllium	6.75×10^{-6}	NA
Boron	2.01×10^{-3}	NA
Cadmium	3.56×10^{-2}	NA

TABLE D.3-8
(Continued)

Constituent	Highest On-Property Concentration	Highest Property Boundary Concentration
Chromium	1.78×10^{-6}	NA
Cobalt	3.68×10^{-1}	NA
Copper	3.65×10^{-3}	NA
Manganese	8.65×10^{-5}	NA
Mercury	1.68×10^{-5}	NA
Molybdenum	3.75×10^{-4}	NA
Nickel	1.85×10^{-2}	NA
Selenium	6.61×10^{-2}	NA
Silver	3.87×10^{-4}	NA
Thallium	6.98×10^{-3}	NA
Vanadium	4.31×10^{-1}	NA
Zinc	4.13×10^{-4}	NA

NA - Not applicable

effect that future surface water runoff from Operable Unit 4 might have on exposure point concentrations. The Modified Universal Soil Loss Equation (MUSLE), a commonly used soil loading model, is used to determine if soil runoff with sorbed and dissolved contaminants would contribute significantly to contaminant concentrations in Paddys Run, and in the Great Miami River. A summary of the model and modeling results is presented in Section 5.0 and Appendix E of the Operable Unit 4 RI Report. Modeling the transport of soil by runoff requires characterization of the contaminants in the initial soil or waste source term. Surface soil surrounding the silos was chosen as one source term (current source-term scenario). It is also assumed that failure of Silo 3 may occur in the future (future source-term release scenario), with the silo contents spread onto the surface soil subject to erosion by runoff. Therefore, the contents of Silo 3 are used as a second source term. Because the K-65 silos are surrounded by berms, it is assumed that even under the future source-term scenario, the contents of these silos would be contained by the berms and not subject to erosion. The source term concentrations, as well as a detailed description of the model assumptions, equations, and parameters can be found in Section 5.0 and Appendix E of the Operable Unit 4 RI Report. Tables D.3-9 and D.3-10 present exposure point concentrations for surface water using the soil and Silo 3 contents as source terms and using the MUSLE model for a single storm event.

Concentrations are diluted to a great extent (approximately four orders of magnitude) when Paddys Run flows into and mixes with the Great Miami River because of the much higher flow rates in the Great Miami River. None of the modeled surface water concentrations of uranium in the Great Miami River exceed 1 µg/L. Realistically, these concentrations should remain only through the duration of the storm. When rainfall and runoff cease, surface water concentrations are expected to return to background levels. However, assuming that multiple storm events occur during each year over an extended exposure duration, the modeled surface water concentrations in Paddys Run and the Great Miami River are used to quantify the continuous receptor exposures to surface water identified in Section D.3.1.

D.3.3 QUANTIFICATION OF INTAKE

This section describes the method used to quantify chronic exposures for exposure pathways of concern at the FEMP. With the exception of the CT exposure calculation, this method employs the concept of the RME. The RME is the maximum exposure reasonably expected to occur at the site (EPA 1989a). If the RME is determined to be acceptable, then it is likely that all other lesser exposures at the site will also be acceptable. Tables D.3-2 and D.3-3 shows the exposure pathways selected to be quantified for the Operable Unit 4 baseline risk assessment.

The models, equations, and input parameter values used to quantify intakes are described in the Work Plan Addendum and have been obtained from EPA risk assessment guidance (EPA 1989a) or from discussions with EPA Region V. In cases where models were not available from EPA, models

TABLE D.3-9

EXPOSURE POINT CONCENTRATIONS FOR SURFACE WATER FROM SOIL[a] UNDER THE CURRENT SOURCE-TERM SCENARIO

Constituents	Paddys Run	Great Miami River
Radionuclides (pCi/L)		
Lead-210	3.1×10^{-2}	9.3×10^{-7}
Polonium-210	2.4×10^{-1}	7.0×10^{-6}
Radium-224	3.5×10^{-2}	1.0×10^{-6}
Radium-226	2.0×10^{-1}	5.8×10^{-6}
Radium-228	3.8×10^{-2}	1.1×10^{-6}
Strontium-90	3.1×10^{0}	9.1×10^{-5}
Technetium-99	8.8×10^{1}	2.6×10^{-3}
Thorium-230	1.6×10^{-2}	4.9×10^{-7}
Thorium-232	5.7×10^{-3}	1.7×10^{-7}
Uranium-234	3.9×10^{1}	1.2×10^{-3}
Uranium-238	1.5×10^{2}	4.4×10^{-3}
Organics (mg/L)		
2-Butanone	5.7×10^{-4}	3.4×10^{-8}
2-Hexanone	1.1×10^{-4}	6.2×10^{-9}
4-Methyl-2-Pentanone	1.1×10^{-4}	6.2×10^{-9}
Acenaphthylene	2.3×10^{-5}	1.4×10^{-9}
Acetone	6.3×10^{-3}	3.7×10^{-7}
Anthracene	6.1×10^{-6}	3.6×10^{-10}
Aroclor-1254	1.7×10^{-8}	1.0×10^{-12}
Benzo(a)anthracene	6.4×10^{-7}	3.8×10^{-11}
Benzo(a)pyrene	3.4×10^{-6}	2.0×10^{-10}
Benzo(b)fluoranthene	8.7×10^{-8}	5.1×10^{-12}
Benzo(g,h,i)perylene	1.6×10^{-8}	9.7×10^{-13}
Benzoic acid	4.6×10^{-4}	2.7×10^{-8}
bis(2-Ethylhexyl)phthalate	1.2×10^{-6}	6.9×10^{-11}
Chrysene	6.0×10^{-7}	3.5×10^{-11}
Dibenzo(a,h)anthracene	1.9×10^{-7}	1.1×10^{-11}
Di-n-butylphthalate	7.5×10^{-7}	4.4×10^{-11}
Fluoranthene	1.2×10^{-6}	7.2×10^{-11}
Indeno(1,2,3-cd)pyrene	5.8×10^{-9}	3.4×10^{-13}
Lead	5.4×10^{-5}	3.2×10^{-9}
Methylene chloride	5.4×10^{-4}	3.2×10^{-8}
Phenol	4.2×10^{-3}	2.5×10^{-7}

TABLE D.3-9
(Continued)

Constituents	Paddys Run	Great Miami River
Phenanthrene	8.0×10^{-6}	4.7×10^{-10}
Pyrene	1.8×10^{-6}	1.1×10^{-10}
Toluene	1.0×10^{-5}	6.0×10^{-10}
Xylenes (Total)	3.4×10^{-6}	2.0×10^{-10}
Inorganics (mg/L)		
Antimony	1.4×10^{-3}	8.0×10^{-8}
Beryllium	7.7×10^{-6}	4.6×10^{-10}
Cadmium	1.3×10^{-4}	7.5×10^{-9}
Chromium	1.6×10^{-4}	9.5×10^{-9}
Copper	2.0×10^{-3}	1.2×10^{-7}
Nickel	5.6×10^{-4}	3.3×10^{-8}
Silver	6.5×10^{-4}	3.8×10^{-8}
Thallium	2.5×10^{-6}	1.5×10^{-10}
Uranium	2.2×10^{-1}	1.3×10^{-5}

[a]Surface soil and berm fill used for the surface water runoff model source term.

TABLE D.3-10

EXPOSURE POINT CONCENTRATIONS FOR SURFACE WATER FROM SILO 3 UNDER THE FUTURE SOURCE-TERM SCENARIO

Constituent	Paddys Run	Great Miami River
Radionuclides (pCi/L)		
Actinium-227	7.8×10^{0}	1.1×10^{-4}
Lead-210	3.7×10^{1}	5.4×10^{-4}
Protactinium-231	8.2×10^{0}	1.2×10^{-4}
Radium-224	1.3×10^{1}	1.8×10^{-4}
Radium-226	1.3×10^{2}	1.9×10^{-3}
Radium-228	1.4×10^{1}	2.0×10^{-4}
Thorium-228	5.5×10^{0}	7.9×10^{-5}
Thorium-230	2.3×10^{2}	3.4×10^{-3}
Thorium-232	4.0×10^{0}	5.8×10^{-5}
Uranium-234	2.5×10^{4}	3.6×10^{-1}
Uranium-235/236	1.5×10^{3}	2.2×10^{-2}
Uranium-238	2.3×10^{4}	3.3×10^{-1}
Inorganics (mg/L)		
Antimony	1.3×10^{-4}	7.6×10^{-9}
Arsenic	9.3×10^{-2}	5.4×10^{-6}
Barium	1.3×10^{-3}	7.8×10^{-8}
Beryllium	1.3×10^{-4}	7.7×10^{-9}
Cadmium	1.1×10^{-3}	6.5×10^{-8}
Chromium	1.5×10^{-3}	9.1×10^{-8}
Cobalt	3.1×10^{-2}	1.8×10^{-6}
Copper	1.6×10^{-1}	9.2×10^{-6}
Lead	4.6×10^{-3}	2.7×10^{-7}
Manganese	1.7×10^{-1}	9.9×10^{-6}
Mercury	4.0×10^{-4}	2.4×10^{-8}
Nickel	3.9×10^{-2}	2.3×10^{-6}
Selenium	1.8×10^{-3}	1.1×10^{-7}
Silver	6.0×10^{-4}	3.5×10^{-8}
Thallium	2.2×10^{-4}	1.3×10^{-8}
Uranium	1.7×10^{1}	9.8×10^{-4}
Vanadium	2.0×10^{-2}	1.2×10^{-6}
Zinc	1.3×10^{-3}	7.7×10^{-8}

developed by the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109 (NRC 1977) were used. Model equations are presented below. Model parameters, as specified in the Work Plan Addendum and in discussions with the EPA, are presented in Tables D.3-11 and D.3-12. Chemical-specific parameters used in the models are presented in Table D.3-13.

D.3.3.1 Ingestion of Soil

The estimation of intake of contaminants in soils is determined by using the UCL concentration in the soil or the Silo 3 waste. Evaluation of the soil ingestion pathway is performed for adults and children. For variables that are common to both chemical and radionuclide intake equations, units for the radionuclide equations are listed first. The equations used to quantify intake (EPA 1989a) are:

(radionuclides) $I_s = (C_s)(IR)(ED)(EF)(FI)$ (D.3-1)

(chemicals) $I_s = (Cs)(IR)(CF)(FI)(EF)(ED)/(BW)(AT)$ (D.3-2)

where

I_s	=	intake from soil (pCi) (mg/kg/day)
C_s	=	concentration in soil (pCi/g) (mg/kg)
IR	=	ingestion rate (g/day) (mg/day)
CF	=	conversion factor 10^{-6} kg/mg
FI	=	fraction ingested from contaminated source (unitless)
EF	=	exposure frequency (days/yr)
ED	=	exposure duration (yr)
BW	=	body weight (kg)
AT	=	averaging time (equals ED x 365 days/yr) (days)

D.3.3.2 Ingestion of Vegetables

Ingestion of farm and homegrown products irrigated with contaminated groundwater or surface water is evaluated in the Operable Unit 4 risk assessment for the future land use pathways. The equations used to estimate exposure to chemicals and radionuclides via ingestion of vegetables irrigated with contaminated water are from the NRC (NRC 1977) and the EPA (EPA 1989a). The two-step process first involves the calculation of the concentration of the contaminant on and in the plant as a result of foliar deposition and root uptake, followed by the calculation of intake from consumption of the plant by humans. The model used to estimate the concentration in and on vegetation irrigated with contaminated water is (NRC 1977):

$$C_{ivw} = d_w \left[\frac{r_w(1 - e^{-\lambda_{Ei} t_e})}{Y \lambda_{Ei}} + \frac{f_w B_{iv(1)}(1 - e^{-\lambda_{ri} t_{bw}})}{\rho \lambda_{ri}} \right] e^{-\lambda_{ri} t_h} \qquad \text{(D.3-3)}$$

TABLE D.3-11

PARAMETERS USED TO ESTIMATE POTENTIAL EXPOSURES FOR CURRENT LAND USE RECEPTORS[a]

Pathway Parameters	Trespassing Child Age 7-18	Groundskeeper Worker	Off-property Resident Farmer Age 1-70	Off-Property User of Surface Water Age 1-70
Inhalation of VOCs, Fugitive Dust, and Radon				
IR (m^3/hr)	0.83[b]	0.83[b]	0.83[b]	NA[c]
ET (hr/d)	4[d]	8[e]	5.7[f]	NA
EF (d/yr)	52[d]	35[e]	350[g]	NA
ED (yr)	12	25[h]	70	NA
BW (kg)	43	70	70	NA
AT-Noncancer (d)[i]	4380	9125	25550	NA
AT-Cancer (d)[i]	25550	25550	25550	NA
Incidental Ingestion of Soil/Sediment				
IR (g/d)	0.1	0.050[h]	NA	NA
FI	0.25[j]	1[h]	NA	NA
EF (d/yr)	52[d]	35[e]	NA	NA
ED (yr)	12	25[h]	NA	NA
BW (kg)	43	70	NA	NA
AT-Noncancer (d)[i]	4380	9125	NA	NA
AT-Cancer (d)[i]	25550	25550	NA	NA
Dermal Contact with Soil/Sediment				
SA (m^2)	0.38[k]	0.5[k]	NA	NA
AF (mg/cm^2)	1.0[l]	1.0[l]	NA	NA
ABS (unitless)	csv[m]	csv	NA	NA
EF (d/yr)	52[d]	35[e]	NA	NA
ED (yr)	12	25[h]	NA	NA
BW (kg)	43	70	NA	NA
AT-Noncancer (d)[i]	4380	9125	NA	NA
AT-Cancer (d)[i]	25550	25550	NA	NA
External Radiation Exposure				
DR (mrem/hr)	csv	csv	NA	NA
ET indoors (hr/d)	NA	NA	NA	NA
ET outdoors (hr/d)	4[d]	8[e]	NA	NA
EF (d/yr)	52[d]	35[e]	NA	NA
ED (yr)	12	25[h]	NA	NA
SH indoors (unitless)	NA	NA	NA	NA
SH outdoors (unitless)	0	0	NA	NA

TABLE D.3-11
(Continued)

Pathway Parameters	Trespassing Child Age 7-18	Groundskeeper Worker	Off-property Resident Farmer Age 1-70	Off-Property User of Surface Water Age 1-70
Incidental Ingestion of Surface Water				
IR x FI (L/hr)	0.05[n]	NA	NA	NA
ET (hr/d)	0.5[l]	NA	NA	NA
EF (d/yr)	5[l]	NA	NA	NA
ED (yr)	12	NA	NA	NA
BW (kg)	43	NA	NA	NA
AT-Noncancer (d)[i]	4380	NA	NA	NA
AT-Cancer (d)[i]	25550	NA	NA	NA
Dermal Contact with Surface Water				
SA (m^2)	1.5[l]	NA	NA	NA
PC (cm/hr)	csv	NA	NA	NA
ET (hr/d)	0.5[l]	NA	NA	NA
EF (d/yr)	5[l]	NA	NA	NA
ED (yr)	12	NA	NA	NA
BW (kg)	43	NA	NA	NA
AT-Noncancer (d)[i]	4380	NA	NA	NA
AT-Cancer (d)[i]	25550	NA	NA	NA
Drinking Water Ingestion				
IR x FI (L/d)	NA	NA	2	2
EF (d/yr)	NA	NA	350[g]	350[g]
ED (yr)	NA	NA	70	70
BW (kg)	NA	NA	70	70
AT-Noncancer (d)[i]	NA	NA	25550	25550
AT-Cancer (d)[i]	NA	NA	25550	25550
Ingestion of Fruits and Vegetables				
IR x FI (g/d)	NA	NA	122	122
EF (d/yr)	NA	NA	350[g]	350[g]
ED (yr)	NA	NA	70	70
BW (kg)	NA	NA	70	70
AT-Noncancer (d)[i]	NA	NA	25550	25550
AT-Cancer (d)[i]	NA	NA	25550	25550
Ingestion of Meat, Milk, and Fish				
IR (meat) x FI (g/d)	NA	NA	75	75
IR (milk) x FI (L/d)	NA	NA	0.3	0.3
IR (fish) x FI (g/d)	NA	NA	NA	54

TABLE D.3-11
(Continued)

Pathway Parameters	Trespassing Child Age 7-18	Groundskeeper Worker	Off-property Resident Farmer Age 1-70	Off-Property User of Surface Water Age 1-70
EF (d/yr)	NA	NA	350[g]	350[g]
ED (yr)	NA	NA	70	70
BW (kg)	NA	NA	70	70
AT-Noncancer (d)[i]	NA	NA	25550	25550
AT-Cancer (d)[i]	NA	NA	25550	25550
Dermal Contact While Bathing				
SA (m^2)	NA	NA	2.00[j]	2.00[j]
PC (cm/hr)	NA	NA	csv	csv
ET (hr/d)	NA	NA	0.25[j]	0.25[j]
EF (d/yr)	NA	NA	350[g]	350[g]
ED (yr)	NA	NA	70	70
BW (kg)	NA	NA	70	70
AT-Noncancer (d)[i]	NA	NA	25550	25550
AT-Cancer (d)[i]	NA	NA	25550	25550
Inhalation of Volatiles Released from Household Water Use				
IR (m^3/d)	NA	NA	15[h]	15[h]
EF (d/yr)	NA	NA	350[g]	350[g]
ED (yr)	NA	NA	70	70
BW (kg)	NA	NA	70	70
AT-Noncancer (d)[i]	NA	NA	25550	25550
AT-Cancer (d)[i]	NA	NA	25550	25550

[a] Parameter values obtained from the Risk Assessment Work Plan Addendum (DOE 1992a) unless otherwise noted.
[b] Derived by dividing the default adult human inhalation rate of 20 m^3/day (U.S. EPA, 1989, Risk Assessment Guidance for Superfund) by 24 hours/day, and rounding to two significant figures.
[c] NA = Not applicable.
[d] Specific guidance from US EPA Region 5: standard tresspass scenario assumes 4 hr/d, 52 d/yr.
[e] Assumes the worker is a groundskeeper, who works 8 hours/day, 1 day/week 35 weeks/year on the grounds of OU4.
[f] Assumes a farmer works outdoors for 2000 hours/year (US EPA, Region V).
[g] U.S. EPA (1991), "Risk Assessment Guidance for Superfund: Vol. I – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)," OSWER Directive 9285.7-01B.
[h] U.S. EPA (1990b), Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Supplemental Guidance, "Standard Exposure Factors", Final Draft, OSWER Directive: 9285.6-03, pg. 10.
[i] Calculated as the product of ED (years) x 365 days/year.
[j] Assumes a small child spends 4 of 16 waking hours/day on-site.
[k] US EPA (1992) "Dermal Exposure Assessment: Principals and Applications, EPA/600/8-91/011B, Section 8.4: 25% of total body surface area, based on 50th percentile body weight, as described in US EPA (1989) Risk Assessment Guidance for Superfund, Sections 6.1 and 6.2.

TABLE D.3-11
(Continued)

[l] US EPA (1992) "Dermal Exposure Assessment: Principals and Applications," EPA/600/8-91/011B: AF from pg. 8-17; EF from pg. 8-6; ET and SA adult from pg. 8-7 or Table 10-1; SA child from Section 8-4.

[m] csv = Chemical specific value.

[n] US EPA (1989), "Risk Assessment Guidance for Superfund Vol. I, Human Health Evaluation Manual (Part A)," pg. 6-36.

TABLE D.3-12

PARAMETERS USED TO ESTIMATE POTENTIAL EXPOSURES FOR FUTURE LAND USE RECEPTORS[a]

Pathway Parameters	Off-property User of Surface Water Age 1-70	CT On-property Resident Age 1-70	Off-property Resident Farmer Age 1-70	RME On-property Farmer Age 1-70	On-property Resident Child Age 1-6
Inhalation of Dusts, Volatiles, and Radon					
IR (m^3/hr)	NA[b]	0.83[c]	0.83[c]	0.83[c]	0.83[c]
ET Indoors (hr/d)	NA	19.8[d]	18.3[d]	18.3[d]	22[e]
ET Outdoors (hr/d)	NA	4.2[d]	5.7[d]	5.7[d]	2[e]
EF (d/yr)	NA	275[d]	350[f]	350[f]	350[f]
ED (yr)	NA	9[g]	70	70	6
BW (kg)	NA	70	70	70	15
AT-Noncancer (d)[h]	NA	3285	25550	25550	2190
AT-Cancer (d)[h]	NA	25550	25550	25550	25550
Ingestion of Drinking Water					
IR x FI (ℓ/d)	2	1.4[d]	2	2	1.4[i]
EF (d/yr)	350[f]	275[d]	350[f]	350[f]	350[f]
ED (yr)	70	9[g]	70	70	6
BW (kg)	70	70	70	70	15
AT-Noncancer (d)[h]	25550	3285	25550	25550	2190
AT-Cancer (d)[h]	25550	25550	25550	25550	25550
Inhalation of Volatiles Released from Household Water Uses					
IR (m^3/d)	15[h]	15[h]	15[h]	15[h]	15[h]
ET (hr/d)	0.25[j]	0.17[j]	0.25[j]	0.25[j]	0.33[j]
EF (d/yr)	350[f]	275[d]	350[f]	350[f]	350[f]
ED (yr)	70	9[g]	70	70	6
BW (kg)	70	70	70	70	15
AT-Noncancer (d)[h]	25550	3285	25550	25550	2190
AT-Cancer (d)[h]	25550	25550	25550	25550	25550
Dermal Contact While Bathing					
SA (m^2)	2.0[j]	2.0[j]	2.0[j]	2.0[j]	0.7[j]
PC (cm/hr)	csv[k]	csv	csv	csv	csv
ET (hr/d)	0.25[j]	0.17[j]	0.25[j]	0.25[j]	0.33[j]
EF (d/yr)	350[f]	275[d]	350[f]	350[f]	350[f]
ED (yr)	70	9[g]	70	70	6
BW (kg)	70	70	70	70	15
AT-Noncancer (d)[h]	25550	3285	25550	25550	2190
AT-Cancer (d)[h]	25550	25550	25550	25550	25550

TABLE D.3-12
(Continued)

Pathway Parameters	Off-property User of Surface Water Age 1-70	CT On-property Resident Age 1-70	Off-property Resident Farmer Age 1-70	RME On-property Farmer Age 1-70	On-property Resident Child Age 1-6
Incidental Ingestion of Soil/Sediment					
IR (g/d)	NA	0.1[d]	NA	0.48[d]	0.2
FI	NA	1[l]	NA	1[l]	1[l]
EF (d/yr)	NA	275[d]	NA	350[f]	350[f]
ED (yr)	NA	9[g]	NA	70	6
BW (kg)	NA	70	NA	70	15
AT-Noncancer (d)[h]	NA	3285	NA	25550	2190
AT-Cancer (d)[h]	NA	25550	NA	25550	25550
Dermal Contact with Soil/Sediment					
SA (m^2)	NA	0.5[m]	NA	0.5[m]	0.18[m]
AF (mg/cm^2)	NA	0.2[j]	NA	1.0[j]	1.0[j]
ABS (unitless)	NA	csv	NA	csv	csv
EF (d/yr)	NA	40[j]	NA	350[f]	350[f]
ED (yr)	NA	9[e]	NA	70	6
BW (kg)	NA	70	NA	70	15
AT-Noncancer (d)[h]	NA	3285	NA	25550	2190
AT-Cancer (d)[h]	NA	25550	NA	25550	25550
External Radiation Exposure					
DR (mrem/hr)	NA	csv	NA	csv	csv
ET Indoors (hr/d)	NA	19.8[d]	NA	18.3[d]	22[e]
ET Outdoors (hr/d)	NA	4.2[d]	NA	5.7[d]	2[e]
EF (d/yr)	NA	275[d]	NA	350[f]	350[f]
ED (yr)	NA	9[g]	NA	70	6
SH Indoors (unitless)	NA	0.5	NA	0.5	0.5
SH Outdoors (unitless)	NA	0	NA	0	0
Ingestion of Vegetables and Fruit					
IR x FI (g/d)	122	78[d]	122	122	101.5[n]
EF (d/yr)	350[f]	275[d]	350[f]	350[f]	350[f]
ED (yr)	70	9[g]	70	70	6
BW (kg)	70	70	70	70	15
AT-Noncancer (d)[h]	25550	3285	25550	25550	2190
AT-Cancer (d)[h]	25550	25550	25550	25550	25550
Ingestion of Meat					
IR x FI (g/d)	75	50[d]	75	75	29
EF (d/yr)	350[f]	275[d]	350[f]	350[f]	350[f]
ED (yr)	70	9[g]	70	70	6
BW (kg)	70	70	70	70	15

TABLE D.3-12
(Continued)

Pathway Parameters	Off-property User of Surface Water Age 1-70	CT On-property Resident Age 1-70	Off-property Resident Farmer Age 1-70	RME On-property Farmer Age 1-70	On-property Resident Child Age 1-6
AT-Noncancer (d)[h]	25550	3285	25550	25550	2190
AT-Cancer (d)[h]	25550	25550	25550	25550	25550
Ingestion of Milk					
IR x FI (L/d)	0.3	0.2[d]	0.3	0.3	0.9
EF (d/yr)	350[f]	275[d]	350[f]	350[f]	350[f]
ED (yr)	70	9[g]	70	70	6
BW (kg)	70	70	70	70	15
AT-Noncancer (d)[h]	25550	3285	25550	25550	2190
AT-Cancer (d)[h]	25550	25550	25550	25550	25550
Ingestion of Fish					
IR x FI (g/d)	54	NA	NA	NA	NA
EF (d/yr)	350[f]	NA	NA	NA	NA
ED (yr)	70	NA	NA	NA	NA
BW (kg)	70	NA	NA	NA	NA
AT-Noncancer (d)[h]	25550	NA	NA	NA	NA
AT-Cancer (d)[h]	25550	NA	NA	NA	NA
Incidental Ingestion of Surface Water During Swim or Play					
IR x FI (L/hr)	NA	NA	NA	NA	0.05[n]
ET (hr/d)	NA	NA	NA	NA	0.5[j]
EF (d/yr)	NA	NA	NA	NA	5[j]
ED (yr)	NA	NA	NA	NA	6
BW (kg)	NA	NA	NA	NA	15
AT-Noncancer (d)[h]	NA	NA	NA	NA	2190
AT-Cancer (d)[h]	NA	NA	NA	NA	25550
Dermal Contact with Surface Water During Swim or Play					
SA (m^2)	NA	NA	NA	NA	0.7[j]
PC (cm/hr)	NA	NA	NA	NA	csv
ET (hr/d)	NA	NA	NA	NA	0.5[j]
EF (d/yr)	NA	NA	NA	NA	5[j]
ED (yr)	NA	NA	NA	NA	6
BW (kg)	NA	NA	NA	NA	15
AT-Noncancer (d)[h]	NA	NA	NA	NA	2190
AT-Cancer (d)[h]	NA	NA	NA	NA	25550

[a] Parameter values obtained from the Risk Assessment Work Plan Addendum (DOE 1992a) unless otherwise noted.
[b] NA = Not applicable.
[c] Derived by dividing the default adult human inhalation rate of 20 m^3/day (U.S. EPA, 1989, Risk Assessment Guidance for Superfund) by 24 hours/day, and rounding to two significant figures.

TABLE D.3-12
(Continued)

[d] Special guidance from US EPA Region V.
[e] Assumes a resident small child spends 700 hours/year outdoors.
[f] U.S. EPA (1991), "Risk Assessment Guidance for Superfund: Vol. I – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)," OSWER Directive 9285.7-01B.
[g] Oswer Standard Default Exposure Parameters (EPA 1991); 50th percentile at one residence.
[h] Calculated as the product of ED (years) x 365 days/year.
[i] Drinking water consumption rate of 1.4 L/day from NRC (Nuclear Regulatory Commission), 1977, U.S. Nuclear Regulatory Commission Regulatory Guide 1.109; NCRP (National Council on Radiation Protection) Report No. 76.
[j] US EPA (1992) "Dermal Exposure Assessment: Principals and Applications," EPA/600/8-91/011B: AF from pg. 8-17; EF from pg. 8-6; ET and SA adult from Table 10-1; SA child from Section 8-4.
[k] csv = Chemical specific value.
[l] Assumed value, based on fraction of day spent on site.
[m] US EPA (1992) "Dermal Exposure Assessment: Principals and Applications, EPA/600/8-91/011B, Section 8.4: 25% of total body surface area, based on 50th percentile body weight, as described in US EPA (1989) Risk Assessment Guidance for Superfund, Sections 6.1 and 6.2.
[n] US EPA (1989) Risk Assessment Guidance for Superfund, pg. 6-36.

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TABLE D.3-13

TRANSFER COEFFICIENTS USED IN EXPOSURE MODELS

Constituent	Transfer Coefficients									
	BCF FISH	Ref.	BEEF TF[a]	Ref.	MILK TF[a]	Ref.	Bv TF[a]	Ref.	Br TF[a]	Ref.
Radionuclides										
Actinium	2.50×10^{1}	b	6.00×10^{-2}	b	2.00×10^{-5}	a	3.50×10^{-3}	a	3.50×10^{-4}	a
Protactinium	1.10×10^{1}	b	8.00×10^{-2}	b	5.00×10^{-4}	a	2.50×10^{-3}	a	2.50×10^{-4}	a
Radium	5.00×10^{1}	b	2.50×10^{-4}	a	4.50×10^{-4}	a	1.50×10^{-2}	a	1.50×10^{-3}	a
Strontium	3.00×10^{1}	b	3.00×10^{-4}	a	1.50×10^{-3}	a	2.50×10^{0}	a	2.50×10^{-1}	a
Technetium	1.50×10^{1}	b	4.00×10^{-1}	b	1.00×10^{-2}	a	9.50×10^{0}	a	1.50×10^{0}	a
Thorium	3.00×10^{1}	b	6.00×10^{-6}	a	5.00×10^{-6}	a	8.50×10^{-4}	a	8.50×10^{-5}	a
Uranium	2.00×10^{0}	b	2.00×10^{-4}	a	6.00×10^{-4}	a	8.50×10^{-3}	a	4.00×10^{-3}	a
Inorganics										
Antimony	1.00×10^{0}	c	1.00×10^{-3}	a	1.00×10^{-4}	a	2.00×10^{-1}	a	3.00×10^{-2}	a
Arsenic	4.40×10^{1}	c	2.00×10^{-3}	a	6.00×10^{-5}	a	4.00×10^{-2}	a	6.00×10^{-3}	a
Barium	ND		1.50×10^{-4}	a	3.50×10^{-4}	a	1.50×10^{-1}	a	1.50×10^{-2}	a
Beryllium	1.90×10^{1}	c	1.00×10^{-3}	a	9.00×10^{-7}	a	1.00×10^{-2}	a	1.50×10^{-3}	a
Boron	ND		8.00×10^{-4}	a	1.50×10^{-3}	a	4.00×10^{0}	a	2.00×10^{0}	a
Cadmium (food)	8.10×10^{1}	c	5.50×10^{-4}	a	1.00×10^{-3}	a	5.50×10^{-1}	a	1.50×10^{-1}	a
Chromium	1.60×10^{1}	c	5.50×10^{-3}	a	1.50×10^{-3}	a	7.50×10^{-3}	a	4.50×10^{-3}	a
Cobalt	ND		2.00×10^{-2}	a	2.00×10^{-3}	a	2.00×10^{-2}	a	7.00×10^{-3}	a
Copper	2.00×10^{2}	c	1.00×10^{-2}	a	1.50×10^{-3}	a	4.00×10^{-1}	a	2.50×10^{-1}	a
Cyanide	0.00	c	ND		ND		ND		ND	
Lead	4.90×10^{1}	c	3.00×10^{-4}	a	2.50×10^{-4}	a	4.50×10^{-2}	a	9.00×10^{-3}	a
Manganese	ND		4.00×10^{-4}	a	3.50×10^{-4}	a	2.50×10^{-1}	a	5.00×10^{-2}	a
Mercury	5.50×10^{3}	c	2.50×10^{-1}	a	4.50×10^{-4}	a	9.00×10^{-1}	a	2.00×10^{-1}	a
Molybdenum	ND		6.00×10^{-3}	a	1.50×10^{-3}	a	2.50×10^{-1}	a	6.00×10^{-2}	a
Nickel	4.70×10^{1}	c	6.00×10^{-3}	a	1.00×10^{-3}	a	6.00×10^{-2}	a	6.00×10^{-2}	a

TABLE D.3-13
(Continued)

Constituent	Transfer Coefficients									
	BCF FISH	Ref.	BEEF TF[a]	Ref.	MILK TF[a]	Ref.	Bv TF[a]	Ref.	Br TF[a]	Ref.
Selenium	1.60×10^{1}	c	1.50×10^{-2}	a	4.00×10^{-3}	a	2.50×10^{-2}	a	2.50×10^{-2}	a
Silver	3.08×10^{3}	c	3.00×10^{-3}	a	2.00×10^{-2}	a	4.00×10^{-1}	a	1.00×10^{-1}	a
Thallium	ND		4.00×10^{-2}	a	2.00×10^{-3}	a	4.00×10^{-3}	a	4.00×10^{-4}	a
Uranium	ND		2.00×10^{-4}	a	6.00×10^{-4}	a	8.50×10^{-3}	a	4.00×10^{-3}	a
Vanadium	ND		2.50×10^{-3}	a	2.00×10^{-5}	a	5.50×10^{-3}	a	3.00×10^{-3}	a
Zinc	4.70×10^{1}	c	1.00×10^{-1}	a	1.00×10^{-2}	a	1.50×10^{0}	a	9.00×10^{-1}	a
Organics										
2-Butanone	0.00×10^{0}	c	4.57×10^{-8}	d	1.45×10^{-8}	e	2.74×10^{1}	f	2.74×10^{1}	g
2-Hexanone	6.59×10^{0}	h	6.03×10^{-7}	d	1.91×10^{-7}	e	6.17×10^{0}	f	6.17×10^{0}	g
3-Methyl-2-butanone, 3-Methyl	ND	h	ND	d	ND	e	ND	f	ND	g
4-Methyl-2-pentanone	3.97×10^{0}	h	3.09×10^{-7}	d	9.77×10^{-8}	e	9.08×10^{0}	f	9.08×10^{0}	g
Acetone	3.87×10^{-1}	h	1.45×10^{-8}	d	4.57×10^{-9}	e	5.33×10^{1}	f	5.33×10^{1}	g
Carbon tetrachloride	1.90×10^{1}	c	1.35×10^{-5}	d	4.27×10^{-6}	e	1.02×10^{0}	f	1.02×10^{0}	g
Chloroform	3.75×10^{0}	c	2.34×10^{-6}	d	7.41×10^{-7}	e	2.81×10^{0}	f	2.81×10^{0}	g
Methylene chloride	5.00×10^{0}	c	4.47×10^{-7}	d	1.41×10^{-7}	e	7.34×10^{0}	f	7.34×10^{0}	g
Tetrachloroethene	3.10×10^{1}	c	8.51×10^{-6}	d	2.69×10^{-6}	e	1.34×10^{0}	f	1.34×10^{0}	g
Toluene	1.07×10^{1}	c	1.23×10^{-5}	d	3.89×10^{-6}	e	1.08×10^{0}	f	1.08×10^{0}	g
Total xylenes	1.20×10^{2}	h	2.75×10^{-5}	d	8.71×10^{-6}	e	6.77×10^{-1}	f	6.77×10^{-1}	g
Semivolatile Organics										
Acenaphthylene	5.61×10^{2}	h	2.09×10^{-4}	d	6.61×10^{-5}	e	2.10×10^{-1}	f	2.10×10^{-1}	g
Aldrin	4.50×10^{3}	h	8.51×10^{-2}	i	2.40×10^{-2}	i	2.14×10^{-2}	i	2.14×10^{-2}	g
Anthracene	9.17×10^{2}	j	7.08×10^{-4}	d	2.24×10^{-4}	e	1.04×10^{-1}	f	1.04×10^{-1}	g
Benzo(a)anthracene	1.01×10^{4}	j	1.00×10^{-2}	d	3.16×10^{-3}	e	2.24×10^{-2}	f	2.24×10^{-2}	g
Benzo(a)pyrene	2.06×10^{4}	h	2.40×10^{-2}	d	7.59×10^{-3}	e	5.62×10^{-2}	i	5.62×10^{-2}	g

TABLE D.3-13
(Continued)

Constituent	Transfer Coefficients									
	BCF FISH	Ref.	BEEF TF[a]	Ref.	MILK TF[a]	Ref.	Bv TF[a]	Ref.	Br TF[a]	Ref.
Benzo(b)fluoranthene	5.80×10^{4}	h	9.33×10^{-2}	d	2.95×10^{-2}	e	6.17×10^{-3}	f	6.17×10^{-3}	g
Benzo(g,h,i)perylene	1.84×10^{5}	h	4.27×10^{-1}	d	1.35×10^{-1}	e	2.56×10^{-3}	f	2.56×10^{-3}	g
Benzoic acid	1.55×10^{1}	h	1.86×10^{-6}	d	5.89×10^{-7}	e	3.21×10^{0}	f	3.21×10^{0}	g
bis(2-Ethylhexyl)phthalate	8.50×10^{2}	j	5.01×10^{-3}	d	1.58×10^{-3}	e	3.35×10^{-2}	f	3.35×10^{-2}	g
Butanoic acid, methyl ester	ND	h	ND	d	ND	e	ND	f	ND	g
Chrysene	1.06×10^{4}	h	1.00×10^{-2}	d	3.16×10^{-3}	e	2.24×10^{-2}	f	2.24×10^{-2}	g
Di-n-butylphthalate	5.27×10^{3}	h	3.98×10^{-3}	d	1.26×10^{-3}	e	3.82×10^{-2}	f	3.82×10^{-2}	g
Di-n-octylphthalate	5.78×10^{6}	h	3.98×10^{1}	d	1.26×10^{1}	e	1.86×10^{-4}	f	1.86×10^{-4}	g
Dibenzo(a,h)anthracene	2.03×10^{4}	h	2.34×10^{-2}	d	7.41×10^{-3}	e	1.37×10^{-2}	f	1.37×10^{-2}	g
Diethyl phthalate	1.17×10^{2}	c	2.29×10^{-5}	d	7.24×10^{-6}	e	7.54×10^{-1}	f	7.54×10^{-1}	g
Dimethyl phthalate	5.70×10^{1}	j	1.86×10^{-6}	d	5.89×10^{-7}	e	3.22×10^{0}	f	3.22×10^{0}	g
Fluoranthene	1.15×10^{3}	c	5.37×10^{-3}	d	1.70×10^{-3}	e	3.22×10^{-2}	f	3.22×10^{-2}	g
Indeno(1,2,3-cd)pyrene	3.90×10^{5}	h	1.15×10^{0}	d	3.63×10^{-1}	e	1.45×10^{-3}	f	1.45×10^{-3}	g
N-Nitroso-di-n-propylamine	5.83×10^{0}	h	5.13×10^{-7}	d	1.62×10^{-7}	e	6.77×10^{0}	f	6.77×10^{0}	g
Phenanthrene	2.63×10^{3}	c	7.24×10^{-4}	d	2.29×10^{-4}	e	1.02×10^{-1}	f	1.02×10^{-1}	g
Phenol	1.40×10^{0}	c	7.08×10^{-7}	d	2.24×10^{-7}	e	5.62×10^{0}	f	5.62×10^{0}	g
Pyrene	2.70×10^{3}	j	3.80×10^{-3}	d	1.20×10^{-3}	e	3.93×10^{-2}	f	3.93×10^{-2}	g
Styrene	1.48×10^{2}	h	3.63×10^{-5}	d	1.15×10^{-5}	e	5.78×10^{-1}	f	5.78×10^{-1}	g
Tributyl phosphate	6.46×10^{2}	h	2.51×10^{-4}	d	7.94×10^{-5}	e	1.89×10^{-1}	f	1.89×10^{-1}	g
Pesticides/PCBs										
Aroclor-1242	4.90×10^{4}	j	3.24×10^{-4}	d	1.02×10^{-4}	e	1.63×10^{-1}	f	1.63×10^{-1}	g
Aroclor-1248	7.05×10^{4}	j	1.41×10^{-2}	d	4.47×10^{-3}	e	1.84×10^{-2}	f	1.84×10^{-2}	g
Aroclor-1254	1.00×10^{5}	c	5.25×10^{-2}	i	1.12×10^{-2}	i	1.70×10^{-2}	i	1.70×10^{-2}	g
Aroclor-1260	1.94×10^{5}	j	3.24×10^{-2}	d	1.02×10^{-2}	e	1.14×10^{-2}	f	1.14×10^{-2}	g
DDE	5.10×10^{4}	c	4.90×10^{-2}	i	9.55×10^{-3}	i	1.05×10^{-1}	i	1.05×10^{-1}	g

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TABLE D.3-13
(Continued)

Constituent	Transfer Coefficients									
	BCF FISH	Ref.	BEEF TF[a]	Ref.	MILK TF[a]	Ref.	Bv TF[a]	Ref.	Br TF[a]	Ref.
DDT	5.40×10^{4}	c	2.82×10^{-2}	i	2.40×10^{-3}	i	1.58×10^{-2}	i	1.58×10^{-2}	g
Dieldrin	4.76×10^{3}	c	7.94×10^{-3}	i	1.72×10^{-2}	i	9.77×10^{-2}	i	9.77×10^{-2}	g
Endosulfan II	2.94×10^{2}	h	2.19×10^{-4}	i	2.82×10^{-5}	e	3.44×10^{-1}	f	3.44×10^{-1}	g
Endosulfan I	3.32×10^{2}	h	2.19×10^{-4}	i	3.11×10^{-5}	e	3.13×10^{-1}	f	3.13×10^{-1}	g
Endrin	4.60×10^{3}	j	1.20×10^{-2}	i	1.74×10^{-3}	i	1.51×10^{-2}	i	1.51×10^{-2}	g
Heptachlor epoxide	1.44×10^{4}	c	7.94×10^{-2}	i	3.55×10^{-2}	i	2.40×10^{-2}	i	2.40×10^{-2}	g

[a]Baes, C. F. III, R. D. Sharp, A. L. Sjoreen, R. W. Shor, 1984, "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides Through Agriculture," U.S. DOE, ORNL-5786.
[b]NRC, 1984, "De Minimis Waste Impacts Analysis Methodolgy," NUREG/CR-3585.
[c]EPA, 1986a, Superfund Public Health Evaluation Manual (SPHEM).
[d]Log of biotransfer factor in beef (Log Bb) calculated from geometric mean regression model: Log Bb= -7.6 + Log Kow (Travis & Arms 1988).
[e]Log of biotransfer factor in milk (Log Bm) calculated from geometric mean regression model: Log Bm = -8.10 + Log Kow (Travis & Arms 1988).
[f]Log of bioconcentration factor in vegetation (Log Bv) calculated from geometric mean regression model: Log Bv = 1.588 - 0.578 Log Kow (Travis & Arms 1988).
[g]This value was used for leafy vegetable uptake as well as forage plant uptake.
[h]Calculated from log BCF = 0.76 * log Kow - 0.23 (Lyman et al. 1990).
[i]Value reported in Travis, C. C., and A. D. Arms, 1988, "Bioconcentration of Organics in Beef, Milk, and Vegetation," ES&T Vol. 22, No. 3, pp. 271-274.
[j]Value reported in Lyman et al. 1990, Handbook of Chemical Property Estimation Methods.

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λ_{Ei}	=	effective depletion constant of ith contaminant on the surface plants (hr^{-1})
λ_{ri}	=	radioactive or chemical decay constant of ith contaminant (hr^{-1})
$B_{iv(1)}$	=	dry soil to wet plant partitioning coefficient of ith contaminant (C_{iv}/C_s)
C_{ivd}	=	concentration of ith contaminant in plants as a result of deposition of contaminated dust on plants (pCi/kg) (mg/kg)
C_{ivw}	=	concentration of ith contaminant in plants as a result of irrigating plants with contaminated water (pCi/kg) (mg/kg)
d_w	=	irrigation deposition rate (pCi/m^2-hr) (mg/m^2-hr)
f_w	=	fraction of year plant is downwind (unitless)
ρ	=	effective dry surface density of the soil (kg/m^2)
r_w	=	fraction of water borne material retained on plant surface (unitless)
t_{bw}	=	duration of irrigation use (hr)
t_e	=	growing season (hrs)
t_h	=	duration of period between harvest and consumption (hr)
Y	=	agricultural yield (kg/m^2)

Transfer factors used are listed in Table D.3-13.

In addition to being exposed to contaminated irrigation water and dust, vegetables and livestock feed may be contaminated by root uptake from contaminated soil or waste. A contribution via this pathway is accounted for in the irrigation model; however, this pathway is also considered for areas that are not irrigated with contaminated water but that exhibit surface soil contamination from historical deposition on the soil by various means. The following equation can be used to calculate the contaminant concentration in the plant from root uptake of contaminants already in the soil.

$$C_{ivs} = (C_s)(B_{iv(1)})(e^{-\lambda_{ri}(t_e + t_h)}) \qquad \text{(D.3-4)}$$

where

C_{ivs}	=	concentration of ith contaminant in plants as a result of root uptake from contaminated soil (pCi/kg) (mg/kg)
C_s	=	concentration of ith contaminant in dry soil at the beginning of the growing season (pCi/kg) (mg/kg)

The total concentration of contaminants in vegetables (C_{iv}) is calculated with the following equation:

$$C_{iv} = C_{ivw} + C_{ivd} + C_{ivs} \qquad \text{(D.3-5)}$$

Once the concentration in vegetation has been determined, intake can be calculated with the following equations:

(radionuclides) $I_{iv} = (C_{iv})(IR)(ED)(FI)$ (D.3-6)

(chemicals) $I_{iv} = (C_{iv})(IR)(FI)(EF)(ED)/(BW)(AT)$ (D.3-7)

where

I_{iv}	=	intake from vegetation (pCi) (mg/kg-day)
C_{iv}	=	total concentration of contaminants in vegetable (pCi/kg) (mg/kg)
IR	=	ingestion rate (kg/yr) (kg/day)
FI	=	fraction ingested from contaminated source (unitless)
EF	=	exposure frequency (days/yr)
ED	=	exposure duration (yr)
BW	=	body weight (kg)
AT	=	averaging time (days); for noncarcinogens, AT equals (ED)(365 days/yr); for carcinogens, AT equals (70-year lifetime)(365 days/yr)

Although EPA (1989a) "Risk Assessment Guidance for Superfund" specifies that IR x FI is expressed in g/meal for foods, and that EF should be expressed in meals/year, by assuming a standard number of meals/day, g/meal becomes proportional to g/day and L/day, respectively. Therefore, IR x FI may be expressed as g/day so long as EF is expressed as days/yr. The same would apply to ingestion of animal products (Section D.3.4.3) and ingestion of fish (Section D.3.4.8).

Equations of the same form are used to determine the contaminant concentration in livestock feed, substituting concentration factors for livestock feed in place of those for vegetables consumed by man. Once the contaminant concentrations in vegetables and livestock feed have been determined, intake can be estimated using the intake equations presented for ingestion of vegetables contaminated by irrigation and ingestion of animal products.

D.3.3.3 Ingestion of Animal Products

As in the quantification of intake following exposure to vegetables, the concentration in animal products must be estimated prior to the determination of intake. The concentration of a contaminant in animal products, such as beef or milk, is determined using the following equation (NRC 1977):

$$C_{iA} = F_{iA}[(C_{if})(Q_f) + (C_{iAw})(Q_{Aw})] \qquad \text{(D.3-8)}$$

where

C_{iA}	=	concentration of ith contaminant in the animal product (pCi/L for milk, pCi/kg for beef) (mg/L for milk, mg/kg for beef)
F_{iA}	=	element (stable) transfer coefficient that relates the daily intake by an animal to the concentration of ith contaminant in an edible portion of the animal product (day/L for milk, day/kg for meat)
C_{if}	=	concentration of ith contaminant in forage (pCi/kg) (mg/kg)
Q_f	=	consumption rate of contaminated forage by an animal (kg/day)
C_{iAw}	=	concentration of ith contaminant in livestock water (pCi/L) (mg/L)
Q_{Aw}	=	consumption rate of contaminated water by an animal (L/day)

Transfer factors used are listed in Table D.3-13.

In addition to intake from irrigated forage and water, cows may receive a significant intake from soil ingestion if the soil is also a source of contamination (Zach and Mayoh 1984). The following equation can be used to calculate the concentration in the animal product from soil ingestion (EPA 1989a):

$$C_{iA} = F_{iA}[(C_s)(Q_s)] \qquad \text{(D.3-9)}$$

where

C_s = concentration of contaminant in soil (pCi/kg) (mg/kg)
Q_s = consumption rate of soil by livestock (kg/day)

Once the concentration in the animal product is determined, human intake can be calculated using the following equations:

$$\text{(radionuclides)} \quad I_{iA} = (C_{iA})(IR)(ED)(FI) \qquad \text{(D.3-10)}$$
$$\text{(chemicals)} \quad I_{iA} = (C_{iA})(IR)(FI)(EF)(ED)/(BW)(AT) \qquad \text{(D.3-11)}$$

where

I_{iA} = intake of chemical in animal product (pCi) (mg/kg/day)
C_{iA} = concentration of ith contaminant in the animal product (pCi/L for milk, pCi/kg for beef) (mg/L for milk, mg/kg for beef)
IR = ingestion rate (L/yr for milk; kg/yr for beef) (L/day for milk; kg/day for beef)
FI = fraction ingested from contaminated source (unitless)
EF = exposure frequency (days/yr)
ED = exposure duration (yr)
BW = body weight (kg)
AT = averaging time (days); for noncarcinogens, AT equals (ED)(365 days/yr); for carcinogens, AT equals (70-year lifetime)(365 days/yr)

As discussed in Section D.3.4.2, IR x FI is expressed as g/day for meat and L/day for milk, and EF is expressed as days/yr.

D.3.3.4 Dermal Contact with Soil or Water

For most metals and radionuclides at the FEMP, dermal absorption is not a significant pathway because penetration through the skin is minimal. However, it may be necessary to evaluate dermal absorption if other constituents are found to contribute to potential risks at the site. The amount of a chemical taken into the body upon exposure via dermal contact is referred to as an absorbed dose and is calculated using the following equation (EPA 1992d):

$$DAD = (DA_e)(SA)(EV)(ED)(EF)/(BW)(AT) \qquad \text{(D.3-12)}$$

where

DAD = decimally absorbed dose from contact with water (mg/kg/day)
DA_e = absorbed dose per event (mg/cm^2 - event)
SA = skin surface area available for contact (cm^2)
EV = event frequency (events/day)
ED = exposure duration (yr)
EF = exposure frequency (days/yr)
BW = body weight (kg)
AT = averaging time (days); for noncarcinogens, AT equals (ED)(365 days/yr); for carcinogens, AT equals (70-year lifetime)(365 days/yr)

The term DA_e is calculated as per EPA (1992d), Section 5.3. DA_e is a function of K_p, the water permeability coefficient. Values for K_p are presented in Table D.3-14.

Dermal absorption may also occur upon contact with contaminated soil and sediment and is calculated using the following equation (EPA 1989a):

$$AB_s = (C_s)(CF)(SA)(AF)(ABS)(ED)(EF)/(BW)(AT) \qquad \text{(D.3-13)}$$

where

AB_s = absorbed dose from contact with soil (mg/kg/day)
C_s = concentration in soil (mg/kg)
SA = skin surface area available for contact (cm^2/event)
AF = skin adherence factor (mg/cm^2)
ABS = absorption factor (unitless)
CF = conversion factor (10^{-6} kg/mg)
ED = exposure duration (yr)
EF = exposure frequency (days/yr)
BW = body weight (kg)
AT = averaging time (days); for noncarcinogens, AT equals (ED)(365 days/yr); for carcinogens, AT equals (70-year lifetime)(365 days/yr)

Dermal absorption coefficients are presented in Table D.3-14.

D.3.3.5 Inhalation

The equations used to quantify intake from the inhalation pathway adapted from EPA (EPA 1989a) are:

(radionuclides) $I_a = (C_a)(IR)(ED)$ (D.3-14)
(chemicals) $I_a = (C_a)(IR)(EF)(ED)/(BW)(AT)$ (D.3-15)

where

I_a = intake from inhalation (pCi) (mg/kg/day)
C_a = concentration in air (pCi/m^3) (mg/m^3)

TABLE D.3-14

DERMAL ABSORPTION COEFFICIENTS AND HENRY'S LAW CONSTANTS USED IN EXPOSURE MODEL

Constituent	Water Permeability Coefficient[a] (cm/hr)	Soil Absorption Coefficient[b] (unitless)	Henry's Law Constant[c] (atm-m^3/mol)	Reference
Inorganics				
Antimony	1.00×10^{-3}	1.00×10^{-2}	ND[d]	
Arsenic	1.00×10^{-3}	1.00×10^{-2}	ND	
Barium	1.00×10^{-3}	1.00×10^{-2}	ND	
Beryllium	1.00×10^{-3}	1.00×10^{-2}	ND	
Boron	1.00×10^{-3}	1.00×10^{-2}	ND	
Cadmium (food)	1.00×10^{-3}	1.00×10^{-3}	ND	
Chromium	1.00×10^{-3}	1.00×10^{-2}	ND	
Cobalt	1.00×10^{-3}	1.00×10^{-2}	ND	
Cyanide	1.00×10^{-3}	1.00×10^{-2}	ND	
Copper	1.00×10^{-3}	1.00×10^{-2}	ND	
Lead	1.00×10^{-3}	1.00×10^{-2}	ND	
Manganese	1.00×10^{-3}	1.00×10^{-2}	ND	
Mercury	1.00×10^{-3}	1.00×10^{-2}	ND	
Molybdenum	1.00×10^{-3}	1.00×10^{-2}	ND	
Nickel	1.00×10^{-3}	1.00×10^{-2}	ND	
Selenium	1.00×10^{-3}	1.00×10^{-2}	ND	
Silver	1.00×10^{-3}	1.00×10^{-2}	ND	
Thallium	1.00×10^{-3}	1.00×10^{-2}	ND	
Uranium	1.00×10^{-3}	1.00×10^{-2}	ND	
Vanadium	1.00×10^{-3}	1.00×10^{-2}	ND	
Zinc	1.00×10^{-3}	1.00×10^{-2}	ND	
Volatile Organics				
2-Butanone	1.10×10^{-3}	1.00×10^{0}	2.74×10^{-5}	
2-Hexanone	ND	1.00×10^{0}	ND	
3-Methyl-2-butanone	ND	1.00×10^{0}	ND	
4-Methyl-2-pentanone	3.30×10^{-3}	1.00×10^{0}	ND	

TABLE D.3-14
(Continued)

Constituent	Water Permeability Coefficient[a] (cm/hr)	Soil Absorption Coefficient[b] (unitless)	Henry's Law Constant[c] (atm-m^3/mol)	Reference
Acetone	5.69×10^{-4}	1.00×10^{0}	2.06×10^{-5}	
Carbon tetrachloride	2.20×10^{-2}	3.00×10^{-2}	2.41×10^{-2}	
Chloroform	8.90×10^{-3}	3.00×10^{-2}	2.87×10^{-3}	
Methylene chloride	4.50×10^{-3}	4.00×10^{-1}	2.03×10^{-3}	
Tetrachloroethene	4.80×10^{-2}	3.00×10^{-2}	2.59×10^{-2}	
Toluene	4.50×10^{-2}	3.00×10^{-2}	6.37×10^{-3}	
Total xylenes	8.00×10^{-2}	3.00×10^{-2}	7.04×10^{-3}	
Semivolatile Organics				
Acenaphthylene	ND	1.00×10^{0}	ND	
Anthracene	2.25×10^{-1}	4.00×10^{-1}	1.02×10^{-3}	
Benzo(a)anthracene	8.10×10^{-1}	1.00×10^{0}	1.16×10^{-6}	
Benzo(a)pyrene	1.20×10^{0}	1.00×10^{0}	1.55×10^{-6}	
Benzo(b)fluoranthene	1.20×10^{0}	2.00×10^{-1}	1.19×10^{-5}	
Benzo(g,h,i)perylene	ND	1.00×10^{-1}	5.34×10^{-8}	
Butanoic acid, methyl ester	ND	1.00×10^{0}	ND	
Benzoic acid	7.30×10^{-3}	1.00×10^{0}	ND	
bis(2-Ethylhexyl)phthalate	3.30×10^{-2}	1.00×10^{0}	1.47×10^{-5}	e
Chrysene	8.10×10^{-1}	1.00×10^{0}	1.05×10^{-6}	
Di-n-butylphthalate	3.30×10^{-2}	1.00×10^{0}	2.82×10^{-7}	
Di-n-octylphthalate	2.67×10^{1}	1.00×10^{0}	ND	
Dibenzo(a,h)anthracene	2.70×10^{0}	1.00×10^{0}	7.33×10^{-8}	
Diethyl phthalate	4.80×10^{-3}	1.00×10^{0}	1.14×10^{-6}	
Dimethyl phthalate	1.60×10^{-3}	1.00×10^{0}	1.05×10^{-7}	e
Fluoranthene	3.60×10^{-1}	1.00×10^{0}	6.46×10^{-6}	
Indeno(1,2,3-cd)pyrene	1.90×10^{0}	1.00×10^{-1}	6.86×10^{-8}	
N-Nitroso-di-n-propylamine	2.61×10^{-3}	1.00×10^{0}	2.25×10^{-6}	e
Phenanthrene	2.70×10^{-1}	4.00×10^{-1}	1.59×10^{-4}	
Phenol	5.50×10^{-3}	1.00×10^{0}	4.54×10^{-7}	
Pyrene	5.30×10^{-1}	1.00×10^{0}	5.04×10^{-6}	

TABLE D.3-14
(Continued)

Constituent	Water Permeability Coefficient[a] (cm/hr)	Soil Absorption Coefficient[b] (unitless)	Henry's Law Constant[c] (atm-m^3/mol)	Reference
Styrene	5.50×10^{-2}	1.00×10^{0}	2.83×10^{-3}	e
Tributyl phosphate	ND	1.00×10^{0}	ND	
Pesticide/PCBs				
Aldrin	1.60×10^{-3}	1.00×10^{0}	1.60×10^{-5}	
Aroclor-1242	1.30×10^{0}	1.00×10^{-1}	1.07×10^{-3}	
Aroclor-1248	1.30×10^{0}	1.00×10^{-1}	1.07×10^{-3}	
Aroclor-1254	7.10×10^{-1}	1.00×10^{-1}	1.07×10^{-3}	
Aroclor-1260	7.10×10^{-1}	1.00×10^{-1}	1.07×10^{-3}	
DDT	4.30×10^{-1}	3.00×10^{-1}	5.13×10^{-4}	
DDE	2.40×10^{-1}	3.00×10^{-1}	6.80×10^{-5}	
Dieldrin	1.60×10^{-2}	1.00×10^{0}	4.58×10^{-7}	
Endosulfan I	2.33×10^{-3}	1.00×10^{0}	ND	
Endosulfan II	2.08×10^{-3}	1.00×10^{0}	ND	
Endrin	1.60×10^{-2}	1.00×10^{0}	ND	
Heptachlor epoxide	3.00×10^{-2}	4.00×10^{-1}	4.39×10^{-4}	

[a]EPA, 1992d, "Interim Guidance for Dermal Exposure Assessment," Office of Health and Environmental Assessment-EPA/600/8-91/011B January 1992; 0.001 is the default value for the water permeability coefficient for metals; Aroclor-1242 and -1248 used Kp for PCBs with 4 chlorines; Aroclor-1254 and -1260 used Kp for PCBs with 6 chlorines; acetone, anthracene, endosulfan, n-nitroso-di-n-proplyamine, pyrene, and heptachlor epoxide - Kps estimated using regression equation in EPA 1992d, MW and Kow.
[b]Cadmium, PCBs, DDE, DDT values from Schaum, 1991; other organics from McKone (1990); other inorganics from Wester et al. (1991) NOTE: Wester et al. (1991) report a range for cadmium of 0.1% to 1.0%. The upper value of this range was used for all other metals.
[c]Superfund Public Health Evaluation Manual, Oct. 1986 (SPHEM) unless otherwise noted
[d]ND - No data.
[e]From EPA, Office of Toxic Substances, 1990b, "Toxic Chemical Release Inventory," SARA Title III, Section 313 database.

IR = inhalation rate (m^3/yr) (m^3/day)
EF = exposure frequency (days/yr)
ED = exposure duration (yr)
BW = body weight (kg)
AT = averaging time (days); for noncarcinogens, AT equals (ED)(365 days/yr); for carcinogens, AT equals (70-year lifetime)(365 days/yr)

D.3.3.6 External Exposure

The radiation dose equivalent resulting from exposure to direct penetrating radiation is calculated in the following manner:

$$DE = (DR)(EF)(ED)(MF)(1\text{-}SH) \qquad \text{(D.3-16)}$$

where

DE = dose equivalent (mrem)
DR = dose equivalent rate (mrem/day)
EF = exposure frequency (days/yr)
ED = exposure duration (yr)
MF = modifying factor for hours spent outdoors; hours indoors (unitless)
SH = building shielding factor for dose equivalent rate reduction indoors (unitless)

D.3.3.7 Drinking Water

The equations used to estimate intake from drinking water are adapted from EPA (1989a). The intake equations are:

$$\text{(radionuclides)} \quad I_w = (C_w)(IR)(ED) \qquad \text{(D.3-17)}$$

$$\text{(chemicals)} \quad I_w = (C_w)(IR)(ED)(EF)/(BW)(AT) \qquad \text{(D.3-18)}$$

where

I_w = intake from drinking water (pCi) (mg/kg/day)
C_w = concentration in water (pCi/L) (mg/L)
IR = ingestion rate (L/yr) (L/day)
EF = exposure frequency (days/yr)
ED = exposure duration (yr)
BW = body weight (kg)
AT = averaging time (days); for noncarcinogens, AT equals (ED)(365 days/yr); for carcinogens, AT equals (70-year lifetime)(365 days/yr)

D.3.3.8 Ingestion of Fish

Intake from ingestion of fish may require a one- or two-step process. If the concentration of a constituent in fish is unknown, it is necessary to determine the concentration in the fish based on the concentration in the surface water. For example:

$$C_F = (C_{sw})(BCF) \qquad \text{(D.3-19)}$$

where

C_F = concentration in the fish meat (pCi/kg) (mg/kg)
C_{sw} = concentration in surface water (pCi/L) (mg/L)
BCF = fish bioconcentration factor (pCi/kg fish per pCi/L) (mg/kg fish per mg/L)

Values used for bioconcentration factors (BCFs) are presented in Table D.3-12.

Once the concentration in fish has been determined, or if measured concentrations in edible portions of fish are available, intake can be calculated as (EPA 1989a):

(radionuclides) $I_F = (C_F)(IR)(FI)(ED)(EF)$ (D.3-20)
(chemicals) $I_F = (C_F)(IR)(FI)(ED)(EF)/(BW)(AT)$ (D.3-21)

where

I_F = intake from fish ingestion (pCi) (mg/kg/day)
C_F = concentration in fish (pCi/kg) (mg/kg)
IR = ingestion rate (kg/day)
FI = fraction ingested from contaminated source (unitless)
ED = exposure duration (yr)
EF = exposure frequency (days/yr)
BW = body weight (kg)
AT = averaging time (days); for noncarcinogens, AT equals (ED)(365 days/yr); for carcinogens, AT equals (70-year lifetime)(365 days/yr)

As discussed in Section D.3.4.2, IR x FI is expressed as g/day and EF is expressed as days/yr.

Calculation of potential intakes of contaminants is discussed in Section D.3.3. Calculated intakes are not presented because this is an interim step to risk characterization. The unit risk factors that incorporate calculation of exposure intakes are presented in Attachment D.I. The models (and formulae) used for intake calculations are generally accepted as the most appropriate for an exposure assessment. Specific model parameters were selected to provide reasonable, upper bound estimates of intake. Discussions of the appropriateness of selected parameters are given in numerous references cited in the Work Plan Addendum (DOE 1992a). It can be concluded, however, that the selected parameters as a whole will lead to overestimates, rather than underestimates, of the potential intakes by hypothetical receptors.

D.4.0 TOXICITY ASSESSMENT

This toxicity assessment examines information concerning the potential effects of exposure to contaminants of concern. The goal is to provide, for each contaminant of potential concern, a quantitative estimate of the relationship between exposure and severity or probability of effect. The toxicity assessment contains a compilation of toxic and carcinogenic effects of contaminants of potential concern followed by detailed evaluations of the major contaminants of potential concern.

D.4.1 TOXICITY INFORMATION FOR CONTAMINANTS OF POTENTIAL CONCERN

This section presents tabulated summary toxicity information for noncarcinogenic and carcinogenic effects. It also presents brief toxicological profiles for the contaminants of concern that are most significant in terms of risk, or for which toxicological issues require clarification (e.g., use of the EPA uptake-biokinetic (UBK) model to evaluate the risk for children exposed to lead).

D.4.1.1 Noncarcinogens

The reference dose (RfD) is the toxicity value used to quantitatively express the hazard of noncarcinogenic contaminants. The RfD is expressed in units of mg/kg/day and represents a daily intake of contaminant per kilogram of body weight that is not sufficient to cause the threshold effect of concern for the contaminant. The RfD is usually based on data from exposure of animals; therefore, an uncertainty factor is incorporated into the RfD to reduce the numerical value. The uncertainty factor is intended to account for uncertainties such as the extrapolation from animals to humans. Separate RfDs are presented for ingestion and inhalation pathways. Reference doses for noncarcinogenic effects of the contaminants of concern are presented in Table D.4-1. The primary source of values for reference doses are the HEAST and Integrated Risk Information System (IRIS) compiled by EPA (EPA 1992b, 1992e). Table D.4-1 includes the uncertainty factors incorporated into RfDs.

D.4.1.2 Chemical Carcinogens

The cancer slope factor is the toxicity value used to quantitatively express the carcinogenic hazard of cancer-causing contaminants. The slope factor is expressed in units of $(mg/kg/day)^{-1}$ and represents the cancer risk per unit daily intake of carcinogenic chemical contaminants. Slope factors for chemical contaminants are presented in Table D.4-2. The primary sources of these toxicity values are the HEAST and IRIS (EPA 1992b, 1992e).

D.4.1.3 Radiocarcinogens

Slope factors for radionuclide contaminants are presented in Table D.4-3. The radionuclide slope factor is expressed in units of $(pCi)^{-1}$ and represents the risk of cancer incidence per unit radioactivity intake of a radionuclide contaminant. The EPA HEAST is the source of slope factors for radionuclides (EPA 1992b).

TABLE D.4-1

REFERENCE DOSES FOR NONCARCINOGENIC EFFECTS OF CONSTITUENTS OF CONCERN IN OPERABLE UNIT 4

Chemical	Oral Reference Dose (mg/kg/day)	Inhalation Reference Dose (mg/kg/day)	Effect of Concern		Uncertainty Factor		
			Oral	Inhalation	Oral	Inhalation	Reference
Inorganics							
Antimony	0.0004	ND[a]	Reduced lifespan, blood glucose, and cholesterol	ND	1000	ND	b
Arsenic	0.0003	ND	Keratosis and hyperpigmentation	ND	3	ND	b
Barium	0.07	0.00014	Increased blood pressure	Fetotoxcity	3	1000	bc
Beryllium	0.005	ND	None observed	ND	100	ND	b
Boron	0.09	0.0057	Testicular atsophy	Respiratory tract irritation, bronchitis	100	100	bc
Cadmium (food)	0.001	ND	Significant proteinuria	Cancer	10	ND	b
Cadmium (water)	0.0005	ND	Significant proteinuria	Cancer	10	ND	b
Chromium (VI)	0.005	ND	None reported	ND	500	ND	b
Cobalt	0.06	0.0000003	Cardiomyopathy	Lesions in respiratory epithelium	ND	1000	de
Copper	ND	ND	ND	ND	ND	ND	f
Cyanide	0.02	ND	Weight loss, thyroid effects and myelin degeneration	ND	100	ND	b
Lead	ND	ND	CNS effects	CNS effects	ND	ND	bg
Manganese	0.14 (food) 0.005 (water)	0.00011	CNS effects CNS effects	Respiratory symptoms; psychomotor disturbances	1 1	300	b b
Mercury	0.0003	0.000086	Kidney effects	Neurotoxicity	1000	30	bc
Molybdenum	0.005	ND	Changes in urine and blood chemistry	ND	30	ND	c
Nickel	0.02	ND	Reduced body weight and organ weight	Cancer - refinery dust	300	ND	b
Selenium	0.005	ND	Clinical selenosis	ND	3	ND	b
Silver	0.005	ND	Argyria	ND	3	ND	b

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TABLE D.4-1
(Continued)

Chemical	Oral Reference Dose (mg/kg/day)	Inhalation Reference Dose (mg/kg/day)	Effect of Concern		Uncertainty Factor		
			Oral	Inhalation	Oral	Inhalation	Reference
Inorganics							
Thallium	0.00006	ND	Increased SGOT and serum LDH levels	ND	3000	ND	h
Uranium	0.003	ND	Nephrotoxicity	ND	1000	ND	h
Vanadium	0.007	ND	None observed	ND	100	ND	c
Zinc	0.2	ND	Anemia	ND	10	ND	b
Volatiles							
2-Butanone	0.05	0.3	None observed	Decreased birth weight	1000	1000	bc
2-Butanone, 3-Methyl-	ND	ND	ND	ND	ND	ND	a
2-Hexanone	ND	ND	ND	ND	ND	ND	c
4-Methyl-2-pentanone	0.05	ND	Liver, kidney effects	ND	1000	ND	c
Acetone	0.1	ND	Increased liver; kidney weight, nephrotoxicity	ND	1000	ND	b
Carbon tetrachloride	0.0007	ND	Liver lesion	ND	1000	ND	b
Chloroform	0.01	ND	Cyst formation in liver	ND	1000	ND	b
Methylene chloride	0.06	0.86	Liver toxicity	Liver toxicity	100	100	bc
Tetrachloroethene	0.01	ND	Hepatotoxicity, weight gain	ND	1000	ND	b
Toluene	0.2	0.11	Changes in liver and kidney weights	CNS effects	1000	300	b
Total xylenes	2	ND	Hyperactivity, increased BW; increased mortality	ND	100	ND	b
Semivolatiles							
Acenaphthylene	ND	ND	ND	ND	ND	ND	b
Aldrin	0.00003	ND	Liver toxicity	ND	1000	ND	b
Anthracene	0.3	ND	No observed effects	ND	3000	ND	b
Benzo(a)anthracene	ND	ND	ND	ND	ND	ND	b

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TABLE D.4-1
(Continued)

Chemical	Oral Reference Dose (mg/kg/day)	Inhalation Reference Dose (mg/kg/day)	Effect of Concern		Uncertainty Factor		
			Oral	Inhalation	Oral	Inhalation	Reference
Semivolatiles							
Benzo(a)pyrene	ND	ND	ND	ND	ND	ND	bc
Benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND	b
Benzoic acid	4	ND	No adverse effects observed	ND	1	ND	b
bis(2-Ethylhexyl)phthalate	0.02	ND	Increased relative liver weight	ND	1000	ND	b
Butanoic acid, methyl ester	ND	ND	ND	ND	ND	ND	a
Chrysene	ND	ND	ND	ND	ND	ND	b
Di-n-butylphthalate	0.1	ND	Increased mortality	ND	1000	ND	b
Di-n-octylphthalate	0.02	ND	Increased liver and kidney weights	ND	1000	ND	c
Dibenzo(a,h)anthracene	ND	ND	ND	ND	ND	ND	b
Diethyl phthalate	0.8	ND	Decreased growth rate, altered organ weights	ND	1000	ND	b
Dimethyl phthalate	1	ND	Kidney effects	ND	100	ND	c
Fluoranthene	0.04	ND	Nephropathy, increased liver weight, hematological changes	ND	3000	ND	b
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	ND	b
N-Nitroso-di-n-propylamine	ND	ND	ND	ND	ND	ND	b
Phenanthrene	ND	ND	ND	ND	ND	ND	b
Phenol	0.6	ND	Reduced fetal body weight	ND	100	ND	b
Pyrene	0.03	ND	Renal effects	ND	3000	ND	b
Styrene	0.2	ND	Red blood cell and liver effects	ND	1000	ND	b
Tributyl phosphate	ND	ND	ND	ND	ND	ND	a

TABLE D.4-1
(Continued)

Chemical	Oral Reference Dose (mg/kg/day)	Inhalation Reference Dose (mg/kg/day)	Effect of Concern		Uncertainty Factor		
			Oral	Inhalation	Oral	Inhalation	Reference
Pesticides/PCBs							
Aroclor-1242	ND	ND	ND	ND	ND	ND	b
Aroclor-1248	ND	ND	ND	ND	ND	ND	b
Aroclor-1254	ND	ND	ND	ND	ND	ND	b
Aroclor-1260	ND	ND	ND	ND	ND	ND	b
DDE	ND	ND	ND	ND	ND	ND	b
DDT	0.0005	ND	Liver lesions	ND	100	ND	b
Dieldrin	0.00005	ND	Liver lesions	ND	100	ND	b
Endosulfan II	0.00005	ND	Kidney toxicity	ND	3000	ND	b
Endosulfan I	0.00005	ND	Kidney toxicity	ND	3000	ND	b
Endrin	0.0003	ND	Convulsions, liver lesions	ND	100	ND	b
Heptachlor epoxide	0.000015	ND	Increased liver to body weight ratio	ND	1000	ND	b

[a]ND - no data
[b]IRIS, 1992 (EPA 1992e)
[c]EPA, Health Effects Assessment Summary Tables, Annual FY 92 (EPA 1992b)
[d]EPA 1992f, Memorandum from D. L. Forman, U.S. EPA Region VII, Philadelphia, Pennsylvania, "Subject: Cobalt Toxicity," dated March 12, 1992.
[e]EPA 1990c, Memorandum from Pei-Fung Hurst, ECAO, Cincinnati, Ohio, to R. Riccio, U.S. EPA Region III, Philadelphia, Pennsylvania, "Subject: Toxicity of Cobalt (Halby Chemical/Wilmington, Delaware)," dated October 9, 1990.
[f]See D.4.2.10
[g]See D.4.2.11
[h]Derived by analogy to thallium sulfate

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TABLE D.4-2

CANCER SLOPE FACTORS FOR CARCINOGENIC EFFECTS OF CONSTITUENTS OF CONCERN IN OPERABLE UNIT 4

Chemical	Oral Cancer Slope Factor $(mg/kg/day)^{-1}$	Inhalation Cancer Slope Factor $(mg/kg/day)^{-1}$	Tumor Site		Cancer Classification[a]	Reference
			Oral	Inhalation		
Inorganics						
Antimony	ND[b]	ND	ND	ND	D	c
Arsenic	1.75	15	skin	respiratory tract	A	d
Barium	ND	ND	ND	ND	D	c
Beryllium	4.3	8.4	gross tumors	lung	B2	d
Boron	ND	ND	ND	ND	ND	de
Cadmium (food)	ND	6.3	ND	respiratory tract	B1	d
Cadmium (water)	ND	6.3	ND	respiratory tract	B1	d
Chromium	ND	42	ND	lung	A	d
Cobalt	ND	ND	ND	ND	ND	de
Copper	ND	ND	ND	ND	D	d
Cyanide	ND	ND	ND	ND	D	d
Lead	ND	ND	kidney	ND	B2	d
Manganese	ND	ND	ND	ND	D	d
Mercury	ND	ND	ND	ND	D	de
Molybdenum	ND	ND	ND	ND	D	c
Nickel	ND	0.84	ND	respiratory tract	A	d
Selenium	ND	ND	ND	ND	D	d
Silver	ND	ND	ND	ND	D	d
Thallium	ND	ND	ND	ND	ND	e
Uranium	ND	ND	ND	ND	ND	f
Vanadium	ND	ND	ND	ND	ND	de
Zinc	ND	ND	ND	ND	D	d

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TABLE D.4-2
(Continued)

Chemical	Oral Cancer Slope Factor (mg/kg/day)$^{-1}$	Inhalation Cancer Slope Factor (mg/kg/day)$^{-1}$	Tumor Site		Cancer Classification[a]	Reference
			Oral	Inhalation		
Volatiles						
2-Butanone	ND	ND	ND	ND	D	de
2-Butanone, 3-Methyl-	ND	ND	ND	ND	ND	b
2-Hexanone	ND	ND	ND	ND	ND	e
4-Methyl-2-pentanone	ND	ND	ND	ND	ND	e
Acetone	ND	ND	ND	ND	ND	d
Carbon tetrachloride	0.13	0.053	liver	ND	B2	d
Chloroform	0.0061	0.081	kidney	liver	B2	d
Methylene chloride	0.0075	0.0016	liver	lung, liver	B2	e
Tetrachloroethene	0.052	0.002	lung	lung	B2-C	g
Toluene	ND	ND	ND	ND	D	d
Total xylenes	ND	ND	ND	ND	D	d
Semivolatiles						
Acenaphthylene	ND	ND	ND	ND	D	d
Aldrin	17	ND	liver	ND	B2	d
Anthracene	ND	ND	ND	ND	D	d
Benzo(a)anthracene	7.3	6.1	ND	ND	B2	h
Benzo(a)pyrene	7.3	6.1	stomach	respiratory tract	B2	eih
Benzo(b)fluoranthene	7.3	6.1	ND	ND	B2	h
Benzo(g,h,i)perylene	ND	ND	ND	ND	D	a
Benzoic acid	ND	ND	ND	ND	D	a
bis(2-Ethylhexyl)phthalate	0.014	ND	liver	ND	B2	d
Butanoic acid, methyl ester	ND	ND	ND	ND	ND	b
Chrysene	7.3	6.1	lymphoma, skin	ND	B2	h

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TABLE D.4-2
(Continued)

Chemical	Oral Cancer Slope Factor $(mg/kg/day)^{-1}$	Inhalation Cancer Slope Factor $(mg/kg/day)^{-1}$	Tumor Site		Cancer Classification[a]	Reference
			Oral	Inhalation		
Semivolatiles						
Di-n-butylphthalate	ND	ND	ND	ND	D	d
Di-n-octylphthalate	ND	ND	ND	ND	ND	e
Dibenzo(a,h)anthracene	7.3	6.1	ND	ND	B2	h
Diethyl phthalate	ND	ND	ND	ND	D	a
Dimethyl phthalate	ND	ND	ND	ND	D	de
Fluoranthene	ND	ND	ND	ND	D	d
Indeno(1,2,3-cd)pyrene	7.3	6.1	ND	ND	B2	h
N-Nitroso-di-n-propylamine	7	ND	multiple	ND	B2	d
Phenanthrene	ND	ND	ND	ND	D	d
Phenol	ND	ND	ND	ND	D	d
Pyrene	ND	ND	ND	ND	D	d
Styrene	ND	ND	ND	ND	ND	g
Tributyl phosphate	ND	ND	ND	ND	ND	b
Pesticides/PCBs						
Aroclor-1242	7.7	ND	liver	ND	B2	j
Aroclor-1248	7.7	ND	liver	ND	B2	j
Aroclor-1254	7.7	ND	liver	ND	B2	j
Aroclor-1260	7.7	ND	liver	ND	B2	j
DDE	0.34	ND	liver	ND	B2	d
DDT	0.34	0.34	liver	liver	B2	d
Dieldrin	16	16	liver	ND	B2	d
Endosulfan II	ND	ND	ND	ND	ND	d
Endosulfan I	ND	ND	ND	ND	ND	d

TABLE D.4-2
(Continued)

Chemical	Oral Cancer Slope Factor $(mg/kg/day)^{-1}$	Inhalation Cancer Slope Factor $(mg/kg/day)^{-1}$	Tumor Site		Cancer Classification[a]	Reference
			Oral	Inhalation		
Pesticides/PCBs						
Endrin	ND	ND	ND	ND	D	d
Heptachlor epoxide	9.1	9.1	liver	ND	B2	d

[a]Cancer weight-of-evidence Group A = human carcinogen; Group B1 and B2 = probable human carcinogen; Group C = possible human carcinogen; Group D - not classifiable as to carcinogenicity to humans; Group E = evidence of noncarcinogenicity to humans
[b]ND = no data
[c]EPA 1992g, "Drinking Water Regulations and Health Advisories"
[d]IRIS, 1992 (EPA 1992e)
[e]EPA, Health Effects Assessment Summary Tables, Annual FY 92 (EPA 1992b)
[f]IRIS, 1991 (EPA 1991c)
[g]EPA 1992h, RATS (Risk Assessment Teleconference for Superfund) Meeting Notes, May 13, 1992
[h]The oral and inhalation cancer slope factors for benzo(a)pyrene are used for the other polyaromatic hydrocarbons assigned to cancer classification B2 (see the toxicological profile for polyaromatic hydrocarbons [Section D.4.2.17] for additional information).
[i]EPA 1992i, Special Notice, Subject: Corrected Toxicity Value for Benzo(a)Pyrene, July 10, 1992
[j]The oral cancer slope factor for polychlorinated biphenyls available on IRIS is applied to all aroclors.

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TABLE D.4-3

CANCER SLOPE FACTORS FOR OPERABLE UNIT 4 RADIONUCLIDES OF CONCERN

Radionuclide	ICRP Lung Class[a]	Inhalation $(pCi)^{-1}$	GI Absorption Factor (f_1)	Ingestion $(pCi)^{-1}$	Penetrating External Exposure $(pCi \cdot yr/g)^{-1}$
Ac-227 + 7 dtrs	Y	8.8×10^{-8}	1.0×10^{-3}	3.5×10^{-10}	8.5×10^{-7}
Pa-231	Y	3.6×10^{-8}	1.0×10^{-3}	9.2×10^{-11}	2.6×10^{-8}
Pb-210 + 2 dtrs	D	4.0×10^{-9}	2.0×10^{-1}	6.6×10^{-10}	1.6×10^{-10}
Ra-226 + 5 dtrs	W	3.0×10^{-9}	2.0×10^{-1}	1.2×10^{-10}	6.0×10^{-6}
Ra-228 + 1 dtr	W	6.9×10^{-10}	2.0×10^{-1}	1.0×10^{-10}	2.9×10^{-6}
Rn-222 + 4 dtrs	Gas	7.7×10^{-12}	1.0×10^{0}	1.7×10^{-12}	5.9×10^{-6}
Sr-90 + 1 dtr	D	6.2×10^{-11}	3.0×10^{-1}	3.6×10^{-11}	0.0×10^{0}
Tc-99	W	8.3×10^{-12}	8.0×10^{-1}	1.3×10^{-12}	6.0×10^{-13}
Th-228 + 7 dtrs	Y	7.8×10^{-8}	2.0×10^{-4}	5.5×10^{-11}	5.6×10^{-6}
Th-230	Y	2.9×10^{-8}	2.0×10^{-4}	1.3×10^{-11}	5.4×10^{-11}
Th-232	Y	2.8×10^{-8}	2.0×10^{-4}	1.2×10^{-11}	2.6×10^{-11}
U-234	Y	2.6×10^{-8}	5.0×10^{-2}	1.6×10^{-11}	3.0×10^{-11}
U-235 + 1 dtr	Y	2.5×10^{-8}	5.0×10^{-2}	1.6×10^{-11}	2.4×10^{-7}
U-238 + 2 dtrs	Y	5.2×10^{-8}	5.0×10^{-2}	2.8×10^{-11}	3.6×10^{-8}

[a]Classification recommended by the ICRP for half-time for clearance from the lung. "Y" = years, "W" = weeks, "D" = days.

As noted by EPA (1989b), fundamental differences exist between radionuclides and chemicals with respect to toxicity assessments. The principal adverse biological effects associated with radiation exposures from radioactive materials in the environment are carcinogenicity, mutagenicity, and teratogenicity (EPA 1989b). Of these, carcinogenicity is the limiting effect at low levels of radiation dose (environmental levels). The incidence-to-fatality ratio for radiogenic cancers is approximately two-to-one, when averaged over all cancer types (EPA 1989b). Data presented in EPA's HEAST (EPA 1992b) present the relationship between cancer incidence and exposure to radioactive materials.

D.4.1.4 Dermal Reference Doses and Cancer Slope Factors

Dermal RfD values and cancer slope factors are derived from the corresponding oral values. In the derivation of a dermal RfD, the oral RfD is multiplied by the gastrointestinal (GI) efficiency factor, expressed as a fraction. The resulting dermal RfD is an RfD based on absorbed dose. The RfD based on absorbed dose is the appropriate value with which to compare a dermal dose, because dermal doses are expressed as absorbed rather than exposure doses. In a similar manner, and for the same reasons, a dermal cancer slope factor is derived by dividing the oral cancer slope factor by the GI absorption efficiency. The oral slope factor is divided, rather than multiplied, by the GI absorption efficiency because cancer slope factors are expressed as reciprocal dose. Dermal RfD values and cancer slope factors for the chemicals of concern in Fernald Operable Unit 4 are presented in Table D.4-4.

The most important consideration regarding the uncertainty associated with a dermal RfD or cancer slope factor is the accuracy of the GI absorption efficiency factor. For this reason, the toxicity profiles presented in Section D.4.2 contain pharmacokinetics sections in which the oral absorption data are evaluated. Where appropriate, the low (most conservative) end of the range of available GI absorption data for humans is used in the derivation of the dermal RfD or cancer slope factor. When the human data are insufficient, animal data are used. Data from high-dose experiments are not used if more suitable data are available and it appears that saturation of the GI absorption process could have occurred.

When sufficient quantitative data were not located, a default GI absorption factor was used. As noted by EPA (1989a), the GI absorption of many metals from the GI tract is limited, and 0.05 is a reasonable default for metals and inorganic substances.

EPA (1989) did not recommend a separate default value for organic chemicals. A compilation of data for 19 organic chemicals presented GI absorption efficiencies ranging from 0.5 to 1.0. All but 3 of the 19 chemicals had GI absorption efficiencies of at least 0.9, indicating that organic chemicals are generally readily absorbed. The arithmetic average of the GI efficiencies for the 19 organic chemicals, 0.91368, equivalent to 0.9 when rounded to one significant figure, appears to be a reasonable default GI absorption efficiency factor for organic chemicals. The default of 0.9 for GI absorption is used for

TABLE D.4-4

DERMAL REFERENCE DOSES AND CANCER SLOPE FACTORS FOR CHEMICAL CONSTITUENTS OF CONCERN IN OPERABLE UNIT 4

Chemical	Gastrointestinal Absorption Fraction	Dermal Reference Dose (mg/kg/day)	Dermal Slope Factor (per mg/kg/day)
Inorganics			
Antimony	0.15[a]	6.00×10^{-5}	ND[b]
Arsenic	0.5[a]	1.50×10^{-4}	3.50×10^{0}
Barium	0.05[c]	3.50×10^{-3}	ND
Beryllium	0.05[c]	2.50×10^{-4}	8.60×10^{1}
Boron	0.05[c]	4.50×10^{-3}	ND
Cadmium (food)	0.05[a]	5.00×10^{-5}	ND
Chromium	0.05[c]	2.50×10^{-4}	ND
Cobalt	0.05[a]	3.00×10^{-3}	ND
Copper	0.15[a]	ND	ND
Cyanide	0.72[d]	1.44×10^{-2}	ND
Manganese (food)	0.03[a]	4.20×10^{-3}	ND
Mercury	0.02[a]	6.00×10^{-6}	ND
Molybdenum	0.38[a]	1.90×10^{-3}	ND
Nickel	0.05[c]	1.00×10^{-3}	ND
Selenium	0.8[a]	4.00×10^{-3}	ND
Silver	0.05[c]	2.50×10^{-4}	ND
Thallium	1[a]	6.00×10^{-5}	ND
Uranium	0.05[c]	1.50×10^{-4}	ND[e]
Vanadium	0.05[c]	3.50×10^{-4}	ND
Zinc	0.2[a]	4.00×10^{-2}	ND
Volatiles			
2-Butanone	0.9[f]	4.50×10^{-2}	ND
2-Hexanone	0.9[f]	ND	ND
3-Methyl-2-butanone	0.9[f]	ND	ND
4-Methyl-2-pentanone	0.9[f]	4.50×10^{-2}	ND

TABLE D.4-4
(Continued)

Chemical	Gastrointestinal Absorption Fraction	Dermal Reference Dose (mg/kg/day)	Dermal Slope Factor (per mg/kg/day)
Acetone	0.9[f]	9.00×10^{-2}	ND
Carbon tetrachloride	0.9[f]	6.30×10^{-4}	1.44×10^{-1}
Chloroform	1[g]	1.00×10^{-2}	6.10×10^{-3}
Methylene chloride	1[a]	6.00×10^{-2}	7.50×10^{-3}
Tetrachloroethene	0.9[f]	9.00×10^{-3}	5.78×10^{-2}
Toluene	1[g]	2.00×10^{-1}	ND
Total xylenes	1[g]	2.00×10^{0}	ND
Semivolatiles			
Acenaphthylene	0.43[a]	ND	ND
Aldrin	0.9[f]	2.70×10^{-5}	1.89×10^{1}
Anthracene	0.43[a]	1.29×10^{-1}	ND
Benzo(a)anthracene	0.43[a]	ND	1.70×10^{1}
Benzo(a)pyrene	0.43[a]	ND	1.70×10^{1}
Benzo(b)fluoranthene	0.43[a]	ND	1.70×10^{1}
Benzo(g,h,i)perylene	0.43[a]	ND	ND
Benzoic acid	0.9[f]	3.60×10^{0}	ND
bis(2-Ethylhexyl)phthalate	0.9[f]	1.80×10^{-2}	1.56×10^{-2}
Butanoic acid, methyl ester	0.9[f]	ND	ND
Chrysene	0.43[a]	ND	1.70×10^{1}
Di-n-butylphthalate	0.85[g]	8.50×10^{-2}	ND
Di-n-octylphthalate	0.9[f]	1.80×10^{-2}	ND
Dibenzo(a,h)anthracene	0.43[a]	ND	1.70×10^{1}
Diethyl phthalate	0.9[f]	7.20×10^{-1}	ND
Dimethyl phthalate	0.9[f]	9.00×10^{-1}	ND
Fluoranthene	0.43[a]	1.72×10^{-2}	ND
Indeno(1,2,3-cd)pyrene	0.43[a]	ND	1.70×10^{1}
N-Nitroso-di-n-propylamine	0.9[f]	ND	7.78×10^{0}
Phenanthrene	0.9[f]	ND	ND
Phenol	0.9[f]	5.40×10^{-1}	ND

TABLE D.4-4
(Continued)

Chemical	Gastrointestinal Absorption Fraction	Dermal Reference Dose (mg/kg/day)	Dermal Slope Factor (per mg/kg/day)
Pyrene	0.43[f]	1.29×10^{-2}	ND
Styrene	0.9[f]	1.80×10^{-1}	ND
Tributyl phosphate	0.9[f]	ND	ND
Pesticides/PCBs			
Aroclor-1242	0.75[a]	ND	1.03×10^{1}
Aroclor-1248	0.75[a]	ND	1.03×10^{1}
Aroclor-1254	0.75[a]	ND	1.03×10^{1}
Aroclor-1260	0.75[a]	ND	1.03×10^{1}
DDE	0.9[g]	ND	3.78×10^{-1}
DDT	0.9[g]	4.50×10^{-4}	3.78×10^{-1}
Dieldrin	0.9[g]	4.50×10^{-5}	1.78×10^{1}
Endosulfan I	0.9[g]	4.50×10^{-5}	ND
Endosulfan II	0.9[g]	4.50×10^{-5}	ND
Endrin	0.9[g]	2.70×10^{-4}	ND
Heptachlor epoxide	0.9[g]	1.35×10^{-5}	1.01×10^{1}

[a]See the Toxicity Profile for this chemical in Section D.4.2
[b]ND - not derived
[c]U.S. EPA, 1989b, "Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), "EPA/540/1-89/002, pp. A-2 to A-3
[d]ATSDR (Agency for Toxic Substances and Disease Registry), 1988a, "Toxicological Profile for Cyanide," Draft for Public Comment. U.S. Public Health Service, Atlanta, Georgia
[e]The carcinogenicity of uranium is due to its radioactivity rather than chemical toxicity; its cancer potency due to penetrating external radiation is presented in Table D.4-3
[f]Section D.4.1.4
[g]Jones, T. D. and B. A. Owen, 1989, "Health Risks from Mixtures of Radionuclides and Chemicals in Drinking Water," Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-6533

organic chemicals for which quantitative data were not sufficient. The GI efficiency factors used to derive the dermal RfD values and cancer slope factors are presented in Table D.4-4.

D.4.2 TOXICITY PROFILES

This subsection presents more detailed toxicity information for individual contaminants of potential concern. Detailed evaluations are presented for those contaminants that are most prevalent in Operable Unit 4 sources or that yielded an ILCR greater than or equal to 1×10^{-6}, or a Hazard Index (HI) greater than or equal to 1.0. Chemicals for which there is an issue requiring explanation (e.g., use of the EPA uptake-biokinetic model, rather than an oral or inhalation RfD, to evaluate the toxicity of lead) are also included. Data evaluated for each contaminant include pharmacokinetics, noncancer toxicity, and carcinogenicity. The pharmacokinetics evaluations focus principally on GI and dermal absorption efficiencies because of the need to consider route- and medium-specific absorption efficiencies in estimating dermal RfD values and cancer slope factors from oral data. The chemicals are profiled in alphabetical order.

D.4.2.1 Actinium-227

D.4.2.1.1 Pharmacokinetics

Data from animal studies suggest that the extent of GI absorption of actinium is very low (no quantification provided) (Burkart 1988a); however, the extent of GI absorption may be greater in humans exposed to low levels in the environment (Burkart 1988b). EPA (1992b) presented a GI absorption factor of 0.001, but documentation was not provided. Accidental human exposure studies show that inhaled oxides and hydroxides of actinium are cleared very slowly from the lungs (Burkart 1988a). Actinium was assigned to International Commission on Radiological Protection (ICRP) class "Y," meaning that clearance from the lungs is expected to take years (EPA 1992b). Absorbed actinium is concentrated principally in the liver and skeleton, and to a lesser degree in the kidneys.

D.4.2.1.2 Noncancer Toxicity

Data regarding the noncancer effects of actinium were not located.

D.4.2.1.3 Carcinogenicity

The EPA classifies all radionuclides as weight-of-evidence Group A substances (human carcinogens) based on their characteristic of emitting ionizing radiation and on the extensive epidemiologic data associating exposure with radiogenic cancers in humans (EPA 1992b). The carcinogenicity of actinium-227 is due to its emission of low-energy beta particles (Burkart 1988a). EPA (1992b) presents cancer potency slope factors for actinium-227 and its seven radioactive decay products (alpha, beta, and gamma emitters) of 3.5×10^{-10} per pCi for ingestion, 8.8×10^{-8} per pCi for inhalation, and 8.5×10^{-7} per pCi yr/g for external exposure.

D.4.2.2 Antimony

D.4.2.2.1 Pharmacokinetics

Antimony exists in the tri- and tetravalent states (Budavari 1989). The pharmacokinetics of antimony appears to be strongly valence- and species-dependent. Elinder and Friberg (1986a) estimated GI absorption to be at least 15 percent in mice given a single oral dose of labeled trivalent antimony potassium tartrate. This estimate was based on the recovery of labeled antimony in urine and tissues. Actual absorption may have been considerably higher, because GI excretion starts immediately after absorption following an oral dose. The 15 percent absorption efficiency is considered sufficiently conservative and well documented for use in estimating a dermal RfD from the oral RfD.

Although quantitative data were not provided, Elinder and Friberg (1986a) stated that the pulmonary absorption of inhaled trivalent antimony is substantial.

Patterns of tissue distribution of absorbed antimony appear to be largely species-dependent. In humans injected with labeled sodium antimony dimercaptosuccinate, highest amounts of antimony are located in the liver, thyroid, and heart (Elinder and Friberg 1986a). Smelter workers exposed to inhaled antimony compounds retain antimony in their lungs for several years. Single or repeated injections of trivalent or pentavalent antimony in monkeys, dogs, and mice result in highest levels in the kidney, liver, and thyroid. Rats appear to retain higher levels in the blood than do other laboratory animals. In rats, trivalent antimony is retained principally in the erythrocytes (at least 95 percent), but pentavalent antimony is retained principally in the plasma (about 90 percent).

In humans, pentavalent antimony appears to be cleared from the body more efficiently than trivalent antimony (Elinder and Friberg 1986a). Urinary excretion predominates over fecal excretion for both penta- and trivalent antimony, but particularly for pentavalent antimony. In rats and hamsters, urinary excretion predominates for pentavalent antimony and fecal excretion predominates for trivalent antimony.

D.4.2.2.2. Noncancer Toxicity

Chronic oral exposure studies in laboratory animals include two briefly reported lifetime drinking water studies with potassium antimony tartrate fed to rats and mice, which reported reduced longevity in both species and reduced mean heart weight and altered blood chemistry in the rats (EPA 1992e). A verified chronic oral RfD of 0.0004 mg/kg/day was based on the rat study and an uncertainty factor of 1000.

Chronic effects from occupational exposure include irritation of the respiratory tract, pneumoconiosis, pustular eruptions of the skin called "antimony spots," allergic contact dermatitis, and cardiac effects, including abnormalities of the electrocardiograph (ECG) and myocardial changes (Elinder and Friberg

1986a). Cardiac effects were also observed in rats and rabbits exposed by inhalation for six weeks and in animals (dogs, and possibly other species) treated by intravenous injection. Inhalation reference concentration (RfC) or RfD values were not located. The heart, respiratory tract, and skin are the principal target organs for antimony.

D.4.2.2.3 Carcinogenicity

Data were not located regarding the carcinogenicity of antimony to humans. Antimony fed to rats did not produce an excess of tumors (Goyer 1991), but a high frequency of lung tumors was observed in rats exposed by inhalation to antimony trioxide for one year (Elinder and Friberg 1986a). The EPA (1992g) classifies antimony a cancer weight-of-evidence Group D substance. Quantitative cancer risks are not estimated for Group D substances.

D.4.2.3 Aroclors (Polychlorinated Biphenyls [PCBs])

D.4.2.3.1 Pharmacokinetics

PCBs were detected in the serum and breast milk of women who consumed PCB-contaminated fish from Lack Michigan, and in the blood of volunteers who ingested PCB mixtures. These detections provide qualitative evidence of GI absorption in humans (Agency for Toxic Substances and Disease Registry [ATSDR] 1991). In volunteers who ingested PCBs in fish, blood levels peaked in approximately 5 hours after the meal and returned to baseline levels 17 hours later, suggesting that absorption is rapid. Quantitative GI absorption studies with rats, monkeys, and ferrets dosed with individual PCB congeners revealed retention of 75 to 95 percent of the administered dose, with some evidence that absorption efficiency may be inversely related to the extent of chlorination. The 75 percent GI absorption efficiency is considered sufficiently conservative and well documented for use in estimating a dermal RfD and cancer slope factor from the respective oral values.

Quantitative inhalation absorption data were not located for humans or animals. ATSDR (1991) reviewed the occupational exposure data presented by Wolff (1985) and concluded that inhalation uptake contributed up to 80 percent of the concentration measured in the adipose tissue of exposed workers. Dermal uptake accounted for the remainder. Dermal application studies with PCBs containing 42 and 54 percent chlorine in animals revealed uptakes of 15 to 34 percent of the applied dose in monkeys and 56 percent in guinea pigs (ATSDR 1991). The dosing vehicle appeared to influence absorption; uptake in monkeys was 29 percent from mineral oil and 15 percent from trichlorobenzene.

In humans, PCBs distribute preferentially to adipose tissue (ATSDR 1991). In occupationally exposed workers, the adipose/plasma partition ratio ranged from 185/1 to 210/1. Inhalation and oral exposure data in animals revealed that distribution is biphasic, first to liver and muscle followed by redistribution to adipose tissue. PCB residues were detected in human breast milk and in umbilical

cord blood, indicating transfer to the fetus and offspring. Studies in several species suggested that transfer to the offspring is greater through nursing than through placental transfer (ATSDR 1991).

PCB residues in human fat consisted largely of the more highly chlorinated congeners that were unsubstituted in the meta-para vicinal positions, probably because these congeners are relatively more resistant to metabolism (ATSDR 1991). In vitro studies with human microsomes and animal studies indicated that metabolism involves hydroxylation, preferentially at the para position in the least chlorinated phenyl ring. Some PCB congeners were transformed to dihydrodiols, probably through a pathway involving formation of an arene oxide intermediate. The hydroxy derivatives may be conjugated with glucuronide or sulfate for excretion. Considerable interspecies variation was noted in the rate of metabolism of specific PCB congeners.

Animal studies indicate that both fecal and urinary excretion are important in the elimination of PCBs and their metabolites (ATSDR 1991). Lactation represented a major excretory pathway in nursing women, resulting in higher concentrations of PCB residues in infant's blood than in maternal blood. In humans who had consumed PCB-contaminated rice, elimination half-lives from blood for individual PCB congeners ranged from 4 to 24 months, with longer half-lives estimated for those congeners that were more resistant to metabolism.

D.4.2.3.2 Noncancer Toxicity

A review of a large number of epidemiological studies by ATSDR (1991) revealed that occupational exposure to PCBs, which involved both inhalation and dermal exposure, was associated with upper respiratory tract and ocular irritation, loss of appetite, liver enlargement, increased serum concentrations of liver enzymes, skin irritation, rashes and chloracne, and, in heavily exposed female workers, decreased birth weight of their infants. Concurrent exposure to PCB contaminants, such as polychlorinated dibenzofurans (PCDFs), confounded the interpretation of the occupational exposure studies. Rats, mice, rabbits, and guinea pigs intermittently exposed to 1.5 mg Aroclor-1254 vapors/m^3 exhibited moderate liver degeneration, decreased body weight gain, and slight renal tubular degeneration (Treon et al. 1956). The accuracy of the reported exposure concentration is in doubt (ATSDR 1991). Neither verified nor provisional chronic inhalation RfC or RfD values are available for the PCBs.

The most well known incident involving oral exposure of humans is the "Yusho" incident in Japan, in which persistent chloracne, GI irritation, and central nervous symptoms followed ingestion of cooking oil contaminated with PCBs (Gaffey 1983). Further investigation, however, revealed that concentrations of PCDFs and polychlorinated quaterphenyls in the cooking oil were similar to those of PCBs, which confounds the interpretation of the data. Epidemiologic studies of women in the United States associated PCB exposure with low birth weight or retarded musculoskeletal or neurobehavioral development of their infants (ATSDR 1991).

A plethora of oral studies in animals established the liver as the target organ in all species and the thyroid as an additional target organ in the rat (ATSDR 1991). Effects observed in monkeys included gastritis, anemia, chloracne-like dermatitis, and immunosuppression. Oral treatment of animals induced developmental effects, including retarded neurobehavioral and learning development in monkeys. Neither verified nor provisional chronic oral RfD values were located for any of the aroclors.

4.2.3.3 Carcinogenicity

EPA (1992e) lists PCBs as an EPA cancer weight-of-evidence Group B2 material (probable human carcinogen), based on inadequate data in humans and sufficient data in animals. The human data consist of several epidemiologic occupational and accidental oral exposure studies (EPA 1988c) with serious limitations, including poorly quantified concentrations of PCBs and durations of exposure, and probable exposures to other potential carcinogens (ATSDR 1991; Hayes 1987; EPA 1992e).

The animal data consist of several oral studies in rats and mice with various aroclors, kanechlors, or clophens (commercial PCB mixtures manufactured in the United States, Japan, and Germany, respectively). These studies reported increased incidence of liver tumors in both species (ATSDR 1991; EPA 1988c). In addition, Aroclor-1254 may have induced gastric adenocarcinomas in rats (National Cancer Institute [NCI] 1978). The more highly chlorinated mixtures (Aroclor-1260, Kanechlor 500, Clophen A-60) appear to be more potent carcinogens than the less highly chlorinated mixtures (Aroclor-1254, Kanechlor 400, Kanechlor 300, and Clophen A-30) (ATSDR 1991).

The mutagenicity and clastogenicity data for various PCB mixtures are abundant, and include in vitro tests in Salmonella, Chinese hamster V79 cells, rat hepatocytes and human lymphocytes, and in vivo tests in Drosophila, rats, mice, chicken embryos, and ring doves (ATSDR 1991). The majority of the studies yielded negative results. Exceptions include positive tests for chromosomal damage in rat hepatocytes, human lymphocytes, and ring dove embryos.

The EPA (1992e) derived an oral slope factor of 7.7 per mg/kg/day for PCBs based on the combined incidence of hepatocellular carcinomas and neoplastic nodules in a dietary study with Aroclor-1260 in rats (Norbach and Weltman 1985). Although the hepatocellular carcinomas were morphologically classifiable as malignant, they were observed to be particularly unaggressive, nonmetastasizing, and not life-shortening (ATSDR 1989a). This quantitative estimate would apply to all PCB mixtures, and, presumably, all individual PCB congeners, even though it is known that different PCB mixtures vary considerably in their carcinogenic potency (EPA 1992e).

Considerable uncertainty surrounds the application of the oral slope factor, derived for Aroclor-1260, to the other aroclors. First, the dosing protocol for the rat study used as the basis of the quantitative derivation (100 parts per million [ppm] in the diet for 16 months followed by 50 ppm in the diet for 8

months) is more suitable for qualitative rather than quantitative estimation of carcinogenic potential. In addition, it is clear that the less highly chlorinated mixtures are measurably less potent carcinogens than the more highly chlorinated mixtures in rats and mice (ATSDR 1991; EPA 1988c, 1992e).

D.4.2.4 Arsenic

D.4.2.4.1 Pharmacokinetics

Arsenic occurs in compounds in the trivalent and pentavalent forms (Budavari 1989). The extent of the GI absorption of arsenic depends on the particular arsenic compound ingested. Several studies with humans and laboratory animals indicate that the GI absorption of dissolved trivalent or pentavalent arsenic exceeds 90 percent (Ishinishi et al. 1986). Hamsters appear to have somewhat lower (50 to 75 percent) GI absorption of soluble arsenic compounds (ATSDR 1989b). Organic arsenic compounds, such as occur in seafoods, are also readily absorbed (70 to 99.7 percent). The GI absorption of less soluble compounds (e.g., arsanilic acid, arsenic trioxide) is determined by particle size and pH of the gastric juice. The 50 percent GI absorption efficiency is considered to be sufficiently conservative and well documented for use in estimating a dermal RfD and cancer slope factor from the respective oral values.

The extent of absorption of arsenic from the lungs depends on the solubility of the inhaled compound and particle size (ATSDR 1989b; Ishinishi et al. 1986). In a study with arsenite in cigarettes and with arsenic aerosols in lung cancer patients, deposition was estimated at approximately 40 percent, and 75 to 85 percent of the deposited arsenic was absorbed from the lungs within 4 days.

The occurrence of systemic toxic effects following dermal exposure to arsenic acid or arsenic trichloride (Ishinishi et al. 1986) indicates qualitatively that dermal absorption of some arsenic compounds occurs, but quantitative data were not located.

In most animals, all but a small fraction of systemic arsenic is rapidly cleared from the blood and other tissues (ATSDR 1989b). Residual arsenic is located in tissues (liver, kidney, spleen, heart, skin, hair, epithelium of the upper GI tract) containing a high concentration of sulfhydryl groups, to which arsenic preferentially binds (Arnold 1988; Ishinishi et al. 1986). In rats, more than in the other laboratory animals and in humans, arsenic binds to the erythrocytes with high affinity and clearance from the blood is slow (ATSDR 1989b).

Arsenic is extensively metabolized, principally in the liver, in humans and animals (ATSDR 1989b). Metabolism involves methylation of trivalent arsenic (arsenite) to dimethylarsinic acid, or, to a lesser extent, to monomethylarsonic acid. Both methylation products, as well as inorganic arsenic, are excreted principally and rapidly through the urine.

D.4.2.4.2 Noncancer Toxicity

A lethal dose of arsenic trioxide in humans is 70 to 180 mg (approximately 50 to 140 mg arsenic (Ishinishi et al. 1986). Acute oral exposure of humans to high doses of arsenic produces liver swelling, skin lesions, disturbed heart function, and neurological effects. The only noncancer effects in humans clearly attributable to chronic oral exposure to arsenic are dermal hyperpigmentation and keratosis, as revealed by studies of several hundred Chinese exposed to naturally occurring arsenic in well water (EPA 1992e). Similar effects were observed in persons exposed to high levels of arsenic in water in Utah and the northern part of Mexico. Occupational (predominantly inhalation) exposure is also associated with neurological deficits, anemia, and cardiovascular effects (Ishinishi et al. 1986), but concomitant exposure to other chemicals cannot be ruled out. EPA (1992e) derived a verified RfD of 0.3 μg/kg/day for chronic oral exposure, based on a no observed adverse effect level (NOAEL) of 0.8 μg/kg/day for skin lesions from the Chinese data and an uncertainty factor of 3. The principal target organ for arsenic appears to be the skin. The nervous system and cardiovascular systems appear to be significant target organs for acute exposure to higher levels. Inorganic arsenic may be an essential nutrient, exerting beneficial effects on growth, health, and feed conversion efficiency (Underwood 1977).

D.4.2.4.3 Carcinogenicity

Inorganic arsenic is clearly a carcinogen in humans. Inhalation exposure is associated with increased risk of lung cancer in persons employed as smelter workers, in arsenical pesticide applicators, and in a population residing near a pesticide manufacturing plant (EPA 1992e). Oral exposure to high levels in well water is associated with increased risk of skin cancer (Tseng 1977; EPA 1992e). Extensive animal testing with various forms of arsenic given by many routes of exposure to several species, however, has not demonstrated the carcinogenicity of arsenic (International Agency for Research on Cancer [IARC] 1980). EPA (1992e) classifies inorganic arsenic in cancer weight-of-evidence Group A (human carcinogen) and recommends an oral unit risk of 5×10^{-5} μg/L in drinking water, based on the incidence of skin cancer in the Tseng (1977) study. EPA (1992e) notes that the uncertainties associated with the oral unit risk are considerably less than those for most carcinogens, so that the unit risk might be reduced by an order of magnitude. Assuming humans weigh 70 kg and consume 2 liters of drinking water per day, the unit risk in drinking water is equivalent to 1.75 per mg/kg/day. An inhalation unit risk of 0.0043 $\mu g/m^3$ was derived for inorganic arsenic from the incidence of lung cancer in occupationally exposed men (EPA 1992e). Assuming an inhalation rate of 20 m^3/day and a body weight of 70 kg, the inhalation unit risk is equivalent to 15 per mg/kg/day.

D.4.2.5 Barium

D.4.2.5.1 Pharmacokinetics

Barium is an alkaline earth metal that occurs in compounds as a divalent cation (Reeves 1986a). Soluble barium salts are absorbed by the GI tract. In experiments with barium chloride, absorption

from the GI tract of hamsters was 11 to 32 percent of the dose. Barium sulfate, which is practically insoluble in water, is virtually unabsorbed, which contributes to its usefulness as a contrast agent in radiography of the GI tract. Lacking more definitive data, the default value of 5 percent for GI absorption (EPA 1989a) is used to estimate a dermal RfD from an oral RfD. Soluble forms of barium are readily (60 to 80 percent) absorbed from the respiratory tract. Clearance of barium compounds from the lungs was proportional to their solubilities. Data were not located regarding the dermal absorption of barium.

Following absorption, barium, like other alkaline earth metals, is deposited in the skeleton (Reeves 1986a). The affinity of the skeleton for barium is 1.5 to 5 times the affinity for calcium or strontium. Highest concentrations in soft tissues occur in the submaxillary gland, the pigmented structures of the eye, and in melanoma cells. In humans, the principal route of excretion is through the feces.

D.4.2.5.2 Noncancer Toxicity

The acute oral toxicity of barium is manifested by GI upset, altered cardiac performance, and transient hypertension, convulsions, and muscular paralysis (American Conference of Governmental Industrial Hygienists [ACGIH] 1991). Repeated oral exposures are associated with hypertension. Occupational exposure to insoluble barium sulfate induces benign pneumoconiosis. EPA (1992e) presented a verified chronic oral RfD of 0.07 mg/kg/day, based on an NOAEL of 0.21 mg/kg/day in a ten-week study in humans exposed to barium in drinking water and an uncertainty factor of 3. A provisional chronic inhalation RfC of 0.0005 mg/m^3 was based on a no observed effect level (NOEL) for fetotoxicity in a four-month intermittent-exposure inhalation study in rats (EPA 1992b). An uncertainty factor of 1000 was used for the chronic RfC. The chronic inhalation RfC is equivalent to 1.4×10^{-4} mg/kg/day, assuming a human inhalation rate of 20 m^3/day and body weight of 70 kg. Barium is principally a muscle toxin and targets the GI system, skeletal muscle, the cardiovascular system, and the fetus.

D.4.2.5.3 Carcinogenicity

The EPA (1992g) classifies barium as a cancer weight-of-evidence Group D substance (not classifiable as to carcinogenicity in humans). Cancer risks are not estimated for Group D substances.

D.4.2.6 Beryllium

D.4.2.6.1 Pharmacokinetics

Absorption of beryllium from the GI tract is low, probably not exceeding 20 percent of an ingested dose, because the metal forms insoluble precipitates with phosphate and is eliminated in the feces (Reeves 1986b). In the absence of more precise quantification, the default of 5 percent for GI absorption (EPA 1989a) is used for estimation of a dermal RfD and cancer slope factor from the respective oral values.

Clearance of inhaled beryllium is multiphasic; small quantities of beryllium compounds may remain incapsulated in the lung parenchyma for several years (Reeves 1986b). Water-soluble forms of beryllium at pH 3 are absorbed through the skin of animals (Zorn et al. 1988), but the extent of absorption is probably minimal, because most beryllium salts are insoluble at physiologic pH, and ionized beryllium is readily bound to epidermal contaminants (Reeves 1986b).

Most beryllium in the circulation probably exists as a colloidal phosphate adsorbed to serum protein; minor amounts exist as the citrate or hydroxide (Reeves 1986b). Distribution of small doses is primarily to the skeleton; for larger doses, distribution is primarily to the liver. Secondary distribution results in movement of beryllium from the liver to the skeleton. The primary route of excretion is through the urine.

D.4.2.6.2 Noncancer Toxicity

Beryllium has a low order of toxicity when ingested because it is poorly absorbed from the GI tract (Reeves 1986b). Occupational exposure was associated with dermatitis, acute pneumonitis, and chronic pulmonary granulomatosis (berylliosis). Berylliosis was also observed in humans living in the vicinity of a beryllium plant. Similar pulmonary effects were observed in laboratory animals subjected to inhalation exposure. A verified chronic oral RfD value of 0.005 mg/kg/day was based on an NOAEL in a lifetime drinking water study in rats and an uncertainty factor of 100 (EPA 1992e). The target organ for inhalation exposure appears to be the lung; a target organ is not identified for oral exposure.

D.4.2.6.3 Carcinogenicity

EPA (1992e) classifies beryllium in cancer weight-of-evidence Group B2 (probable human carcinogen) based on inadequate human (occupational) cancer data and sufficient animal data. A significant increase in lung tumors occurred in rats and in rhesus monkeys subjected to inhalation exposure or intratracheal instillation of a variety of beryllium compounds. Osteogenic sarcomas were induced in rabbits and mice, but not in rats or guinea pigs, injected intravenously with various beryllium compounds. Oral studies in animals yielded inconclusive results. EPA (1992e) derived an oral slope factor of 4.3 per mg/kg/day from a statistically nonsignificant increase in total tumors in a lifetime drinking water study in rats. An inhalation unit risk of 0.0024 per $\mu g/m^3$, equivalent to 8.4 per mg/kg/day (assuming an inhalation rate of 20 m^3/day and body weight of 70 kg for humans), was derived from an occupational study.

D.4.2.7 Cadmium

D.4.2.7.1 Pharmacokinetics

GI absorption of ingested cadmium is ordinarily 5 to 8 percent, but may reach 20 percent in cases of serious dietary iron deficiency (Friberg et al. 1986; Goyer 1991). The 5 percent estimate for GI

absorption is considered sufficiently conservative and well-documented to serve as the basis for extrapolation of a dermal RfD from an oral RfD.

Estimates of cadmium uptake by the respiratory tract range from 10 to 50 percent; uptake is greatest for fumes and small particles and least for large dust particles (Friberg et al. 1986; Goyer 1991). Highest tissue levels are normally found in the kidneys followed by the liver, although levels in the liver may exceed those in the kidneys of persons suffering from cadmium-induced renal dysfunction. The half-life of cadmium in the kidneys and liver may be as long as 10 to 30 years. Fecal and urinary excretion of cadmium are approximately equivalent in normal humans exposed to small amounts. Urinary excretion increases markedly in humans with cadmium-induced renal disease.

D.4.2.7.2 Noncancer Toxicity

Acute inhalation exposure to fumes or particles of cadmium induces respiratory symptoms, general weakness, and, in severe cases, respiratory insufficiency, shock, and death (Friberg et al. 1986). Acute oral exposure induces GI disturbances. Chronic inhalation exposure induces pulmonary emphysema, and chronic inhalation or oral exposure consistently produce renal tubular disease in humans and laboratory animals. Proteinuria is a reliable early indicator of cadmium-induced kidney disease. The combination of pulmonary emphysema and renal tubular disease, if severe, may result in early mortality. Painful osteomalacia and osteoporosis may arise from altered metabolism of bone minerals secondary to renal damage. The combination of renal and skeletal damage is called itai-itai disease in Japan. Cadmium exposure has been associated with liver damage, but the liver appears to be less sensitive than the kidney. EPA (1992e) derived chronic oral RfD values of 0.0005 mg/kg/day for cadmium ingested in water and 0.001 mg/kg/day for cadmium ingested in food, based on a toxicokinetic model that predicted NOAELs from renal cortical concentrations of cadmium in humans. An uncertainty factor of 10 was used. The kidney is the primary target organ of cadmium toxicity.

D.4.2.7.3 Carcinogenicity

Carcinogenicity data in humans consist of several occupational studies that associate cadmium exposure with lung cancer, but concomitant exposure to other carcinogenic chemicals and smoking were not adequately controlled (EPA 1992e). Other occupational studies reported significantly increased risk of prostatic cancer, but this effect was not observed in the largest occupational study of workers exposed to high levels (Thun et al. 1985). The animal data consist of an inhalation study in rats that showed a significant increase in lung tumors, and several parenteral injection studies that produced injection site tumors. No evidence of carcinogenicity, however, was observed in seven oral studies in rats and mice. The EPA (1992e) classifies cadmium as a cancer weight-of-evidence Group B1 substance for inhalation exposure on the basis of limited evidence of carcinogenicity in humans and sufficient evidence in animals. The data were insufficient to classify cadmium as carcinogenic to humans exposed by the oral route. EPA (1992e) derived an inhalation unit risk of 0.0018 per $\mu g/m^3$

from the occupational exposure study by Thun et al. (1985). The unit risk is equivalent to 6.3 per mg/kg/day, assuming an inhalation rate of 20 m^3/day, and a body weight of 70 kg for humans.

D.4.2.8 Chromium

D.4.2.8.1 Pharmacokinetics

Chromium exists principally in three oxidation states: +2, +3, and +6 (Langård and Norseth 1986). Chromium is poorly absorbed from the GI tract. Absorption efficiencies less than 1 percent were reported for trivalent chromium, and absorption efficiencies of 3 to 6 percent in rats and approximately 2 percent in humans were reported for chromates (hexavalent chromium). These absorption efficiencies may be underestimations, because they were based on urinary excretion, which disregards excretion by other routes (e.g., intestinal and biliary secretion), and retention in the body tissues. In the absence of more precisely quantified estimates of GI absorption efficiency, the default value of 5 percent (EPA 1989a) will be used to estimate a dermal RfD from an oral RfD.

The observation of high levels of chromium in the lungs of exposed humans indicates that at least part of the inhaled chromium is deposited as insoluble compounds that are cleared slowly from the lungs (Langård and Norseth 1986). Water soluble hexavalent chromium compounds and some trivalent chromium compounds are cleared more rapidly. In animals treated by intratracheal instillation, 53 to 85 percent of hexavalent and 5 to 30 percent of trivalent compounds were cleared from the lungs (duration of evaluation not specified) (ATSDR 1989c).

Direct evidence from human volunteers and indirect evidence from occupational exposure indicate that dermal uptake of chromium occurs (ATSDR 1989c). The extent of dermal uptake appears to depend more on the specific compound rather than the valence of chromium. Quantitative absorption data were not located.

D.4.2.8.2 Noncancer Toxicity

In nature, chromium (III) predominates over chromium (VI) (Langård and Norseth 1986). Little chromium (VI) exists in biological materials, except shortly after exposure, because reduction to chromium (III) occurs rapidly. Chromium (III) is considered a nutritionally essential trace element and is considerably less toxic than chromium (IV). No effects were observed in rats consuming 1800 mg chromium (III)/kg/day in the diet for over two years (EPA 1992e). The NOEL of 1800 mg/kg/day and an uncertainty factor of 1000 was the basis for a verified chronic oral RfD for chromium (III) of 1 mg/kg/day (EPA 1992e).

Acute oral exposure of humans to high doses of chromium (VI) induces neurological effects, GI hemorrhage and fluid loss, and kidney and liver effects. Parenteral dosing of animals with chromium (VI) is selectively toxic to the kidney tubules. An NOAEL of 2.4 mg chromium (VI)/kg/day in a one-

year drinking water study in rats and an uncertainty factor of 500 was the basis of a verified RfD for chromium (VI) of 0.005 mg/kg/day for chronic oral exposure (EPA 1992e).

Occupational (inhalation and dermal) exposure to chromium (III) compounds induces dermatitis (ACGIH 1991). Similar exposure to chromium (VI) induces ulcerative and allergic contact dermatitis, irritation of the upper respiratory tract, including ulceration of the mucosa and perforation of the nasal septum, and possibly kidney effects. Inhalation RfC values were not located.

A target organ was not identified for chromium (III). The kidney appears to be the principal target organ for repeated oral dosing with chromium (VI). Additional target organs for dermal and inhalation exposure include the skin and respiratory tract.

D.4.2.8.3 Carcinogenicity

Data were not located regarding the carcinogenicity of chromium (III). EPA (1992e) classifies chromium (VI) in cancer weight-of-evidence Group A (human carcinogen), based on the consistent observation of increased risk of lung cancer in occupational studies of workers in chromate production or the chrome pigment industry. Parenteral dosing of animals with chromium (VI) compounds consistently induced injection-site tumors. There is no evidence that oral exposure to chromium (VI) induces cancer. An inhalation unit risk of 0.012 per $\mu g/m^3$, equivalent to 42 per mg/kg/day, assuming humans inhale 20 m^3 of air per day and weigh 70 kg, was based on increased risk of lung cancer deaths in chromate production workers.

D.4.2.9 Cobalt

D.4.2.9.1 Pharmacokinetics

There is considerable individual variation in the extent of GI absorption of cobalt in humans. Estimates of GI absorption range from 5 to 45 percent, based on recovery of cobalt in the feces in volunteers given radiolabeled cobalt chloride (Elinder and Friberg 1986b). The 5 percent estimate is considered sufficiently conservative and well documented for use in estimating a dermal RfD from an oral RfD.

Quantitative data regarding respiratory tract absorption of cobalt were not located. Occupational exposure data, however, indicate that substantial respiratory tract uptake occurs (Elinder and Friberg 1986b). Blood and urinary levels of cobalt were markedly increased, compared to pre-exposure levels or to unexposed controls, in workers exposed for a short time to 0.09 mg cobalt per m^3 in workroom air. Data regarding dermal absorption were not located.

In both humans and animals, cobalt distributes preferentially to the liver and kidneys (Elinder and Friberg 1986b). In pregnant mice treated with radioactive cobalt, substantial levels of radioactivity

located in the liver, kidney, fetuses, and placenta. After parenteral administration or occupational exposure to cobalt, excretion is principally through the urine, although fecal (possibly biliary) excretion is also significant.

D.4.2.9.2 Noncancer Toxicity

Acute high oral or parenteral doses of cobalt in humans or animals induce myocardial degeneration often leading to mortality, erythropoiesis, enlarged thyroid, and, in animals, renal tubular degeneration (Elinder and Friberg 1986b). Chronic ingestion from the consumption of beer containing high concentrations of cobalt is associated with "beer-drinkers cardiomyopathy," which includes polycythemia and goiter, as well as marked myocardial degeneration and mortality. The therapeutic use of 0.16 to 0.32 mg cobalt/kg-day in anemic, anephric dialysis patients for 12 to 32 weeks induces a significant, but reversible, rise in blood hemoglobin concentration (EPA 1992f).

Occupational (inhalation and dermal) exposure is associated with allergic dermatitis, chronic interstitial pneumonitis, reversibly impaired lung function, occupational asthma, and myocardial effects (ACGIH 1991). Cobalt was determined to be the etiologic factor in hard metal disease, a syndrome of respiratory symptoms, and pneumoconiosis associated with inhalation exposure to dusts containing tungsten carbide with cobalt powder as a binder (Elinder and Friberg 1986b). The lowest occupational air concentration of cobalt associated with hard metal disease was 0.003 mg cobalt per m^3 (Sprince et al. 1988). It should be noted that the workers were also exposed to tungsten and sometimes to titanium, tantalum and niobium (Elinder and Friberg 1986b). Similar lung effects were seen in animals exposed to cobalt by inhalation.

The developmental toxicity of cobalt was tested in rodents treated orally with cobalt chloride (EPA 1992f). Maternal effects (unspecified) were reported in rats treated with 5.4 to 21.8 mg cobalt per kg/day from gestation day 14 through lactation day 21. Effects on the offspring included stunted growth at 5.4 mg cobalt per kg/day and reduced survival at 21.8 mg cobalt per kg/day. In rats treated with 6.2, 12.4 or 24.8 mg cobalt per kg/day on gestation days 6 to 15, maternal effects included reduced food consumption and body weight gain, and altered hematologic parameters, although it is unclear at what dose level(s) these effects occurred. There were no effects on fetal survival, but a nonsignificant increase in fetal stunting was observed in rats treated with ≥12.4 mg cobalt per kg/day. Mice treated with 81.7 mg cobalt per kg/day had reduced maternal weight gain, but no fetal effects.

Several studies reported testicular degeneration and atrophy in rats treated with cobalt chloride in the diet or drinking water at concentrations equivalent to doses of 5.7 to 30.2 mg cobalt per kg/day (EPA 1992f).

Cobalt is nutritionally essential as a cofactor in cyanocobalamin (vitamin B12) (EPA 1992f) and is universally present in the diet. Average daily adult dietary intakes of cobalt range from 0.16 to 0.58

mg/day (0.002 to 0.008 mg/kg/day, assuming adults weigh 70 kg) (Tipton et al. 1966; Schroeder et al. 1967). In 9- to 12-year-old children, dietary intakes of cobalt range from 0.3 to 1.77 mg/day (Murthy et al. 1971; National Research Council 1989). Assuming an average weight for children in this age range of 28 kg (National Research Council 1989), the dietary intakes are equivalent to 0.01 to 0.06 mg/kg/day.

EPA (1992f) concluded that the oral toxicity data were insufficient for derivation of an oral RfD for cobalt. The relatively well characterized dietary intake data, however, can provide useful guidance. EPA (1992f) noted that the upper range of dietary intake for children, 0.06 mg/kg/day, was below the level associated with enhanced erythropoiesis in anephric patients. Therefore, the upper range of dietary intake, 0.06 mg cobalt per kg/day, can be considered a guidance level for the oral intake of cobalt and can be used in place of an oral RfD in CERCLA and Resource Conservation and Recovery Act (RCRA) risk assessments.

EPA (1990) derived an interim inhalation RfC from the lowest observed adverse effect level (LOAEL) of 0.003 mg cobalt per m^3 associated with hard metal disease in occupationally exposed humans (Sprince et al. 1988). Correcting for intermittent occupational exposure (10 m^3 of air inhaled per workday ÷ 20 m^3 of air inhaled per day x 5 workdays per week, ÷ 7 days per week) yielded an adjusted LOAEL of 0.001 mg/m^3. Application of an uncertainty factor of 1000 resulted in an interim chronic inhalation RfC of 1×10^{-6} mg/m^3. Assuming humans inhale 20 m^3 of air/day and weigh 70 kg, the RfC is equivalent to 2.9×10^{-7} mg/kg/day, which may be rounded to 3×10^{-7} mg/kg/day.

Important target organs in orally exposed humans are the heart, erythrocyte, and thyroid. Target organs for occupational exposure are the skin, lungs, and heart.

D.4.2.9.3 Carcinogenicity

Data regarding the carcinogenicity of cobalt were not located.

D.4.2.10 Copper

D.4.2.10.1 Pharmacokinetics

Estimates of the absorption of copper from the GI tract range from 15 to 97 percent, with an average of approximately 60 percent (ATSDR 1989d). Several factors, including the dose of copper, the presence of other metals in the diet, the form of copper administered, and the presence of substances that inhibit uptake (vitamin C, phytate, fiber), influence the extent of GI absorption. The 15 percent estimate is considered sufficiently conservative and well documented to use in estimation of a dermal RfD from an oral RfD.

Quantitative data were not located regarding the uptake of copper from the respiratory tract. The observation of elevated plasma copper levels in some workers in a heavily polluted industrial atmosphere indicates that respiratory tract uptake occurs (Aaseth and Norseth 1986). Data were not located regarding the dermal uptake of copper.

Circulating copper is taken up by the liver, transferred to the high molecular weight protein, ceruloplasmin, reenters the circulation, and accumulates in liver, heart, brain, kidney, and muscles (Aaseth and Norseth 1986). Excretion is principally through the bile.

D.4.2.10.2 Noncancer Toxicity

Copper is a nutritionally essential element that functions as a cofactor in several enzyme systems (Aaseth and Norseth 1986). Acute exposure to large oral doses of copper salts is associated with GI disturbances, hemolysis, and liver and kidney lesions. Chronic oral toxicity in humans has not been reported. Chronic oral exposure of animals is associated with an iron-deficiency type of anemia, hemolysis, and lesions in the liver and kidneys. Occupational exposure induces metal fume fever, and, in cases of chronic exposure to high levels, hemolysis, and anemia (ACGIH 1991). Neither oral nor inhalation RfD or RfC values were located for copper. The target organs for copper are the erythrocyte, liver, and kidney, and, for inhalation exposure, the lung.

EPA (1991d) concluded that the health effects data were inadequate for derivation of a chronic oral RfD for copper. The current drinking water maximum contaminant level goal (MCLG) for copper is 1.3 mg/L, which is based on an LOAEL for GI effects in acutely exposed humans, and an uncertainty factor of 2. The MCLG is equivalent to a daily intake from water of 2.6 mg/day, assuming a drinking water ingestion rate of 2 L/day. The MCLG of 1.3 mg/L is an inappropriate basis for a toxicity value for use in CERCLA risk assessment for several reasons:

- It is based on effects resulting from acute exposure, and it is not reasonable to assume that a toxicity value designed to protect against effects from short-term exposure would sufficiently protect against effects from chronic exposure

- The estimated safe and adequate daily dietary intake of copper for adults is 1.5 to 3.0 mg/day (National Research Council 1989), which exceeds the equivalent daily intake from drinking water estimated from the MCLG

- The estimated adult daily intake of copper from food is 2.0 to 4.0 mg/day (EPA 1985), which also exceeds the equivalent daily intake from drinking water estimated from the MCLG.

D.4.2.10.3 Carcinogenicity

Copper is classified in cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans) (EPA 1992e). Quantitative risk estimates are not derived for Group D chemicals.

D.4.2.11 Lead

D.4.2.11.1 Pharmacokinetics

Studies in humans indicate that an average of 10 percent of ingested lead is absorbed, but estimates as high as 40 percent were obtained in some individuals (Tsuchiya 1986). Nutritional factors have a profound effect on GI absorption efficiency. Children absorb ingested lead more efficiently than adults; absorption efficiencies up to 53 percent were recorded for children three months to eight years of age. Similar results were obtained for laboratory animals; absorption efficiencies of 5 to 10 percent were obtained for adults and ≥50 percent were obtained for young animals. The deposition rate of inhaled lead averages approximately 30 to 50 percent, depending on particle size, with as much as 60 percent deposition of very small particles (0.03 μm) near highways. All lead deposited in the lungs is eventually absorbed.

Approximately 95 percent of the lead in the blood is located in the erythrocytes (EPA 1990d). Lead in the plasma exchanges with several body compartments, including the internal organs, bone, and several excretory pathways. In humans, lead concentrations in bone increase with age (Tsuchiya, 1986). About 90 percent of the body burden of lead is located in the skeleton. Neonatal blood concentrations are about 85 percent of maternal concentrations (EPA 1990d). Excretion of absorbed lead is principally through the urine, although GI secretion, biliary excretion, and loss through hair, nails, and sweat are also significant.

D.4.2.11.2 Noncancer Toxicity

The noncancer toxicity of lead to humans has been well characterized through decades of medical observation and scientific research (EPA 1992e). The principal effects of acute oral exposure are colic with diffuse paroxysmal abdominal pain (probably due to vagal irritation), anemia, and, in severe cases, acute encephalopathy, particularly in children (Tsuchiya 1986). The primary effects of long-term exposure are neurological and hematological. Limited occupational data indicate that long-term exposure to lead may induce kidney damage. The principal target organs of lead toxicity are the erythrocyte and the nervous system. Some of the effects on the blood, particularly changes in levels of certain blood enzymes, and subtle neurobehavioral changes in children, appear to occur at levels so low as to be considered nonthreshold effects.

EPA (1992b) presents no inhalation RfC for lead, but referred to the National Ambient Air Quality Standard (NAAQS) for lead, which could be used in lieu of an inhalation RfC. The NAAQSs are based solely on human health considerations and are designed to protect the most sensitive subgroup of the human population. The NAAQS for lead is 1.5 $\mu g/m^3$, averaged quarterly (EPA 1992b). The NAAQS is equivalent to 0.00043 mg/kg/day, assuming a body weight of 70 kg and an inhalation rate of 20 m^3/day. The inhalation toxicity value of 0.00043 mg/kg/day is not used in this risk assessment for Fernald Operable Unit 4, because, as will be discussed, the EPA UBK model is used to evaluate

the risk of exposure to lead. This approach is appropriate because the EPA UBK model evaluates exposure to all environmental media, including inhaled ambient air.

The EPA (1990d, 1992e) determined that it is inappropriate to derive an RfD for oral exposure to lead for several reasons. First, the use of an RfD assumes that a threshold for toxicity exists, below which adverse effects are not expected to occur; however, the most sensitive effects of lead exposure, impaired neurobehavioral development in children and altered blood enzyme levels associated with anemia, may occur at blood lead concentrations so low as to be considered practically nonthreshold in nature. Second, RfD values are specific for the route of exposure for which they are derived. Lead, however, is ubiquitous, so that exposure occurs from virtually all media and by all pathways simultaneously, making it practically impossible to quantify the contribution to blood lead from any one route of exposure. Finally, the dose-response relationships common to many toxicants, and upon which derivation of an RfD is based, do not hold true for lead. This is because the fate of lead within the body depends, in part, on the amount and rate of previous exposures, the age of the recipient, and the rate of exposure. There is, however, a reasonably good correlation between blood lead concentration and effect. Therefore, blood lead concentration is the appropriate parameter on which to base the regulation of lead. The EPA UBK mathematical model is used to estimate blood lead concentrations in children 0 to 7 years of age exposed to contaminated media at Fernald Operable Unit 4.

The EPA UBK lead model is an iterated set of equations that estimate blood lead concentration in children aged 0 to 7 years (EPA 1990d; 1991e). The biokinetic part of the model describes the movement of lead between the plasma and several body compartments and estimates the resultant blood lead concentration. The rate of the movement of lead between the plasma and each compartment is a function of the transition or residence time (i.e., the mean time for lead to leave the plasma and enter a given compartment, or the mean residence time for lead in that compartment). Compartments modeled include the erythrocytes, liver, kidneys, all the other soft tissue of the body, cortical bone, and trabecular bone. Excretory pathways and their rates are also modeled. These include the mean time for excretion from the plasma to the urine, from the liver to the bile, and from the other soft tissues to the hair, skin, sweat, etc. The model permits the user to adjust the transition and residence times.

The model starts by estimating the blood lead concentration of the infant at birth from the mother's blood lead concentration (infant model), or from data regarding the mother's exposure to contaminated media (fetal model). The initial amounts of lead in the various compartments are estimated from the blood lead level at birth and assumptions regarding relative lead concentrations in the tissues of neonates. The amounts of lead in the compartments at the end of each iteration are estimated from the amounts present at the beginning of the iteration period, uptake or excretion from the plasma, loss to the plasma, and, in the case of the liver and other soft tissues, loss to the bile and loss to hair, skin, sweat, etc., respectively. The amount in the plasma at the end of each iteration is estimated from the

amount in the plasma at the beginning of the iteration, the amount lost to and gained from each tissue compartment, the amount taken up from inhalation and ingestion, and the amount lost through the urine. Blood lead concentration is calculated from plasma lead concentration.

The uptake part of the model estimates uptake, or absorption, of lead from inhaled air, ingested diet, ingested water, ingested soil and dust, and ingested paint. Dermal uptake is considered to be insignificant and is not modeled.

For inhalation, the model parameters include lead concentration in outdoor and indoor air, portion of the day spent outdoors, and ventilation rates for each year of age. The model allows input of percent uptake from the respiratory tract for each year of age. The default uptake value is 32 percent, based on average particle size, solubility, and breathing pattern (oral versus nasal breathing), all of which affect regional deposition within the respiratory tract.

Lead uptake from each of the ingested media described below can be modeled as either a linear or nonlinear kinetic process. Generally, use of the nonlinear, or saturable, model is recommended as more closely approximating biological reality because it consists of a passive absorption (linear) and an active transport (nonlinear) component. The active transport component is adjusted for rate saturation on the basis of lead concentration in the gut from each ingested medium and the absorption half-concentration for lead from each ingested medium. Both the linear component and the unadjusted nonlinear component may be input to reflect site-specific bioavailability data, if available.

The linear uptake kinetic process consists of the passive absorption component of the kinetic process described in the previous paragraph. The passive absorption coefficient for uptake of lead from each medium may be input or allowed to default to 50 percent for lead in diet and drinking water and 30 percent for lead in soil, dust, and paint.

The model allows input of or provides default values for daily intake of lead from the diet. The model also permits the use of alternate (e.g., homegrown) diet components. For intake of lead from drinking water, the model allows entry of or provides default values for lead concentration in drinking water and daily drinking water consumption. In addition, the model permits entry of lead concentration and the percent of daily water consumption for alternate drinking water sources, to account for water consumed while the child is outside the home.

For lead intake in ingested soil/dust, the model allows input of or provides default values for lead concentration in soil and indoor dust, and the amount of dust ingested daily. The model also allows entry of the fraction of household dust that comes from soil, the contribution of lead in ambient air to lead in household dust, and the lead concentration in and percent of total ingested dust from six alternative sources.

The model allows input of or provides default values for lead intake from ingested paint chips or from chewing painted objects. Lead from paint present in household dust is considered with dust ingestion.

D.4.2.11.3 Carcinogenicity

EPA (1992e) classifies lead in cancer weight-of-evidence Group B2 (probable human carcinogen), based on inadequate evidence of cancer in humans and sufficient animal evidence. The human data consist of several epidemiologic occupational studies that yielded confusing results. All of the studies lacked quantitative exposure data and failed to control for smoking and concomitant exposure to other possibly carcinogenic metals. Rat and mouse bioassays showed statistically significant increases in renal tumors following dietary and subcutaneous exposure to several soluble lead salts. Various lead compounds were observed to induce chromosomal alterations in vivo and in vitro, sister chromatic exchange in exposed workers, and cell transformation in Syrian hamster embryo cells; to enhance simian adenovirus induction; and to alter molecular processes that regulate gene expression. EPA (1992e) declined to estimate risk for oral exposure to lead because many factors (e.g., age, general health, nutritional status, existing body burden and duration of exposure) influence the bioavailability of ingested lead, introducing a great deal of uncertainty into any estimate of risk.

A radioactive isotope of lead, lead-210 (Pb-210), is a radionuclide of concern at Fernald Operable Unit 4. The EPA classifies all radionuclides as weight-of-evidence Group A substances (human carcinogens) based on their characteristic of emitting ionizing radiation and on the extensive epidemiologic data associating exposure with radiogenic cancers in humans (EPA 1992b). EPA (1992b) presented cancer potency slope factors for Pb-210 and its radioactive decay products of 6.6 x 10^{-10} per pCi for ingestion, 4.0 x 10^{-9} per pCi for inhalation, and 1.6 x 10^{-10} per pCi yr/g for external exposure.

D.4.2.12 Manganese

D.4.2.12.1 Pharmacokinetics

Manganese is a nutritionally essential element (Saric 1986). Its absorption from the GI tract is homeostatically controlled. Absorption of manganese from the GI tract of healthy humans was measured at 3 percent of a single 200 µg oral dose. Human epidemiologic data suggest that manganese in drinking water is somewhat more bioavailable than manganese in the diet (EPA 1992e). In humans suffering from manganese toxicity or anemia, GI absorption was measured at 4 and 7.5 percent, respectively. The 3 percent GI absorption estimate is considered sufficiently conservative and well documented to use in estimating a dermal RfD from an oral RfD. Sufficient data were not located for estimating respiratory tract or dermal uptake of manganese.

Distribution of absorbed manganese is first to the liver, and then to other tissues (Saric 1986). Although no tissue accumulates large amounts, highest concentrations of manganese in humans are

located in the liver, kidney, endocrine glands, and the intestines. The principal route of excretion is through the feces, in part due to biliary and pancreatic secretion. Urinary excretion and loss through swear, hair, and lactation also occur.

D.4.2.12.2 Noncancer Toxicity

Humans exposed to approximately 0.8 mg manganese per kg/day in drinking water exhibited lethargy, mental disturbances (1/16 committed suicide), and other neurologic effects. The elderly appear to be more sensitive than children. Oral treatment of laboratory rodents induces biochemical changes in the brain, but rodents do not exhibit the neurological signs exhibited by humans. Occupational exposure to high concentrations in air induces a generally typical spectrum of neurological effects, and increased incidence of pneumonia (ACGIH 1986).

EPA (1992e) derived separate verified RfD values for chronic oral exposure to manganese in drinking water and in the diet, reflecting the presumption of greater bioavailability of manganese from drinking water. The chronic oral RfD for ingestion of manganese in drinking water is 0.005 mg/kg/day, based on an NOAEL of 0.005 mg/kg/day and an LOAEL of 0.06 mg/kg/day associated with neurological impairment in a human epidemiology study. The elderly appeared to more severely affected than children or younger adults. An uncertainty factor of 1 was used. A chronic oral RfD of 0.14 mg/kg/day was based on studies of dietary intake in humans. The intake of 0.14 mg/kg/day was considered an NOAEL; an uncertainty factor of 1 was used. EPA (1992e) presents a verified chronic inhalation RfC of 0.0004 mg/m^3 based on an LOAEL for respiratory symptoms and psychomotor disturbances in occupationally exposed humans and an uncertainty factor of 300. The inhalation RfC is equivalent to 0.00011 mg/kg/day, assuming humans inhale 20 m^3 of air/day and weigh 70 kg. The central nervous system (CNS) and respiratory tract are target organs of inhalation exposure to manganese.

D.4.2.12.3 Carcinogenicity

EPA (1992e) classifies manganese in cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans). Quantitative cancer risk estimates are not derived for Group D chemicals.

D.4.2.13 Mercury

Mercury occurs in three forms: elemental, organic, and inorganic. Although the toxicity of all forms is mediated by the mercury cation, the extent of absorption and pattern of distribution within the body, which determines the effects observed, depends on the form to which the organism is exposed (Goyer 1991).

D.4.2.13.1 Pharmacokinetics

Metallic mercury liquid is poorly absorbed from the GI tract, but metallic mercury vapor is readily absorbed by the lung because of the rapid diffusion of the vapor across the alveolar membrane (Berlin 1986). Although it was suggested that mercury vapor and inorganic mercury can be absorbed by the skin, empirical data were not located. GI absorption of inorganic mercury salts is about 2 to 10 percent in humans, and slightly higher in experimental animals (Berlin 1986; Goyer 1991). The 2 percent GI absorption estimate is considered sufficiently conservative and well documented to use for estimating a dermal RfD from an oral RfD.

Absorbed elemental mercury is oxidized to the inorganic divalent cation (Magos 1988). Inorganic mercury in the blood is roughly equally divided between the plasma and erythrocytes. Distribution is preferentially to the kidney, with somewhat lower concentrations found in the liver, and even lower levels found in the skin, spleen, testes, and brain (Berlin 1986). Inorganic mercury is excreted principally through the feces and urine, with minor pathways including the secretions of exocrine glands and exhalation of elemental mercury vapor.

Methyl mercury is nearly completely (90 to 95 percent) absorbed from the GI tract (Berlin 1986), and probably at least 80 percent absorbed from the respiratory tract (Magos 1988). Methyl mercury is probably absorbed through the skin, but quantitative data were not located (Magos 1988). The concentration of methyl mercury in the erythrocytes is about 10 times that in the plasma. Methyl mercury leaves the blood slowly, showing particular affinity for the brain, particularly in primates. In rats, 1 percent of the body burden of methyl mercury is found in the brain, but in humans, 10 percent of the body burden is found in the brain. Lower levels are found in the liver and kidney. During pregnancy, methyl mercury accumulates in the fetal brain, often at levels higher than in the maternal brain. Most tissues except the brain transform methyl mercury to inorganic mercury. Excretion of methyl mercury is principally through the bile, with a half-life of 70 days in healthy humans. Following exposure to methyl mercury, some of the mercury in the bile exists as methyl mercury and some as the inorganic form. The inorganic form is largely passed in the feces, but the methyl mercury is subject to enterohepatic recirculation. Another important excretory pathway for methyl mercury is lactation.

D.4.2.13.2 Noncancer Toxicity

Acute oral exposure to high doses of inorganic mercury causes severe damage to the GI mucosa, because of the corrosive nature of mercury salts, which may lead to bloody diarrhea, shock, circulatory collapse, and death (Berlin 1986; Goyer 1991). Acute sublethal poisoning induces severe kidney damage. Chronic exposure induces an autoimmune glomerular disease and renal tubular injury. EPA (1992b) presents a verified RfD of 0.3 μg/kg/day for chronic oral exposure to inorganic mercury, based on kidney effects in rats and an uncertainty factor of 30.

Acute or chronic exposure to methyl mercury leads to neurologic dysfunction (Berlin 1986; Goyer 1991). The region of the nervous system affected is species-dependent. In humans, the sensory cortex appears to be more sensitive. Methyl mercury poisoning in rats induces peripheral nerve damage and kidney effects. The brain of the fetus and the neonate may be unusually sensitive to methyl mercury; retarded neurologic development was observed in prenatally exposed children whose mothers showed no clinical signs of poisoning. EPA (1992e) derived a verified RfD of 0.3 µg/kg/day for chronic oral exposure to methyl mercury based on neurological effects in environmentally exposed humans. In this derivation, an intake of 3 µg/kg/day was an LOAEL corresponding to a blood level of 200 ng/mL, which was associated with CNS effects. An uncertainty factor of 10 was used to estimate an NOAEL from an LOAEL. EPA (1992b) presents a provisional inhalation RfC for elemental mercury of 0.0003 mg/m^3, based on an NOAEL for neurotoxicity in humans. An uncertainty factor of 30 was used. The inhalation RfC is equivalent to 8.6×10^{-5} mg/kg/day, assuming an inhalation rate of 20 m^3/day and a body weight of 70 kg for humans.

Target organs for elemental, inorganic or methyl mercury include the kidney, nervous system, fetus, and neonate.

D.4.2.13.3 Carcinogenicity

EPA (1992e) classifies inorganic mercury in cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans), based on no data regarding cancer in humans, and inadequate animal and supporting data. In an intraperitoneal injection study with metallic mercury in rats, sarcomas developed only in those tissues in direct contact with the test material. A two-year dietary study in rats with mercuric acetate (inorganic mercury) yielded no evidence of carcinogenicity (ATSDR 1989e). In mice, however, dietary exposure to high doses of mercury chloride for up to 78 weeks induced renal adenomas and adenocarcinomas (EPA 1992e). The EPA has not yet evaluated the carcinogenicity of organic mercury. No carcinogenic effect, however, was observed in a two-year feeding study with phenylmercuric acetate in rats (ATSDR 1989e).

D.4.2.14 Methylene Chloride

D.4.2.14.1 Pharmacokinetics

The recovery of radiolabeled parent compound and metabolites following a single oral dose of C-14-labeled methylene chloride in rats, indicated that GI absorption was essentially complete (ATSDR 1987a). A GI absorption efficiency of 100 percent is considered sufficiently well documented for purposes of calculating a dermal RfD and cancer slope factor from the respective oral values.

Estimates of absorption from the human respiratory tract range from 31 to 75 percent (ATSDR 1987a). Animal data indicate that dermal absorption occurs, but quantitative data were not located.

The pattern of tissue distribution appears to be strongly dependent on route of exposure. In humans exposed by inhalation, uptake was positively correlated with the degree of obesity, and substantial levels were found in fat (ATSDR 1987a). In animals exposed by inhalation, highest levels were located in the fat, brain, and liver. In animals treated orally with C-14-labeled methylene chloride, highest levels of radioactivity were located in the liver, kidney, and lungs (organs of metabolism and excretion), and lowest levels were located in the fat. These data, as well as other metabolism data, indicate that methylene chloride is rapidly, but saturably, metabolized to carbon monoxide and carbon dioxide. Excretion is accomplished almost exclusively by the exhalation of parent compound and metabolites.

D.4.2.14.2 Noncancer Toxicity

Occupational exposure to high concentrations of methylene chloride may induce liver damage (ACGIH 1986). Liver effects were induced in animals by inhalation or oral exposure (EPA 1992e). EPA (1992e) presents a verified chronic oral RfD for methylene chloride of 0.06 mg/kg/day based on an NOAEL for liver toxicity in male and female rats in chronic drinking water studies and an uncertainty factor of 100. EPA (1992b) presents a provisional chronic inhalation RfC of 3 mg/m^3, derived from an NOAEL for liver toxicity in a two-year intermittent exposure inhalation study in rats and an uncertainty factor of 100. The inhalation RfC is equivalent to 0.86 mg/kg/day, assuming humans inhale 20 m^3 of air/day and weigh 70 kg. The principal target organ for methylene chloride is the liver.

D.4.2.14.3 Carcinogenicity

Methylene chloride is classified in EPA cancer weight-of-evidence Group B2 (probable human carcinogen), based on inadequate human data and sufficient evidence of carcinogenicity in animals (EPA 1992e). Animal inhalation studies show increased incidence of hepatocellular neoplasms and alveolar/bronchiolar neoplasms in male and female mice, mammary tumors in rats of either sex, salivary gland sarcomas in male rats, and leukemia in female rats. Oral studies were inconclusive. An oral slope factor of 0.0075 per mg/kg/day was based on the incidence of liver tumors in two inhalation studies in mice. An inhalation unit risk of 4.7×10^{-7} per $\mu g/m^3$ was based on the incidence of liver and lung tumors in one inhalation study. The inhalation unit risk is equivalent to 0.0016 per mg/kg/day, based on inhaled dose, assuming humans inhale 20 m^3 of air/day and weigh 70 kg.

D.4.2.15 Molybdenum

Molybdenum is a nutritionally essential trace element (Friberg and Lener 1986). Its most important oxidation states are +2, +3, +4, and +6.

D.4.2.15.1 Pharmacokinetics

Molybdenum from soluble compounds is readily absorbed from the GI or respiratory tracts (Friberg and Lener 1986). Estimates of GI absorption in humans average around 50 percent, but a range of 38

to 72 percent was observed in young women, and 77 percent was reported for school children. The form or oxidation state of molybdenum used in these studies was not specified. Estimates of GI absorption in laboratory animals range from 40 to 85 percent for hexavalent molybdenum. The 38 percent estimate of GI absorption is considered sufficiently conservative and well documented for use in estimating a dermal RfD from an oral RfD.

Inhalation uptake studies with guinea pigs showed that molybdenum disulfide was essentially unabsorbed, but that hexavalent molybdenum was absorbed to an appreciable (unquantified) extent (Friberg and Lener 1986).

Absorbed molybdenum is distributed primarily to the kidney, liver, and bone in several laboratory species (Friberg and Lener 1986). Molybdenum appears to accumulate in the liver, cartilage of the long bones, and skin. In humans and most laboratory animals, the kidney is the principal organ of excretion. The excretion of molybdenum is affected by the level of copper and sulfate in the diet.

D.4.2.15.2 Noncancer Toxicity

Chronic molybdenum poisoning in livestock (heart disease) results from a molybdenum-copper imbalance and is characterized by anemia, GI disturbances, bone disorders, and growth depression (Friberg and Lener 1986). In laboratory animals, excess molybdenum induces effects in the liver, kidneys, and spleen. Gout-like symptoms were observed in humans living in a high molybdenum, low copper area. A few cases of pneumoconiosis were reported in occupationally exposed workers. EPA (1992b) presents a provisional chronic oral RfD of 0.005 mg/kg/day based on an LOAEL in humans exposed to high levels in water and diet and an uncertainty factor of 30. The effects of concern were increased urinary excretion of uric acid, decreased copper levels in the blood, and pain and swelling in the joints. Target organs for molybdenum toxicity include the erythrocyte, joints, liver, and kidney.

D.4.2.15.3 Carcinogenicity

Molybdenum was assigned to EPA cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans), but the documentation for this classification was not provided (EPA 1992g). Risk levels are not estimated for Group D substances.

D.4.2.16 Nickel

D.4.2.16.1 Pharmacokinetics

Estimates of GI absorption in humans range from 1 to 10 percent (ATSDR 1988b). Nickel in water appears to more bioavailable than nickel in food, but absorption was inhibited when the nickel was given in coffee, tea, whole milk, or orange juice. Lacking more precise quantitation, the default GI absorption efficiency of 5 percent (EPA 1989a) is used to derive a dermal RfD from an oral RfD.

Quantitative data were not located for the uptake of inhaled nickel in humans, but the data suggest that the more soluble compounds are more readily absorbed (ATSDR 1988b). Animal data indicate that soluble nickel compounds are cleared from the lungs more rapidly than insoluble compounds. Dermal uptake of nickel in humans ranged from 55 to 77 percent for nickel sulfate when the application site was occluded. In vitro studies indicate that occlusion increases the rate of dermal uptake, and that the nickel cation is absorbed more rapidly from nickel chloride than from nickel sulfate.

Animal studies indicate that systemic nickel is distributed in highest concentrations to the kidney (ATSDR 1988b). Autopsy data from occupationally exposed humans show that nickel accumulates only in the lungs. Excretion is principally through the urine, although excretion through the sweat and through incorporation into hair may be significant.

D.4.2.16.2 Noncancer Toxicity

In a subchronic gavage study with nickel chloride in water, clinical signs of toxicity in rats included lethargy, ataxia, irregular breathing, reduced body temperature, salivation, and discolored extremities (EPA 1992e). Inhalation exposure is associated with asthma and pulmonary fibrosis in welders using nickel alloys (ACGIH 1986). Lung effects were observed in laboratory animals exposed by inhalation. EPA (1992e) presents a verified RfD of 0.02 for chronic oral exposure to nickel, based on an NOAEL for decreased organ and body weights in a two-year dietary study with nickel sulfate in rats and an uncertainty factor of 300. The CNS appears to be the target organ for the oral toxicity of nickel. The lung is clearly the target organ for inhalation exposure.

D.4.2.16.3 Carcinogenicity

Occupational exposure to nickel was associated with increased risk of nasal, laryngeal, and lung cancer (ATSDR 1988b). Inhalation exposure of rats to nickel subsulfide increased the incidence of lung tumors. EPA (1992e) presents a cancer weight-of-evidence Group A classification (human carcinogen) for nickel, and presents an inhalation unit risk of 0.00024 per $\mu g/m^3$ for nickel refinery dust. The unit risk is equivalent to 0.84 per mg/kg/day, assuming humans inhale 20 m^3 of air/day and weigh 70 kg. The quantitative estimate was derived from the human occupational studies.

D.4.2.17 Polyaromatic Hydrocarbons (PAHs)

PAHs of concern at Fernald Operable Unit 4 include acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene.

D.4.2.17.1 Pharmacokinetics

Several rat studies indicate that there is considerable chemical-specific variation (ATSDR 1989f). GI absorption is enhanced by solubilizing the chemical in a readily absorbed vehicle such as oil. Jones and Owen (1989) reported a range of 43 to 58 percent for the GI absorption of benzo(a)pyrene. The

lower end of this range, 43 percent, is considered sufficiently conservative and well documented to use in estimating dermal RfDs and cancer slope factors from the respective oral values for all the PAHs.

The identification of metabolites of PAHs in the urine of occupationally exposed humans is qualitative evidence that respiratory tract uptake occurs, although quantitative uptake data were not located (ATSDR 1989f). Studies in rats indicate that pulmonary absorption of benzo(a)pyrene is rapid. PAHs carried by insoluble particulate matter, however, would be retained in the lung longer than pure PAHs. Human and animal studies suggest that there is considerable chemical-specific variation in dermal absorption. Quantitative estimates in animals treated with radiolabeled compounds range from 33 percent for dibenzo(a,h)anthracene to 93 percent for benzo(a)pyrene.

Inhalation and oral studies in animals with radiolabeled benzo(a)pyrene indicate that distribution of absorbed material is primarily to the lipid fractions of the liver, lung, kidney, and GI tract, with redistribution to the protein fractions of these organs (ATSDR 1989f). Absorbed benzo(a)anthracene, dibenzo(a,h)anthracene, and chrysene are rapidly and widely distributed in orally treated rats. There is considerable chemical-specific variability in the distribution of the PAHs to the fetuses of pregnant rats.

Studies of the metabolism of benzo(a)pyrene provide information relevant to other PAHs, because of the structural similarities of all members of the class. Metabolism involves microsomal mixed function oxidase hydroxylation of one or more of the phenyl rings with the formation of phenols and dihydrodiols, probably via formation of arene oxide intermediates (ATSDR 1989f). The dihydrodiols may be further oxidized to diol epoxides, which, for certain members of the class, are known to be the ultimate carcinogens (EPA 1992e). Conjugation with glutathione or glucuronic acid and reduction to tetrahydrotetrols are important detoxification pathways. Metabolism of naphthalene results in the formation of 1,2-naphthoquinone, which induces cataract formation and retinal damage in rats and rabbits.

Excretion of benzo(a)pyrene is principally through the bile, although there seems to be considerable species variation in the pattern (biliary versus urinary) and rate of excretion (ATSDR 1989). Urinary excretion predominates slightly in rats treated dermally with anthracene.

D.4.2.17.2 Noncancer Toxicity

Of the PAHs of concern, oral noncancer toxicity data are available for anthracene, fluoranthene, and pyrene. Oral RfD values were not available for acenaphthylene, benzo(g,h,i)perylene, phenanthrene, or any of the cancer weight-of-evidence Group B2 PAHs.

The toxic potency of anthracene appears to be very low. EPA (1992e) verified a chronic oral RfD of 0.3 mg/kg/day based on an NOEL of 1000 mg/kg/day in mice and an uncertainty factor of 3000. The data were inadequate to define target organs for the toxicity of anthracene.

Fluoranthene appears to be toxic to the liver, kidney, and blood. EPA (1992e) verifies a chronic oral RfD of 0.04 mg/kg/day from an NOAEL in a comprehensive 13-week gavage study in mice and an uncertainty factor of 3000. The liver, kidney, and blood appear to be the target organs for the toxicity of fluoranthene.

Mild kidney lesions appear to be the critical effects of exposure to pyrene. EPA (1992e) verifies a chronic oral RfD of 0.03 mg/kg/day based on an NOAEL in mice and an uncertainty factor of 3000. The kidney is the target organ for the toxicity of pyrene.

D.4.2.17.3 Carcinogenicity

Benzo(a)pyrene is the most extensively studied PAH, inducing tumors in multiple tissues of virtually all laboratory species tested (ATSDR 1989f). Although epidemiology studies suggested that complex mixtures that contain PAHs (coal tar, soots, coke oven emissions, cigarette smoke) are carcinogenic to humans (EPA 1992e), the carcinogenicity cannot be attributed to PAHs alone because of the presence of other potentially carcinogenic substances in these mixtures (ATSDR 1987b). Because of the lack of human cancer data, assignment of individual PAHs to EPA cancer weight-of-evidence groups was based largely on the results of animal studies with large doses of purified compound (EPA 1992e). Frequently, unnatural routes of exposure, including implants of the test chemical in beeswax and trioctanoin into the lungs of rats, intratracheal instillation, and subcutaneous or intraperitoneal injection, were used.

Acenaphthylene, anthracene, benzo(g,h,i)perylene, fluoranthene, phenanthrene, and pyrene were classified in Group D (not classifiable as to carcinogenicity to humans), and benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene were classified in Group B2 (probable human carcinogen) (EPA 1992e). Quantitative risk estimates are not derived for Group D compounds.

EPA (1992e) verified a slope factor for oral exposure to benzo(a)pyrene of 7.3 per mg/kg/day, based on several dietary studies in mice and rats. A provisional unit risk of 0.0017 per $\mu g/m^3$ was based on respiratory tract tumors in hamsters exposed by inhalation (EPA 1992b). The unit risk is equivalent to 6.1 per mg/kg/day, assuming an inhalation rate of 20 m^3/day and a body weight of 70 kg for humans. Neither verified nor provisional quantitative risk estimates were available for the other PAHs in Group B2. EPA (1980) promulgated an ambient water quality criterion for "total carcinogenic PAHs," based on an oral slope factor derived from a study with benzo(a)pyrene, as being sufficiently protective for

the class. Largely because of this precedent, the quantitative risk estimates for benzo(a)pyrene are adopted for the other carcinogenic PAHs when quantitative estimates were needed.

D.4.2.18 Protactinium

D.4.2.18.1 Pharmacokinetics

Experiments with laboratory animals treated orally with different forms of protactinium yielded absorption efficiencies ranging from 0.01 to 1 percent (Burkart and Kopp 1988). EPA (1992b) presented a GI absorption factor of 0.001 equivalent to 0.1 percent. Quantitative inhalation data for protactinium were not located, but one case of human inhalation yielded a lung clearance half-life of 1000 days (Burkart and Kopp 1988). Protactinium was assigned an ICRP lung class designation of "Y," meaning that clearance of inhaled protactinium would be expected to take years.

Distribution of absorbed protactinium is principally to the skeleton, and to a lesser extent to the liver and kidneys, respectively. Protactinium in the blood is excreted directly (Burkart and Kopp 1988), but the route and rate of excretion were not specified.

D.4.2.18.2 Noncancer Toxicity

Data regarding the noncancer effects of protactinium were not located.

D.4.2.18.3 Carcinogenicity

The EPA classifies all radionuclides as weight-of-evidence Group A substances (human carcinogens) based on their characteristic of emitting ionizing radiation and on the extensive epidemiologic data associating exposure with radiogenic cancers in humans (EPA 1992b). The carcinogenicity of protactinium-231 is due to its emission of alpha particles (Burkart and Kopp 1988). EPA (1992b) presents cancer potency slope factors for protactinium-231 of 9.2×10^{-11} per pCi for ingestion, 3.6×10^{-8} per pCi for inhalation and 2.6×10^{-8} per pCi yr/g for external exposure.

D.4.2.19 Radium

D.4.2.19.1 Noncancer Toxicity

No toxic effects of exposure to radium are documented and EPA has not developed an RfD for radium; therefore, the health hazard for radium is associated with potential radiocarcinogenic effects.

D.4.2.19.2 Carcinogenicity

Four isotopes of radium occur naturally, Ra-223 (actinium series), Ra-224 and Ra-228 (thorium series), and Ra-226 (uranium series); therefore, radium is ubiquitous in the earth's crust and common in groundwater, mineral deposits, soil, food products, and common building materials. Ra-226 has the longest half-life (1600 years) and decays by alpha particle emission. Ra-223 and Ra-224 are also

alpha-particle emitters, and Ra-228 is a beta-particle emitter. The primary uses of radium have been for manufacturing luminous dials and instrument faces and for internal radiation therapy. Thus, the bulk of the human data on effects from intake of radium are available from studies of radium dial painters and medical patients administered therapeutic doses of radium.

Although epidemiological investigations have documented the association between radium exposure and carcinogenic effects, there has been considerable debate over the dose-response relationship involved.

Radium introduced into the body generates decay products including gaseous isotopes of radon. Rn-222 generated in the body persists long enough that it easily diffuses into the bloodstream and accumulates in the sinuses of the head, significantly reducing the alpha dose to the radium accumulating tissues but increasing the dose in the sinus regions of the body. Ultimately the bone tissues are the principal site of radium accumulation because of the similar chemical behavior of radium compared to calcium (National Academy of Sciences [NAS] 1988). In the bone tissues, the radium is initially deposited in endosteal bone surface tissue. There is then a redistribution to the bone volume where the radium resides with a long retention time.

The accumulation of very high levels of radium is associated with severe anemias and leukemia (NAS 1988). However, at lower levels of accumulation, such as experienced by the majority of U.S. radium dial painters, especially in later years, the accumulated radium does not appear to significantly increase the risk of leukemia (NAS 1988). The Biological Effects of Ionizing Radiation (BEIR) IV Committee presents a cancer risk factor of 200×10^{-6} per rad for bone sarcomas from protracted exposure to radium in its report on radon and other alpha emitters (NAS 1988).

D.4.2.20 Radon and Progeny

D.4.2.20.1 Noncancer Toxicity

There are no known toxic effects of exposure to radon gas or its short-lived progeny.

D.4.2.20.2 Carcinogenicity

Exposure to air contaminated with radon gas and associated airborne progeny has been linked to increased risk of lung cancer. The risk is attributed to inhalation of the short-lived progeny of radon that are attached to particulates, which lodge in the lung passages and produce a radiation dose that causes lung cancer. Radon progeny that do not lodge in the lung passages are exhaled, and do not deliver a radiation dose. The induction of lung cancer results when the bronchial epithelium of the lung passages is exposed to alpha particles emitted from decaying radon progeny (e.g., Po-214 and Po-218) lodged in the lung passages.

Three isotopes of radon are of potential concern, one associated with each of the three natural decay series. Rn-222, Rn-220, and Rn-219 are members of the uranium, thorium, and actinium decay series, respectively. Rn-222 (half-life 3.82 days) is the isotope of primary concern because its half-life and mobility as an inert gas facilitate its migration to outdoor and indoor areas, thus potentially exposing receptors to elevated concentrations of Rn-222 and its short-lived progeny. Rn-220 (half-life 55.6 seconds) and Rn-219 (half-life 3.96 seconds) are generally of less concern because their very short half-lives often result in decay before there is sufficient opportunity for migration of the gas and accumulation of elevated quantities where receptors may be exposed. For example, all three isotopes of radon may be of concern in air in buildings that contain the appropriate parent radionuclides (in the form of surface contamination or drummed material for example). However, Rn-220 and Rn-219 are not expected to be released from a source such as the K-65 silos because their shorter half-lives would cause them to decay before migrating out of the waste matrix or out of the containment provided by the silos.

Dose Response Data - Human and Animal

The following discussion regarding the health effects of exposure to radon and radon progeny is summarized from the report of the BEIR IV Committee on radon and other alpha emitters (NAS 1988). The radiological effect of concern from exposure is lung cancer.

The lung cancer hazard associated with working in underground mines was first recognized by Harting and Hesse in 1879 as a result of autopsy studies of European miners (Harting and Hesse 1879). The most important human populations studied with regard to radon progeny exposure are the underground miners exposed to widely differing concentrations of airborne Rn-222 progeny in mines (National Council on Radiation Protection and Measurements [NCRP] 1984). The lung cancer mortality risk estimates for radon progeny exposure published by the BEIR IV Committee (NAS 1988) are based on an epidemiological study of these underground miner populations. The assessment of the risk from exposure to radon progeny by the BEIR IV Committee represents the most recent comprehensive examination of estimated health risks associated with exposure.

The BEIR IV Committee relies heavily on data from four principal studies of miners: Ontario uranium miners, Saskatchewan uranium miners, Swedish metal miners, and Colorado Plateau uranium miners. Underground miners exposed to radon progeny (in the mines) have an increased risk of lung cancer as demonstrated in these epidemiological study populations. Animals experimentally exposed to airborne radon progeny also develop lung cancers. Animal studies have provided information on the dose response relationship and the effects of variation in exposure rate, physical characteristics of the lung, and air quality to supplement the information available from the human epidemiological studies. Thus, both human epidemiological data and animal experimental data indicate that exposure to radon progeny induces lung cancer and describe the relationship between exposure and health effect as a function of influencing factors.

In its study of the human epidemiological data, the BEIR IV Committee has reevaluated the primary data (e.g., exposure histories and mortality) for the four principal epidemiological study groups of underground miners exposed to radon progeny. From this reevaluation, the BEIR IV Committee has developed estimates of the risk of fatal lung cancer. The BEIR IV lifetime risk estimate from lifetime exposure to radon progeny is 350 x 10^{-6} excess fatal lung cancers per cumulative working level month (WLM) exposure. The WLM is defined as cumulative exposure to an airborne concentration of short-lived radon progeny (equal to one working level) for a period of one working month. It must be noted that this estimate is quantified as fatal lung cancer risk, is based primarily on epidemiological studies of humans, and is expressed per unit cumulative exposure to progeny (WLM^{-1}). The EPA slope factors address cancer incidence, are based on calculated radiation doses to organs and tissues, and are expressed per unit radioactivity intake (pCi^{-1}). Thus, the EPA and BEIR IV risk estimates are not directly comparable. The EPA cancer slope factors are used for assessments of risk attributable to radon and radon progeny exposure. It is also noted that EPA adopted a nominal risk estimate of 360 x 10^{-6} per WLM for use in the National Emission Standards for Hazardous Air Pollutants (NESHAP) (EPA 1989a). This estimate is based primarily on EPA's consideration of the BEIR IV assessment; however, EPA did average radon risk estimates derived from BEIR IV and ICRP models to calculate the estimate of 360 x 10^{-6} per WLM.

Although the carcinogenicity of radon progeny is established and the hazards of exposure during mining are well recognized, the hazards of exposure in other environments have not yet been adequately quantified (NAS 1988). A few exploratory epidemiological studies of lung cancer risk associated with radon progeny exposure in homes have been conducted; however, the results are inconclusive and inadequate for the purpose of risk estimation (NAS 1988).

The model developed by the BEIR IV Committee may be used to estimate risks under other environmental conditions to which persons may be routinely exposed; however, it must be recognized that the BEIR IV Committee's model is based on epidemiological evaluations of occupational exposure conditions in underground mines. Therefore, assumptions must be made regarding the similarity of exposed populations, levels of exposure, and factors such as cigarette smoking when using the model for nonoccupational conditions such as in indoor home environments and other environmental settings.

Using the risk factor from the BEIR IV report (NAS 1988) of 350 x 10^{-6} $WLRM^{-1}$ for lung cancer mortality from inhalation of Rn-222 and progeny, and by assuming 51.5 working months (WM) per year (8760 hr/yr divided by 170 hrs worked/month), 100 pCi radon/liter air, short-lived Rn-222 progeny present in 50 percent equilibrium, and an inhalation rate of 20 m^3 day for 365 days/year, one can derive a lung cancer mortality risk factor of 1.2 x 10^{-11} per pCi. The EPA cancer slope factor from the HEAST publication for inhalation of Rn-222 plus progeny is 7.7 x 10^{-12} per pCi (EPA 1992b). It must be noted that the BEIR IV risk estimate pertains to lung cancer mortality while the EPA cancer slope factors all pertain to cancer induction rather than cancer fatality.

D.4.2.21 Selenium

D.4.2.21.1 Pharmacokinetics

Several studies indicate that different forms of selenium (sodium selenite, selenomethionine) are efficiently absorbed from the human GI tract (ATSDR 1989g). Absorption efficiencies ranged from 80 to 97 percent, and appeared to be independent of dose, suggesting the absence of a homeostatic mechanism that limited absorption. Other studies inexplicably reported lower absorption efficiencies (e.g., less than 30 percent for sodium selenite). The observation of high GI absorption efficiencies in animals (80 to 100 percent for sodium selenite, sodium selenate, selenomethionine, selenocystine) supports the high absorption efficiencies observed in humans. The 80 percent GI absorption efficiency is considered adequately conservative and well documented for use in deriving a dermal RfD from an oral RfD.

Inhalation absorption data in humans are limited to occupational studies (ATSDR 1989g). The observation of selenium in the urine of workers exposed to unspecified selenium compounds is qualitative evidence that absorption occurs from the respiratory tract. The urinary excretion of selenium was greater in workers exposed to higher concentrations of selenium in workroom air. In animals, absorption from the respiratory tract is extensive, but the rate of absorption depends on the chemical form. Data regarding the dermal uptake of selenium were not located.

The tissue distribution pattern of selenium in the body is dependent upon the form of selenium administered. Selenium from selenomethionine tends to concentrate in the pancreas of humans, rats and chicks, following oral or intravenous dosing (ATSDR 1989g). Highest tissue concentrations of selenium from sodium selenite or sodium selenate were located in the liver and kidney of humans and laboratory animals following oral or parenteral dosing.

Metabolism of selenium involves incorporation into body proteins, formation of volatile alkyl compounds (dimethyl selenide, dimethyl diselenide) that are excreted in expired air, and formation of soluble compounds (trimethylselonium ion) that are excreted in the urine (ATSDR 1989g). Usually, excretion by the feces and urine each account for about 50 percent of total selenium output; excretion by the respiratory tract assumes greater importance at higher doses.

D.4.2.21.2 Noncancer Toxicity

Selenium is a nutritionally essential trace element that is an integral part of the enzyme glutathione peroxidase and other proteins (Högberg and Alexander 1986). The National Research Council (1989) recommended dietary allowances (RDAs) for humans range from 10 to 75 µg/day. Chronic ingestion of 5 mg/day (0.071 mg/kg/day, assuming humans weigh 70 kg) induces selenosis in humans, characterized by abnormal hair and nail formation (Högberg and Alexander 1986). Effects in domestic grazing animals exposed to high levels of selenium include emaciation, lameness, and loss of hair and

hooves. Occupational exposure to selenium fume or various selenium compounds is associated with intense ocular and respiratory tract irritation, chemical pneumonia, skin rashes, garlic odor to the breath, metallic taste in the mouth, and various socio-psychological effects (ACGIH 1986). EPA (1992e) presented a verified RfD of 0.005 mg/kg/day for chronic oral exposure to selenium, based on effects in humans exposed to selenium in high selenium areas. An uncertainty factor of 3 was used. The principal target organs for oral exposure to selenium are the skin, including the nails and hair, and, in animals, the hooves and joints. Targets for inhalation or dermal exposure include the skin and mucous membranes of the eyes and respiratory tract, and possibly the CNS.

D.4.2.21.3 Carcinogenicity

A large body of data indicates that selenium exerts an anticarcinogenic effect (Högberg and Alexander 1986). In laboratory animals, selenium supplementation decreased the incidence of chemical-induced cancers. In humans, the incidence of lymphomas and cancers of the breast, digestive tract, and lung were lower in geographic areas with high soil selenium levels. Occupational data suggest that selenium may protect against lung cancer. Several animal tests, with various deficiencies in design and conduct, equivocally associate exposure to selenium with cancer induction. In a well controlled oral experiment, selenium sulfide was associated with an increase in the incidence of liver tumors in rats, and with liver and lung tumors in mice. On the basis of this study, EPA (1992e) classifies selenium sulfide a cancer weight-of-evidence Group B2 compound (probable human carcinogen), but declined to derive quantitative risk estimates. Selenium and other selenium compounds were classified in cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans). Quantitative risk estimates are not derived for Group D substances.

D.4.2.22 Silver

D.4.2.22.1 Pharmacokinetics

The GI absorption of ingested silver in animals was estimated at ≤10 percent; however, absorption of 18 percent was estimated for one human subject given silver acetate (Fowler and Nordberg 1986). In the absence of more precisely quantified absorption data, the default of 5 percent (EPA 1989a) is used to estimate a dermal RfD from an oral RfD.

Occupational studies indicate that absorption from the respiratory tract occurs, but absorption could not be quantified (ATSDR 1989h). In a study in dogs exposed to silver metal particles in air, 90 percent of the deposited silver was absorbed. Dermal absorption of silver compounds in humans was estimated at less than 1 percent of the applied dose.

Highest tissue levels are located in the liver; lower levels are located in the lungs, brain, spleen, bone marrow, muscle, and skin (Fowler and Nordberg 1986; Goyer 1991). Excretion is virtually entirely through the bile. The excretion kinetics appear to be species- and organ-dependent. In humans, the

apparent half-life for silver in the liver is approximately 50 days. Silver in skin also has a long half-life (not quantified).

D.4.2.22.2 Noncancer Toxicity

Silver compounds have been used in dentistry, medicinally in the treatment of burns, as a local disinfectant, and as a drinking water disinfectant (Fowler and Nordberg 1986). The classical syndrome of toxicity, called argyria, is a blue-gray to nearly black discoloration of areas of the skin or the viscera resulting from deposition of microscopic granules of silver compounds in the affected tissues. Argyria results from occupational (inhalation), parenteral or oral exposure. EPA (1992e) derived an RfD of 5 µg/kg/day for chronic oral exposure, based on an LOAEL for argyria estimated at 14 µg/kg/day in a 2- to 9-year human intravenous treatment study. An uncertainty factor of 3 was applied.

D.4.2.22.3 Carcinogenicity

EPA (1992e) classifies silver in cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans). The human data consist of no evidence of cancer despite frequent medical use of silver compounds. The animal data are limited to studies of implanted silver foil or injected metallic silver that provided unconvincing indications of a carcinogenic response relevant to humans. Quantitative risk estimates are not derived for Group D chemicals.

D.4.2.23 Strontium

D.4.2.23.1 Pharmacokinetics

The GI absorption of soluble strontium compounds ranges from 5 to 25 percent of the ingested dose (Wennig and Kirsch 1988). EPA (1992b) presents a GI absorption efficiency factor of 0.3. Insoluble strontium compounds are absorbed to about 5 percent. Data were not located regarding inhalation or dermal absorption.

Strontium is an alkaline earth metal similar in chemical behavior to calcium (Wennig and Kirsch 1988). About 99 percent of the body burden is located in the skeleton. Excretion is principally in the urine.

D.4.2.23.2 Noncancer Toxicity

Stable strontium induces rachitic changes in the bones, particularly of the young (EPA 1992e). Presumably, Sr-90 would also induce rachitic changes in bone. The concern at Fernald Operable Unit 4, however, is with the radiological effects (carcinogenicity) of Sr-90, rather than the noncancer toxicity. The carcinogenicity of Sr-90 is discussed in the next section.

D.4.2.23.3 Carcinogenicity

Stable strontium was assigned to cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans) (EPA 1992e). Quantitative cancer risk estimates are not derived for Group D substances. The EPA classifies all radionuclides as weight-of-evidence Group A substances (human carcinogens) based on their characteristic of emitting ionizing radiation and on the extensive epidemiologic data associating exposure with radiogenic cancers in humans (EPA 1992b). EPA (1992b) presents cancer potency slope factors for Sr-90 and its radioactive decay product of 3.6×10^{-11} per pCi for ingestion, and 6.2×10^{-11} per pCi for inhalation. There is no slope factor for external exposure to Sr-90, since Sr-90 does not emit penetrating radiation (gamma-rays or x-rays).

D.4.2.24 Technetium

D.4.2.24.1 Pharmacokinetics

EPA (1992b) presented a GI absorption factor for technetium of 0.8. Data were not located regarding the absorption of technetium following inhalation or dermal exposure. The chemistry of technetium is mediated largely by the pertechnetate ion, which is stable in the absence of strong reducing agents (Clarke and Podbielski 1988). The pertechnetate ion tends to concentrate in the choroid plexus of the brain and the thyroid; it is also fairly rapidly eliminated through the kidneys. Complexes of technetium with phosphates and phosphonates are incorporated into bone. Some monovalent cationic technetium complexes have affinity for heart muscle. Colloidal particles are removed from the circulation by the lymphatic system or the reticuloendothelial system of the liver and spleen.

D.4.2.24.2 Noncancer Toxicity

No isotopes of technetium are stable (Clarke and Podbielski 1988). Lethality due to radiation toxicity usually occurs before the nonradiologic effects of technetium become manifest, hence, little is known of the metabolic effects of the element.

D.4.2.24.3 Carcinogenicity

The EPA classifies all radionuclides as weight-of-evidence Group A substances (human carcinogens) based on their characteristic of emitting ionizing radiation and on the extensive epidemiologic data associating exposure with radiogenic cancers in humans (EPA 1992b). The carcinogenicity of technetium-99 is due to its emission of beta particles (Clarke and Podbielski 1988). EPA (1992b) presents cancer potency slope factors for Tc-99 of 1.3×10^{-12} per pCi for ingestion, 8.3×10^{-12} per pCi for inhalation, and 6.0×10^{-13} per pCi yr/g for external exposure.

D.4.2.25 Thallium

D.4.2.25.1 Pharmacokinetics

Thallium is readily absorbed from the GI and respiratory tracts, and is readily absorbed through the skin (Kazantzis 1986). Absorption from the GI and respiratory tracts may be virtually complete. The GI absorption efficiency of 100 percent is considered sufficiently well documented for use in deriving a dermal RfD from an oral RfD.

Thallium is widely distributed to the tissues of the body, rapidly leaving the blood and entering the tissues against a concentration gradient (Manzo and Sabbioni 1988). Highest tissue concentrations after a single exposure are located in the kidney (Kazantzis 1986). In cases of human intoxication, about 45 percent of the dose was present in the body 24 days after ingestion (Manzo and Sabbioni 1988). Excretion is mainly through the kidney, gut, and salivary glands, with enteric recirculation accounting for the long biological half-life. Loss in the hair and nails are important excretory mechanisms for the long-term reduction of body burden (Kazantzis 1986).

D.4.2.25.2 Noncancer Toxicity

Thallium is highly toxic; acute ingestion by humans or laboratory animals induces gastroenteritis, neurological dysfunction, and renal and liver damage (Kazantzis 1986). Chronic ingestion of smaller doses characteristically causes alopecia. Thallium was used medicinally in humans to induce alopecia in cases of ringworm of the scalp, sometimes with disastrous results. In industrial (inhalation, oral, dermal) exposure, neurologic signs precede alopecia, suggesting that the nervous system is more sensitive than the hair follicle. EPA (1992e) presents verified chronic oral RfD values for several thallium compounds (thallium acetate, thallium carbonate, thallium chloride, thallium nitrate, thallium selenite, and thallium sulfate), based on an NOAEL for increased incidence of alopecia and increased serum levels of liver enzymes indicative of hepatocellular damage in rats treated with 0.25 mg thallium sulfate per kg/day for 90 days. An uncertainty factor of 3000 was used to derive the RfD of 8×10^{-5} mg/kg/day for thallium sulfate. An oral RfD for thallium alone was not presented. The oral RfD values for the thallium compounds were derived from the oral RfD for thallium sulfate, correcting for differences in molecular weight. This approach relies on the assumption that the toxicity of each of these thallium compounds is attributed solely to the thallium moiety. If this assumption is accepted, the same approach can be used to derive a chronic oral RfD for thallium alone. Multiplying the oral RfD of 8×10^{-5} mg/kg/day for thallium sulfate by the ratio of the weight of thallium in thallium sulfate (408.77 daltons) to the weight of thallium sulfate (504.85 daltons) yields an RfD of 6×10^{-5} mg/kg/day for chronic oral exposure to thallium. Target organs for thallium include the GI tract (acute exposure), nervous system, skin, kidney, and liver.

D.4.2.25.3 Carcinogenicity

Several thallium compounds (thallium oxide, thallium acetate, thallium carbonate, thallium chloride, thallium nitrate, thallium sulfate) were classified as cancer weight-of-evidence Group D substances (not classifiable as to carcinogenicity to humans) (EPA 1992e). No weight-of-evidence classification was located for thallium alone.

D.4.2.26 Thorium

D.4.2.26.1 Noncancer Toxicity

No toxic effects of exposure to thorium are documented and EPA has not developed an RfD for thorium; therefore, the health hazard for thorium is associated with potential radiocarcinogenic effects.

D.4.2.26.2 Carcinogenicity

Natural thorium is present in the earth's crust as a primordial element. The Th-232 isotope accounts for approximately 100 percent of the mass abundance of thorium; however, the radioactivities of other isotopes of thorium exist as members of the three natural decay series. The half-life of Th-232 is very long (approximately 10^{10} years), thus the specific activity is relatively low and the rate of decay is slow. Th-232 decays by alpha particle emission as do most of the progeny in the thorium natural decay series.

Thorium has historically been used as a medical imaging agent because it is a heavy atom that provides contrast in radiographic imaging techniques. In this role thorium has been used commercially as Thorotrast, a 25-percent colloidal solution of thorium dioxide. Thorotrast has been used extensively in the United States, Europe, and Japan as an intravascular contrast agent for cerebral and limb angiography. Thorotrast has also been injected into the spleen for hepatolienography and into nasal and paranasal sinuses. These uses of Thorotrast result in deposition of the thorium (and subsequent decay products) in tissues and organs of the body, most frequently in the reticuloendothelial tissues in bone (NAS 1988). Once deposited in these tissues alpha emissions from the decay of Th-232 and its progeny irradiate the tissues for long periods of time at low dose rates.

The human data on health effects of exposure to thorium are primarily based on epidemiological studies of Thorotrast patients in five studies including German patients, Portuguese patients, Japanese patients, Danish patients, and American patients. In the study of German Thorotrast patients (van Kaick et al. 1978a, 1978b, 1983, 1984a, 1984b, 1986) 5159 patients and 5151 controls were followed since 1933 and 1935, respectively. The Thorotrast patients underwent intravascular injections of Thorotrast to enhance the imaging of cerebral and limb angiography.

Human epidemiological studies indicate an excess of malignant cancers among the Thorotrast patients compared to the controls. The excess malignancies are predominantly of the liver and blood (leukemia) types.

Animal experimental evidence indicates that Thorotrast induces cancers as a result of the radiation dose delivered by the solution. The physical presence of particles in the colloid solution and the chemical effect of the thorium are not likely to influence the induction of cancer (NAS 1988).

The human epidemiological evidence from studies of the Thorotrast patients represents the primary source of data from which an estimate of risk can be derived (NAS 1988). These data can be used to derive estimates of risk for liver cancer and leukemia; however, such estimates would only strictly apply to conditions of intravascular Thorotrast injection. The BEIR IV report derives a risk estimate of up to 300 x 10^{-6} per rad of alpha-particle radiation dose to the liver, and emphasizes that these estimates are for Thorotrast, not thorium. The emphasis is because the dosimetry of other isotopes of thorium will differ from that of the Th-232 in the Thorotrast colloid form. The BEIR IV report also derives a risk estimate of up to 60 x 10^{-6} per rad of alpha radiation dose to bone marrow for leukemia, and a value of up to 120 x 10^{-6} per rad alpha radiation dose to the skeleton without marrow for bone cancer (NAS 1988). EPA (1992b) presents cancer potency slop factors for isotopes of Thorium (including Th-228, Th-230, and Th-232) for ingestion, inhalation, and external exposure. These values are presented in Table D.4-3. The values in Table D.4-3 are used in the quantitative risk assessment.

D.4.2.27 Uranium

D.4.2.27.1 Pharmacokinetics

In general, uranium compounds are not easily absorbed across the human GI tract. Soluble uranium compounds demonstrate the best absorption, but in a study in which patients drank a solution of uranyl nitrate hexahydrate, a water soluble compound, only 0.5 to 5 percent of the dose was found to be absorbed (Hursh et al. 1969). Most recently, uranium metabolic models have estimated absorption from the GI tract to the blood to be 0.6 percent (Wrenn et al. 1987). Although human data concerning absorption by dermal exposure are sparse, water-insoluble uranium compounds are not absorbed in significant quantities across the skin and are not believed to pose a risk to humans by this exposure route (Yuile 1973).

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

In addition to being the only soft tissue that stores uranium in any appreciable quantity, the kidney is the main organ of excretion (Hursh and Spoor 1973). Approximately 70 percent of an intake of uranium has been estimated to be excreted by the kidney within 24 hours of intake (Berlin and Rudell 1979). Uranium that is not excreted is stored in both the kidney and the bone. Binding to the bone is thought to be caused by the affinity of uranium for the phosphate groups in the bone structure.

D.4.2.27.2 Noncancer Toxicity

Dose Response Data - Human

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

Dose Response Data - Animal

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

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

An extensive chronic feeding study was performed on rabbits, rats, and dogs for periods of 30 days, 1 year, and 2 years (Maynard and Hodge 1949). These animals received uranium doses of 2.8, 14, and 71 mg/kg/day in the diet. Rabbits were maintained for 30 days, dogs for 1 year, and rats for 1 to 2 years. For all species, water soluble compounds were more toxic than insoluble compounds. LOAELs were established for all compounds and each species (Maynard and Hodge 1949). In all cases, the LOAEL could be established within the first 30 days (EPA 1992e). Of the three species, rabbits appeared to be the most sensitive with renal damage exhibited at all administered dose levels. The renal damage was judged to be only moderate at the lower doses, but moderately severe at the highest

dose. Based on this, the lowest uranium dose of 2.8 mg/kg/day was established as the LOAEL by EPA (EPA 1992e).

Basis for Reference Dose

The EPA (EPA 1992e) has established an RfD for uranium of 3 µg/kg/day. In lieu of an NOAEL, the RfD is based on the LOAEL of 2.8 mg/kg/day (Maynard and Hodge 1949) and an uncertainty factor of 1000. The uncertainty factor accounts for intraspecies and interspecies variability in toxicological response and for the use of the LOAEL rather than an NOAEL. No factor was included to account for the short duration of the exposure (30 days) because it has been shown that chronic nephrotoxic effects can be adequately characterized with experiments of acute/subacute duration (EPA 1992e).

D.4.2.27.3 Carcinogenicity

Uranium can induce cancer as a result of intake into the body through inhalation or ingestion pathways. The induction of cancer results when organs and tissues of the body are exposed to alpha particles emitted from decaying uranium atoms. Alpha particles are energetic emissions that cause molecular ionizations in a very dense pattern along a short path through matter. The effect of an alpha particle is highly localized due to the short path length traveled (low penetrability) and the ability of the particle to produce many ionizations. The ionization events cause biological damage that is believed to be responsible for inducing cells to become cancerous. Although other energetic emissions from radioactive decay of atoms (such as beta particles and gamma rays) also cause molecular ionizations, these radiations do not produce the density of ionizations that alpha particles produce. The dense pattern of ionizations caused by alpha particles and the low penetrability of alpha particles are the factors that determine uranium is of concern as an internal exposure hazard. Alpha particles are not an external exposure hazard because they do not penetrate sensitive tissues from outside the body.

The type of uranium (e.g., natural, enriched, depleted) under consideration is important because different types of uranium have different specific activities (the amount of radioactivity per unit mass). The magnitude of the specific activity of the uranium reflects the number of alpha particles emitted per unit mass. This has a direct impact on the magnitude of the radiological dose delivered internally after the uranium enters the body. Naturally occurring uranium and uranium processed from natural uranium is a mixture of U-234, U-235, and U-238. The difference between natural, enriched, and depleted uranium is defined by the percent U-235 mass enrichment. The higher the U-235 enrichment, the higher the specific activity of the mixture.

Dose Response Data - Human

The following discussion of human data concerning health effects of uranium exposure is summarized from the report of the BEIR IV Committee on radon and other alpha emitters (NAS 1988). Convincing epidemiological evidence of uranium-induced radiocarcinogenic effects in humans is

difficult to obtain. Available epidemiological evidence comes from studies of workers involved in uranium mining and milling operations. It has been noted for some time that uranium workers are at risk of increased cancer mortality; however, inhalation of airborne radon progeny rather than uranium particulates is considered the predominant source of radiation damage to the respiratory tract in uranium miners. Simultaneous exposures to radon progeny and other elements present in uranium ore are considered confounding factors in studies of uranium miners intended to specifically examine the radiological effects of exposure to uranium.

Risk estimation for exposure to uranium is based heavily on the carcinogenic effects of other alpha-emitting radionuclides and animal experiments involving exposure to uranium. Available human epidemiological studies are discussed below.

Available epidemiological studies fail to conclusively demonstrate health effects from chronic exposure to uranium dust involved in uranium mining and milling operations. Neither do the epidemiological data conclusively demonstrate the absence of effect. The power of the studies is limited, weakened by short exposure durations for workers, inadequate estimates of uranium exposures, and insufficient worker follow-up time to adequately evaluate long-term effects.

The likelihood of sarcomas from exposure to naturally occurring uranium is considered low and only demonstratable if a linear dose-response relationship is assumed (Mays et al. 1985). If the dose-response relationship is quadratic then virtually no effect would be expected from naturally occurring uranium. Assuming a linear dose-response relationship and a constant nonoccupational uranium intake of 1 pCi/day, the risk of bone sarcoma induction over a lifetime is estimated to be 1.5 bone sarcomas per million persons (1.5×10^{-6}) (Mays et al. 1985). This is compared to a natural incidence of 750 bone sarcomas in the absence of excess exposure.

Assuming a constant nonoccupational uranium intake rate of 1 pCi/day, an exposure frequency of 365 days/year, and a lifetime of 70 years, a lifetime of uranium intake of nearly 26,000 pCi is calculated. Using the risk factor from Mays (Mays et al. 1985), and dividing by the calculated lifetime intake, one can derive a risk factor of 5.9×10^{-11} per pCi. Comparison of this risk factor with the cancer slope factors from HEAST for ingestion of U-234, U-235, and U-238, indicates that the ratios of the HEAST values to the former value are 0.27, 0.27, and 0.47, respectively. EPA (1992b) presents cancer potency slope factors for isotopes of uranium (including U-234, U-235, and U-238) for ingestion, inhalation, and external exposure. These values are presented in Table D.4-3 and are used in the quantitative risk assessment.

D.4.2.28 Vanadium

D.4.2.28.1 Pharmacokinetics

The GI absorption of ingested vanadium is very low. A study in humans reported absorption of a very soluble compound, oxytartarovanadate, to be 0.1 to 1 percent (Lagerkvist et al. 1986). Uptake from the diet was estimated to be not greater than 1 percent. Uptake of vanadium from vanadium pentoxide was 2.6 percent of the administered dose in rats. In the absence of better quantified absorption data, the EPA (1989a) default of 50 percent is used to derive a dermal RfD from an oral RfD.

The extent of absorption of vanadium from the respiratory tract depends on particle size and solubility of the vanadium compound (Lagerkvist et al. 1986). Although not precisely quantified, the respiratory tract absorption of soluble vanadium compounds was estimated at 25 percent (species not reported). Occupationally exposed workers excrete more vanadium in their urine than do controls. In rats, rapid uptake followed the intratracheal instillation of several vanadium compounds. For example, more than one-half of an intratracheal dose of vanadyl trichloride was absorbed from the lungs within 1 day; 3 percent of the dose remained in the lungs 63 days after treatment. Quantitative dermal absorption data were not located.

In laboratory animals, absorbed vanadium is distributed principally to bone, kidney, liver, and spleen (Lagerkvist et al. 1986). In humans and laboratory animals, systemic vanadium is excreted principally in the urine.

D.4.2.28.2 Noncancer Toxicity

The oral toxicity of vanadium and compounds to humans is very low (Lagerkvist et al. 1986), probably because little vanadium is absorbed from the GI tract. Effects in humans exposed by inhalation include upper and lower respiratory tract irritation. A provisional chronic oral RfD of 0.007 mg/kg/day was derived from an NOEL in rats in a lifetime drinking water study with vanadyl sulfate and an uncertainty factor of 100 (EPA 1992b). A target organ could not be identified for oral exposure. The respiratory tract is the target organ for inhalation exposure.

D.4.2.28.3 Carcinogenicity

Vanadium is classified in cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans) (EPA 1992g). Quantitative risk estimates are not derived for Group D chemicals.

D.4.2.29 Zinc

D.4.2.29.1 Pharmacokinetics

Zinc is a nutritionally required trace element. Estimates of the efficiency of GI absorption of zinc in animals range from less than 10 to 90 percent (Elinder 1986). Estimates in normal humans range from

approximately 20 to 77 percent (Elinder 1986; Goyer 1991). The net absorption of zinc appears to be homeostatically controlled, but it is unclear whether GI absorption, intestinal secretion, or both are regulated. The 20 percent absorption efficiency is considered appropriately conservative and well documented for use in deriving a dermal RfD from an oral RfD.

Data regarding respiratory tract or dermal absorption of zinc were not located.

Distribution of absorbed zinc is primarily to the liver (Goyer 1991), with subsequent redistribution to bone, muscle, and kidney (Elinder 1986). Highest tissue concentrations are found in the prostate. Excretion appears to be principally through the feces, in part from biliary secretion, but the relative importance of fecal and urinary excretion is species-dependent. The half-life of zinc absorbed from the GI tracts of humans in normal zinc homeostasis is approximately 162 to 500 days.

D.4.2.29.2 Noncancer Toxicity

Humans exposed to high concentrations of aerosols of zinc compounds may experience severe pulmonary damage and death (Elinder 1986). The usual occupational exposure is to freshly formed fumes of zinc, which can induce a reversible syndrome known as metal fume fever. Orally, zinc exhibits a low order of acute toxicity. Animals dosed with 100 times dietary requirement showed no evidence of toxicity (Goyer 1991). In humans, acute poisoning from foods or beverages prepared in galvanized containers is characterized by GI upset (Elinder 1986). Chronic oral toxicity in animals is associated with poor growth, GI inflammation, arthritis, lameness, and a microcytic, hypochromic anemia (Elinder 1986), possibly secondary to copper deficiency (Underwood 1977). EPA (1992e) presented a verified RfD of 0.2 mg/kg/day for chronic oral exposure to zinc, based on anemia in humans. Target organs for the chronic effects of zinc include the joints and the hematopoietic system.

D.4.2.29.3 Carcinogenicity

EPA (1992e) classifies zinc in cancer weight-of-evidence Group D (not classifiable as to carcinogenicity to humans) based on inadequate evidence for carcinogenicity in humans and animals. The human data consist largely of occupational exposure studies not designed to detect a carcinogenic response, and of reports that prostatic zinc concentrations were lower in cancerous than in noncancerous tissue. The animal data consist of several dietary, drinking water, and zinc injection studies, none of which provided convincing data for a carcinogenic response. Quantitative cancer risk estimates are not derived for Group D chemicals.

D.4.3 SUMMARY OF THE TOXICITY ASSESSMENT

The toxicity assessment presents a review of health effects studies for the primary contaminants of concern in existing environmental contamination at Operable Unit 4. This includes the studies of the toxic and the carcinogenic effects of 29 contaminants of potential concern.

Uranium is known to be a chemical toxicant, exposure to which leads to nephritis of the kidney, which is considered a more limiting effect than the carcinogenicity of uranium. The BEIR IV Committee recommends that uranium exposure be controlled on the basis of nephrotoxicity rather than radiocarcinogenicity from alpha particle emissions (NAS 1988). The most probable radiocarcinogenic effect of uranium is expressed as excess bone cancers. The likelihood of induction of excess bone cancers from exposure to naturally occurring uranium is considered low and only demonstrable if a linear dose-response relationship is assumed (Mays et al. 1985). The radiocarcinogenic effect of radon and radon progeny is the induction of excess lung cancers. The BEIR IV Committee estimates the lifetime risk of fatal lung cancer due to lifetime exposure (NAS 1988) while the EPA estimates the age-averaged lifetime total excess cancer risk (cancers induced) (EPA 1992b). The radiocarcinogenic effect of radium exposure is induction of excess bone cancers as a result of the long-term deposition of radium on endosteal bone surfaces (NAS 1988). The paranasal sinuses and the mastoid air cells of the head region are an additional site of excess cancer induction resulting from intake of radium. This effect is attributed to the alpha radiation dose delivered by Rn-222 and progeny following migration to those sites from the sites of radium deposition in the bone tissue. The radiocarcinogenic effect of thorium is induction of excess cancer of the liver and leukemia (NAS 1988). For health effects of the major nonradionuclide contaminants of potential concern found in Operable Unit 4, refer to Section D.4.2.

As discussed in Section D.4.1, the toxicity and carcinogenicity values used to estimate toxic and carcinogenic health effects are obtained from the HEAST and IRIS databases compiled by EPA (EPA 1992b, 1992e). These values are presented in Tables D.4-1, D.4-2, and D.4-3.

D.5.0 RISK CHARACTERIZATION

Potential risks to humans following exposure to nonradioactive chemicals and radionuclides of potential concern are estimated using methods established by the EPA when available. Methods described by the EPA are health-protective and are likely to overestimate, rather than underestimate, risk.

D.5.1 METHODS FOR CHARACTERIZING RADIOLOGICAL EXPOSURES

Procedures for estimating the lifetime total excess cancer risk due to continuous, lifetime exposure (i.e., a 70-year lifespan) to a radionuclide are discussed below. In each case, the slope factor simply acts as a "conversion factor" by which a radionuclide intake or a soil concentration is converted to the corresponding cancer risk in a single step. Radiation doses to the whole body or to specific organs or tissues from such exposures cannot be readily calculated by use of slope factors.

D.5.1.1 Internal Exposures

Risk characterization for internal exposures to radionuclides (intake via inhalation or ingestion) is calculated as follows:

$$\text{Risk} = (I)(SF) \qquad \text{(D.5-1)}$$

where

Risk = risk of cancer incidence, expressed as a unitless probability
I = radionuclide intake (pCi)
SF = radionuclide slope factor (pCi^{-1})

In order to consolidate the processes of exposure assessment, toxicity assessment, and risk characterization, URFs have been developed for all radionuclides. The URFs are constituent-, pathway-, scenario-, and medium-specific. They are developed by modeling one unit concentration of each radionuclide (e.g., 1 pCi/g of soil or 1 pCi/L of water) through each of the exposure equations for a given medium and receptor. The URFs for radionuclides are listed in Attachment D.I for soil and groundwater exposure pathways. The risk for each medium/scenario is calculated by multiplying the exposure point concentration of each radionuclide by the corresponding URF.

D.5.1.2 External Gamma Exposures

Risk characterization for external exposure to gamma-emitting radionuclides in contaminated surface soil is calculated as follows:

$$\text{Risk} = (C_s)(SF)(ED)(MF) \qquad \text{(D.5-2)}$$

where

Risk	=	risk of cancer incidence, expressed as a unitless probability
C_s	=	radionuclide soil concentration (pCi/g)
SF	=	radionuclide slope factor (risk/yr per pCi/g)
ED	=	exposure duration (yr)
MF	=	modifying factor, fraction of year exposed (unitless)

Risk characterization for external exposures to gamma-emitting radionuclides in source geometries other than surface soil is calculated as follows:

$$DE = (DR)(EF)(ED)(ET)(1\text{-}SH) \qquad \text{(D.5-3)}$$

where

DE	=	dose equivalent (mrem)
DR	=	dose equivalent rate (mrem/hr)
EF	=	exposure frequency (days/yr)
ET	=	exposure time (hr/day)
ED	=	exposure duration (yr)
SH	=	building shielding factor for dose equivalent rate reduction indoors (unitless)

D.5.2 METHODS FOR CHARACTERIZING HAZARDOUS CHEMICAL EXPOSURES

Risks from hazardous chemicals are calculated for either carcinogenic or noncarcinogenic effects. Some carcinogenic chemicals also may pose a noncarcinogenic hazard; risks from these chemicals are characterized for both types of health effects.

D.5.2.1 Chemical Carcinogens

The risk attributed to exposure to chemical carcinogens is estimated as the probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen. At low doses, the risk of developing cancer is determined as follows (EPA 1989a):

$$Risk = (CDI)(SF) \qquad \text{(D.5-4)}$$

where

Risk	=	risk of cancer incidence, expressed as a unitless probability
CDI	=	chronic daily intake averaged over 70 years (mg/kg/day)
SF	=	slope factor $(mg/kg/day)^{-1}$

U.S. EPA (1989) specifies the one-hit equation:

$$Risk = 1\text{-}exp^{(-CDI \times SF)} \qquad \text{(D.5-5)}$$

where

exp = the exponential of the negative of the risk calculated using the slope factor methodology

CDI and SF are the same as defined for Equation D.5-4, should be used when CDI x SF exceeds 0.01. An examination of Attachment D.II reveals that CDI x SF exceeds 0.01 for two pathways (ingestion of arsenic in vegetables and ingestion of arsenic in beef) in three different scenarios. The largest value for ILCR was 9.33×10^{-2} per mg/kg/day, calculated for ingestion of arsenic in vegetables (Table D.II-24). Applying the one-hit equation to these data generates an ILCR of 8.91×10^{-2} per mg/kg/day. When rounded to one significant figure (EPA 1989), the ILCR calculated by either CDI x SF or the one-hit equation becomes 9×10^{-2} per mg/kg/day. The differences between the one-hit equation and CDI x SF would be even less for smaller values of CDI x SF. As a practical matter, applying the one-hit equation to the cancer data for Operable Unit 4 would make no differences in the estimates of risk for any receptors in any of the scenarios. Therefore, to simplify calculations and conserve resources, all cancer risks are calculated as CDI x SF. This is compatible with the "unit risk factor" approach described in Section D.5.2.3.

As with radionuclides, URFs have been developed for chemical carcinogens. They are developed by modeling one unit concentration of each chemical (e.g., 1 mg/kg of soil or 1 mg/L of water) through each of the exposure equations for a given medium and receptor. They are listed in Attachment D.I for soil and groundwater exposure pathways. The risk for each medium/scenario combination is calculated by multiplying the exposure point concentration of each chemical in each medium by the corresponding URF.

For a given pathway with simultaneous exposure of a receptor to several carcinogens, the following equation is used to sum cancer risks:

$$Risk_P = Risk\ (chem_1) + Risk\ (chem_2) + \ldots Risk\ (chem_i) \qquad (D.5\text{-}6)$$

where

$Risk_P$ = total pathway risk of cancer incidence
$chem_i$ = individual carcinogenic chemical

D.5.2.2 Noncarcinogens

The risks associated with the effects of noncarcinogenic hazardous chemicals are evaluated by comparing an exposure level or intake to a reference dose. The ratio of intake over the reference dose is termed the Hazard Quotient (HQ) (EPA 1989a) and is defined as:

$$HQ = I/RfD \qquad (D.5\text{-}7)$$

where

HQ = hazard quotient (unitless)
I = intake of a chemical (mg/kg/day)
RfD = reference dose (mg/kg/day)

Chemical exposures are evaluated in all cases on a chronic basis, using chronic RfD values.

In order to consolidate the process of exposure assessment, toxicity assessment, and risk characterization for chemical toxicants, UTFs have been developed. They are also constituent-, pathway-, scenario-, and medium-specific. As with URFs, UTFs are developed by modeling one unit concentration of each toxicant through each of the exposure equations for a given medium and receptor. UTFs are also listed in Attachment D.I.

This approach is different from the probabilistic approach used to evaluate carcinogens. An HQ of 0.01 does not imply a 1 in 100 chance of an adverse effect, but indicates only that the estimated intake is 100 times less than the reference dose. An HQ of unity (1) indicates that the exposure intake is equal to the RfD. If the HQ is greater than 1 or "above unity," there may be concern for potential health effects. The level of concern increases as the HQ increases above unity, although the two are not linearly related (EPA 1989a).

In the case of simultaneous exposure of a receptor to several chemicals, a Hazard Index (HI) is calculated as the sum of the Hazard Quotients by:

$$HI = I_1/RfD_1 + I_2/RfD_2 + \ldots I_i/RfD_i \qquad \text{(D.5-8)}$$

where

I_i = intake for the ith toxicant
RfD_i = reference dose for the ith toxicant

In those cases where the total HI for a given scenario (e.g., for the trespassing child exposed to chemicals in Silo 3 contents) is equal to or greater than 1×10^0, chemical-specific target organ data (obtained largely from the toxicity profiles in Section D.4) are used to estimate a total HI for each target organ. Care is taken to select target organ on the basis of duration of exposure (i.e., the target organ for chronic or subchronic exposure to low or moderate doses is selected rather than the target organ for acute exposure to high doses) and route of exposure. In cases involving mixed routes of exposure, the target organ for the predominant route of exposure is selected. For example, target organs for inhalation exposure are chosen for the off-property resident farmer exposed to chemicals from resuspended dust, even though oral exposure is also expected from ingestion of vegetables, meat,

and milk indirectly contaminated by resuspended dust. Target organ-specific total HI values equal to or greater than 1 x 10^0 are presented in the results tables, and the results are mentioned in the text.

D.5.2.3 Calculation of Unit Risk Factors

In CERCLA risk assessment methodology, a linear relationship is assumed to exist between the exposure point concentration of a constituent in a medium and the calculated noncancer or cancer health risk from exposure to the constituent in the medium. The calculated health risk from exposure to the unit concentration of a given constituent in a given environmental medium by a given exposure route is referred to as a "unit risk factor" for that constituent. The URF, therefore, is constituent, scenario, and medium specific. After the exposure models, the exposure parameters and the toxicity values are determined for a site, the URFs can be calculated even though the process of data collection, validation, and statistical analysis has not yet provided exposure point concentrations. When the exposure point concentrations are available, they are multiplied by the appropriate URFs to yield the corresponding hazard quotients and cancer risks. Calculating the URFs before obtaining the exposure point concentrations expedites the risk assessment process. This procedure has no effect on the outcome of the risk assessment results. Additional information and sample calculations are presented in Attachment D.I.

D.5.3 RESULTS OF THE RISK CHARACTERIZATION

D.5.3.1 Current Land Use

Risks are presented for both current conditions (i.e., the assumption that the silos remain intact, precluding direct contact with the silo contents) and future conditions (i.e., the assumption that the silos undergo structural failure, allowing direct contact with the silo contents as well as indirect contact such as escape of contaminants to air, leaching to groundwater or runoff into surface water).

D.5.3.1.1 Trespassing Child

This section presents the ILCR and HI results for radionuclide and chemical COCs for the trespassing child under current land use. Because the impact of access controls on the exposure frequency (hours/day or days/year) could not be quantified, the results presented reflect the absence of access controls; no attempt was made to quantify the risk for the trespassing child with access controls.

Table D.5-1 presents the results for ingestion of and dermal contact with soil and external radiation exposure from soil. The silo structures are assumed to be intact in their present condition. Radiological exposure pathways include ingestion of soil, and exposure to penetrating external radiation from contaminated soil. The radiological risks from the soil ingestion and external radiation pathways combined range from 2 x 10^{-11} (Tc-99) to 1 x 10^{-5} (Ra-226 + 5 daughters). The dominant contribution is from external radiation exposure to soil contaminated by Ra-226 and its five short-lived

TABLE D.5-1

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE TRESPASSING CHILD FROM RADIONUCLIDES AND CHEMICALS IN SOIL UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil	
Radionuclides	ILCR
Pb-210 + 2 dtrs	4.0×10^{-8}
Ra-226 + 5 dtrs	9.9×10^{-6}
Ra-228 + 1 dtr	9.1×10^{-7}
Sr-90 + 1 dtr	7.3×10^{-10}
Tc-99	1.6×10^{-11}
Th-230	8.6×10^{-10}
Th-232	2.8×10^{-10}
U-234	8.3×10^{-10}
U-238 + 2 dtrs	1.3×10^{-7}
TOTAL ILCR	**1.1×10^{-5}**
Chemicals	ILCR
Aroclor-1254	7.0×10^{-8}
Benzo(a)anthracene	1.5×10^{-5}
Benzo(a)pyrene	1.8×10^{-5}
Benzo(b)fluoranthene	3.9×10^{-6}
Beryllium	1.6×10^{-6}
bis(2-Ethylhexyl)phthalate	1.3×10^{-8}
Chrysene	1.4×10^{-5}
Dibenzo(a,h)anthracene	1.1×10^{-5}
Indeno(1,2,3-cd)pyrene	1.6×10^{-6}
Methylene chloride	1.3×10^{-10}
TOTAL ILCR	**6.8×10^{-5}**

TABLE D.5-1
(Continued)

Soil	
Chemicals	Hazard Quotients
2-Butanone	1.8×10^{-6}
4-Methyl-2-pentanone	8.4×10^{-7}
Acetone	8.4×10^{-6}
Anthracene	1.1×10^{-5}
Antimony	6.6×10^{-2}
Benzoic acid	2.1×10^{-7}
Beryllium	4.4×10^{-4}
bis(2-Ethylhexyl)phthalate	2.7×10^{-4}
Cadmium (food)	1.8×10^{-3}
Chromium	1.1×10^{-2}
Di-n-butylphthalate	2.8×10^{-5}
Fluoranthene	3.1×10^{-4}
Methylene chloride	1.7×10^{-6}
Molybdenum	4.9×10^{-4}
Nickel	4.0×10^{-3}
Phenol	5.4×10^{-6}
Pyrene	2.1×10^{-4}
Silver	5.1×10^{-3}
Thallium	1.1×10^{-3}
Toluene	1.9×10^{-8}
Total xylenes	1.4×10^{-9}
Uranium	3.1×10^{-2}
Zinc	1.9×10^{-4}
TOTAL HI	**1.2×10^{-1}**

[a]Radionuclide pathways include incidental ingestion of soil and external radiation exposure from soil. Chemical pathways include incidental ingestion of soil and dermal contact with soil.

progeny (1×10^{-5}). Radionuclides for which the risk exceeds 1×10^{-6} include only Ra-226 plus progeny. The sum of the radiological risks is 1×10^{-5}.

Chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include the carcinogenic PAHs (benzo[a]anthracene, benzo[b]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3-cd]pyrene), and beryllium. No chemical has an ILCR exceeding 1×10^{-4}. The total ILCR for the chemical carcinogens for ingestion of and dermal contact with soil is 7×10^{-5}, attributable almost entirely to benzo(a)pyrene. For the noncarcinogenic effects, all HI values are below 1.0, and the total HI is 1×10^{-1}.

Table D.5-2 presents the results for ingestion of and dermal contact with silo contents, and external radiation exposure from silo contents, assuming structural failure of the silos.

Radiological exposure pathways include ingestion of waste, and exposure to penetrating external radiation from contaminated waste following structural failure of the silos, and spreading of the metal oxide waste in the Operable Unit 4 Study Area. The risks from the ingestion and external radiation pathways combined range from 2×10^{-7} (Th-232) to 7×10^{-3} (Ra-226 + 5 progeny). The dominant contribution is from external radiation exposure from contaminated waste by Ra-226 and its five short-lived progeny (7×10^{-3}). Radionuclides for which the risk exceeds 1×10^{-6} include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Th-228 plus progeny, Th-230, U-235 plus progeny, and U-238 plus progeny. The radiological risk sum is 9×10^{-3}.

Prior to structural failure of the silos, the waste material poses a potential risk to receptors proximal to the silos because of the dose rates from the waste inside the intact silos. The dose rates from the intact silos are modeled using the Microshield computer code for a variety of receptor distances. The corresponding risks are estimated for this scenario using the exposure parameter values and risk characterization methodology for the external radiation pathway. The risks to the trespassing child range from zero (the modeled dose rate is indistinguishable from background) at a location at the base of the K-65 berm to 5×10^{-3} at a location on top of the Silo 1 or 2 dome. The risk at a location immediately adjacent to the wall of Silo 3 is 4×10^{-5}.

Chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include beryllium; the ILCR for arsenic is greater than 1×10^{-4}. The total ILCR for the chemical carcinogens for ingestion of and dermal contact with Silo 3 contents is 4×10^{-4}, attributable largely to arsenic. For the noncarcinogenic effects, HI values for all chemicals are below 1 except for arsenic, selenium, and uranium. The total HI is 1×10^{1}. Target organs with HI values equal to or greater than 1×10^{0} include the kidney (HI = 5×10^{0}), attributable almost entirely to uranium, and the skin (HI = 8×10^{0}), attributable largely to arsenic and selenium.

TABLE D.5-2

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE TRESPASSING CHILD FROM RADIONUCLIDES AND CHEMICALS IN SILO 3 CONTENTS UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Silo 3 Contents	
Radionuclides	ILCR
Ac-227 + 7 dtrs	1.9×10^{-4}
Pa-231	8.2×10^{-5}
Pb-210 + 2 dtrs	4.7×10^{-5}
Ra-226 + 5 dtrs	6.6×10^{-3}
Ra-228 + 1 dtr	3.4×10^{-4}
Th-228 + 7 dtrs	2.1×10^{-3}
Th-230	1.2×10^{-5}
Th-232	2.0×10^{-7}
U-234	5.0×10^{-7}
U-235 + 1 dtr	8.2×10^{-6}
U-238 + 2 dtrs	1.9×10^{-5}
TOTAL ILCR	**9.4×10^{-3}**
Chemicals	ILCR
Arsenic	3.2×10^{-4}
Beryllium	5.6×10^{-5}
TOTAL ILCR	**3.8×10^{-4}**
Chemicals	Hazard Quotients
Antimony (CVS)[b]	1.3×10^{-2}
Arsenic (S)	3.5×10^{0}
Barium (CVS)	6.0×10^{-5}
Beryllium (ND)	1.5×10^{-2}
Cadmium (food) (K)	3.2×10^{-2}
Chromium (K)	2.1×10^{-1}
Cobalt (B)	1.1×10^{-1}
Manganese (CNS)	1.6×10^{-1}
Mercury (K)	2.1×10^{-5}

TABLE D.5-2
(Continued)

Silo 3 Contents	
Chemicals	Hazard Quotients
Nickel (CNS)	5.6×10^{-1}
Selenium (S)	4.9×10^{0}
Silver (S)	9.6×10^{-3}
Thallium (CNS)	2.0×10^{-1}
Uranium (K)	4.6×10^{0}
Vanadium (ND)	1.7×10^{-1}
Zinc (B)	1.9×10^{-3}
TOTAL HI	**1.4×10^{1}**
Total for S[c]	8.4×10^{0}
Total for K[e]	4.8×10^{0}

[a]Radionuclide pathways include incidental ingestion of silo contents and external radiation exposure from silo contents following silo structural failure and release of silo contents. Chemical pathways include incidental ingestion of silo contents and dermal contact with silo contents following silo structural failure and release of silo contents.
[b]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^{0}$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
K: Target organ = kidney
ND: Target organ = not determined
S: Target organ = skin

Table D.5-3 presents the results for ingestion of and dermal contact with surface water.

Radiological exposure includes ingestion of surface water while in Paddys Run. The risks from this pathway under current conditions with the silos intact range from 1×10^{-13} (Th-232) to 6×10^{-9} (U-238 plus progeny). The radiological risk sum with the silos intact is approximately 8×10^{-9}. The risks from this pathway under conditions in which the silos suffer structural failure range from 7×10^{-11} (Th-232) to 1×10^{-6} (U-238 plus progeny). The sum of the radiological risks for this pathway assuming structural failure of the silos is 2×10^{-6}.

No chemical has an ILCR greater than 1×10^{-6} under either current conditions (Silo 3 intact) or future conditions (Silo 3 structural failure). The total ILCR for the chemical carcinogens for ingestion of and dermal contact with surface water in Paddys Run is 9×10^{-8} for current conditions (Silo 3 intact), and 5×10^{-7} for future conditions (Silo 3 structural failure). No chemical has an HI greater than 1 under either current conditions (Silo 3 intact) or future conditions (Silo 3 structural failure). The total HI for noncancer toxicity for current conditions (Silo 3 intact) is 4×10^{-1} and for future conditions (Silo 3 structural failure) is 9×10^{-1}.

Table D.5-4 presents the results for ingestion of sediment and dermal contact with sediment contaminated by the chemicals which gained access to perched water from leachate B (assuming structural failure of the silos).

Radiological exposure includes ingestion of sediment while in Paddys Run. This pathway addresses the potential impact of perched water in the sand lens beneath the silos on sediment in Paddys Run assuming that this water seeps from the sand lens directly into the streambed. Sediment exposure point concentrations are conservatively estimated based on transport modeling from the silo waste source terms. The risks from this pathway range from 3×10^{-18} (Th-232) to 2×10^{-1} (Pb-210 plus progeny). Assuming structural failure of the silos, the sum of radiological risks is 2×10^{-1}.

The only chemical carcinogen with an ILCR greater than 1×10^{-6} is arsenic. No chemical carcinogen results in an ILCR greater than 1×10^{-4}. The total ILCR for the chemical carcinogens for ingestion of and dermal contact with sediment in Paddys Run is 5×10^{-6}, attributable almost entirely to arsenic. For noncancer effects, no chemicals have an HI greater than 1, and the total HI is 3×10^{-1}.

Table D.5-5 presents the results for inhalation of VOCs, fugitive dust and radon.

Radiological exposure includes inhalation of resuspended particulates and radon emissions. Particulates are assumed to be eroded from soil in the Operable Unit 4 Study Area and from Silo 3 waste following silo structural failure. Radon is assumed to be emitted from all of the silos under

TABLE D.5-3

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE TRESPASSING CHILD FROM RADIONUCLIDES AND CHEMICALS IN SURFACE WATER UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	3.1×10^{-11}
Ra-226 + 5 dtrs	3.6×10^{-11}
Ra-228 + 1 dtr	5.7×10^{-12}
Sr-90 + 1 dtr	1.7×10^{-10}
Tc-99	1.8×10^{-10}
Th-230	3.2×10^{-13}
Th-232	1.0×10^{-13}
U-234	9.4×10^{-10}
U-238 + 2 dtrs	6.3×10^{-9}
TOTAL ILCR	**7.7×10^{-9}**
Chemicals	ILCR
Aroclor-1254	2.3×10^{-10}
Benzo(a)anthracene	8.7×10^{-9}
Benzo(a)pyrene	6.8×10^{-8}
Benzo(b)fluoranthene	9.2×10^{-10}
Beryllium	5.9×10^{-11}
bis(2-Ethylhexyl)phthalate	5.7×10^{-12}
Chrysene	7.7×10^{-9}
Dibenzo(a,h)anthracene	3.1×10^{-9}
Indeno(1,2,3-cd)pyrene	1.5×10^{-9}
Methylene chloride	2.1×10^{-11}
TOTAL ILCR	**9.0×10^{-8}**
Chemicals	Hazard Quotients
2-Butanone	1.5×10^{-7}
4-Methyl-2-pentanone	2.4×10^{-8}
Acetone	6.7×10^{-7}

TABLE D.5-3
(Continued)

Soil[b]	
Chemicals	Hazard Quotients
Anthracene	1.0×10^{-7}
Antimony	8.4×10^{-5}
Benzoic acid	7.0×10^{-9}
Beryllium	8.7×10^{-8}
bis(2-Ethylhexyl)phthalate	1.3×10^{-7}
Cadmium (food)	7.3×10^{-6}
Cadmium (water)	1.5×10^{-6}
Chromium	1.8×10^{-6}
Di-n-butylphthalate	3.3×10^{-8}
Fluoranthene	5.4×10^{-7}
Methylene chloride	2.8×10^{-7}
Nickel	1.6×10^{-6}
Phenol	2.9×10^{-7}
Pyrene	4.1×10^{-7}
Silver	7.3×10^{-6}
Thallium	4.3×10^{-7}
Toluene	1.2×10^{-8}
Total xylenes	9.0×10^{-10}
Uranium	3.6×10^{-1}
TOTAL HI	**3.6×10^{-1}**

Silo 3 Contents[c]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	4.1×10^{-9}
Pa-231	1.1×10^{-9}
Pb-210 + 2 dtrs	3.7×10^{-8}
Ra-226 + 5 dtrs	2.3×10^{-8}
Ra-228 + 1 dtr	2.1×10^{-9}
Th-228 + 7 dtrs	4.6×10^{-10}
Th-230	4.6×10^{-9}

TABLE D.5-3
(Continued)

Silo 3 Contents[c]	
Radionuclides	ILCR
Th-232	7.2×10^{-11}
U-234	6.0×10^{-7}
U-235 + 1 dtr	3.6×10^{-8}
U-238 + 2 dtrs	9.7×10^{-7}
TOTAL ILCR	**1.7×10^{-6}**
Chemicals	ILCR
Arsenic	5.1×10^{-7}
Beryllium	1.6×10^{-8}
TOTAL ILCR	**5.3×10^{-7}**
Chemicals	Hazard Quotients
Antimony	1.8×10^{-5}
Arsenic	5.7×10^{-3}
Barium	3.0×10^{-6}
Beryllium	4.2×10^{-6}
Cadmium (food)	1.8×10^{-4}
Cadmium (water)	3.6×10^{-4}
Chromium	4.9×10^{-5}
Cobalt	8.4×10^{-5}
Manganese	3.3×10^{-4}
Mercury	5.3×10^{-4}
Nickel	3.2×10^{-4}
Selenium	4.5×10^{-6}
Silver	1.9×10^{-5}
Thallium	3.8×10^{-5}
Uranium	9.2×10^{-1}
Vanadium	4.6×10^{-4}
Zinc	2.8×10^{-7}
TOTAL HI	**9.3×10^{-1}**

TABLE D.5-3
(Continued)

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[a]Radionuclide pathways include ingestion of surface water in Paddys Run. Chemical pathways include ingestion and dermal contact with surface water in Paddys Run.
[b]Surface water contaminated by runoff from surface soil and berm fill (Silo 3 intact).
[c]Surface water contaminated by runoff from Silo 3 contents, following silo structural failure.

TABLE D.5-4

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE TRESPASSING CHILD FROM RADIONUCLIDES AND CHEMICALS IN SEDIMENT UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Sediment	
Radionuclides	ILCR
Ac-227 + 7 dtrs	3.7×10^{-7}
Pa-231	7.5×10^{-8}
Pb-210 + 2 dtrs	2.3×10^{-1}
Ra-226 + 5 dtrs	4.4×10^{-7}
Ra-228 + 1 dtr	3.8×10^{-8}
Th-228 + 7 dtrs[b]	1.8×10^{-8}
Th-232	2.9×10^{-18}
U-234	4.6×10^{-12}
U-235 + 1 dtr	2.0×10^{-13}
U-238 + 2 dtrs	7.5×10^{-12}
TOTAL ILCR	**2.3×10^{-1}**
Chemicals	ILCR
Arsenic	5.3×10^{-6}
Beryllium	1.7×10^{-8}
TOTAL ILCR	**5.3×10^{-6}**
Chemicals	Hazard Quotients
Antimony	3.1×10^{-4}
Arsenic	5.9×10^{-2}
Barium	5.5×10^{-7}
Beryllium	4.6×10^{-6}
Boron	1.7×10^{-7}
Chromium	1.4×10^{-6}
Cobalt	8.8×10^{-3}
Manganese	4.8×10^{-7}
Mercury	3.6×10^{-6}
Molybdenum	2.8×10^{-6}

TABLE D.5-4
(Continued)

Sediment	
Chemicals	Hazard Quotients
Nickel	1.6×10^{-3}
Selenium	2.4×10^{-3}
Silver	3.6×10^{-5}
Thallium	3.6×10^{-2}
Uranium	4.4×10^{-5}
Vanadium	1.6×10^{-1}
Zinc	3.5×10^{-6}
TOTAL HI	**2.7×10^{-1}**

[a]Radionuclide pathways include ingestion of sediment in Paddys Run. Chemical pathways include ingestion and dermal contact with sediment in Paddys Run.
[b]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 concentration.

TABLE D.5-5

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE TRESPASSING CHILD FROM RADIONUCLIDES AND CHEMICALS IN AIR UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	1.1×10^{-9}
Ra-226 + 5 dtrs	3.8×10^{-9}
Ra-228 + 1 dtr	3.4×10^{-10}
Rn-222 + 4 dtrs	2.6×10^{-6}
Sr-90 + 1 dtr	4.5×10^{-11}
Tc-99	3.1×10^{-12}
Th-228 + 7 dtrs	5.3×10^{-9} [c]
Th-230	6.6×10^{-8}
Th-232	2.5×10^{-9}
U-234	4.0×10^{-8}
U-238 + 2 dtrs	2.8×10^{-7}
TOTAL ILCR	**3.0×10^{-6}**
Chemicals	ILCR
Benzo(a)anthracene	1.3×10^{-9}
Benzo(a)pyrene	1.1×10^{-9}
Benzo(b)fluoranthene	1.7×10^{-9}
Beryllium	3.0×10^{-9}
Cadmium	1.4×10^{-8}
Chromium	3.5×10^{-7}
Chrysene	1.2×10^{-9}
Dibenzo(a,h)anthracene	7.4×10^{-10}
Indeno(1,2,3-c,d)pyrene	1.3×10^{-9}
Methylene chloride	1.2×10^{-14}
Nickel	1.1×10^{-8}
TOTAL ILCR	**3.9×10^{-7}**

TABLE D.5-5
(Continued)

Soil[b]	
Chemicals	Hazard Quotients
2-Butanone	3.7×10^{-11}
Methylene chloride	5.1×10^{-11}
Toluene	5.0×10^{-10}
TOTAL HI	**5.9×10^{-10}**
Silo 3 Contents[d]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	1.8×10^{-5}
Pa-231	1.1×10^{-5}
Pb-210 + 2 dtrs	6.4×10^{-6}
Ra-226 + 5 dtrs	3.9×10^{-6}
Ra-228 + 1 dtr	9.2×10^{-8}
Rn-222 + 4 dtrs	8.6×10^{-5}
Sr-90 + 1 dtr	4.2×10^{-11}
Tc-99	2.7×10^{-12}
Th-228 + 7 dtrs	2.2×10^{-5}
Th-230	5.9×10^{-4}
Th-232	8.1×10^{-6}
U-234	1.7×10^{-5}
U-235 + 1 dtr	9.9×10^{-7}
U-238 + 2 dtrs	3.2×10^{-5}
TOTAL ILCR	**8.0×10^{-4}**
Chemicals	ILCR
Arsenic	1.5×10^{-5}
Benzo(a)anthracene	1.2×10^{-9}
Benzo(a)pyrene	9.9×10^{-10}
Benzo(b)fluoranthene	1.6×10^{-9}
Beryllium	7.7×10^{-8}
Cadmium	1.9×10^{-7}
Chromium	5.1×10^{-6}

TABLE D.5-5
(Continued)

Silo 3 Contents[d]	
Chemicals	ILCR
Chrysene	1.1×10^{-9}
Dibenzo(a,h)anthracene	6.8×10^{-10}
Indeno(1,2,3-c,d)pyrene	1.2×10^{-9}
Methylene chloride	1.2×10^{-14}
Nickel	1.1×10^{-6}
TOTAL ILCR	**2.1×10^{-5}**
Chemicals	Hazard Quotients
2-Butanone (R)[e]	3.7×10^{-11}
Barium (R)	3.3×10^{-3}
Cobalt (R)	1.7×10^{1}
Manganese (CNS)	8.4×10^{-2}
Mercury (K)	1.4×10^{-5}
Methylene chloride (L)	5.1×10^{-11}
Toluene (CNS)	5.0×10^{-10}
TOTAL HI	**1.7×10^{1}**
Total HI for R	1.7×10^{1}

[a]Radionuclide pathways include inhalation of fugitive dust and radon. Chemical pathways include inhalation of fugitive dust and VOCs.
[b]Air contaminated by volatilization or fugitive dust from surface soil and berm fill (Silo 3 intact).
[c]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d]Air contaminated by volatilization or fugitive dust from Silo 3 contents (Silo-3 structural failure).
[e]Target organ information for inhalation exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^{0}$ are presented.

CNS: Target organ = central nervous system
K: Target organ = kidney
L: Target organ = liver
R: Target organ = respiratory system

existing conditions and assuming silo structural failure. Under existing conditions with the silos intact the risks from inhalation of resuspended particulates from soil and radon from the silos range from 3×10^{-12} (Tc-99) to 3×10^{-6} (Rn-222 plus progeny). With the silos intact the radiological risk sum is 3×10^{-6}. Under conditions in which the silos suffer structural failure risks range from 3×10^{-12} (Tc-99) to 6×10^{-4} (Th-230). Radionuclides for which the risk exceeds 1×10^{-6} under existing conditions with the silos intact include only Rn-222 plus progeny. Radionuclides for which the risk exceeds 1×10^{-6} under conditions assuming silo structural failure include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Rn-222 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, and U-238 plus progeny. The radiological risk sum for this pathway considering silo structural failure is calculated to be approximately 8×10^{-4}.

Under current conditions (Silo 3 intact), no chemical carcinogens result in ILCR values greater than 1×10^{-6}. The total ILCR for the chemical carcinogens for inhalation of resuspended dust and volatiles under current conditions is 4×10^{-7}. Under future conditions, (Silo 3 structural failure), arsenic, chromium and nickel result in ILCR values between 1×10^{-6} and 1×10^{-4}. No chemical carcinogens have an ILCR greater than 1×10^{-4}. The total ILCR for chemical carcinogens for future conditions is 2×10^{-5}. Virtually all of the cancer risk arises from direct inhalation of fugitive dust.

Under current conditions (Silo 3 intact), no chemicals result in HI values of 1 or greater and the total HI is 6×10^{-10}. Under future conditions (Silo 3 structural failure), only cobalt results in an HI greater than 1. The total HI is 2×10^{1}, attributable almost entirely to cobalt. Target organs with HI values equal to or greater than 1×10^{0} are limited to the respiratory system (HI = 2×10^{1}), attributable almost entirely to cobalt.

D.5.3.1.2 Groundskeeper Worker

This section presents the ILCR and HI results for radionuclide and chemical COCs for the groundskeeper worker under current land use. Because the presence or absence of access controls would have no effect on exposure frequency, duration or pathways, the groundskeeper worker was evaluated only once, under the scenario without access controls.

Table D.5-6 presents the results for ingestion of and dermal contact with soil, and external radiation exposure from soil. This scenario assumes that current conditions prevail, i.e., Silo 3 remains structurally intact.

Radiological exposure pathways include ingestion of soil, and exposure to penetrating external radiation from contaminated soil. The risks from the soil ingestion and external radiation pathways combined range from 5×10^{-11} (Tc-99) to 3×10^{-5} (Ra-226 + 5 daughters). The dominant contribution is from external radiation exposure to soil contaminated by Ra-226 and its five short-lived

TABLE D.5-6

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE GROUNDSKEEPER WORKER FROM RADIONUCLIDES AND CHEMICALS IN SOIL UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil	
Radionuclides	ILCR
Pb-210 + 2 dtrs	1.2×10^{-7}
Ra-226 + 5 dtrs	2.8×10^{-5}
Ra-228 + 1 dtr	2.5×10^{-6}
Sr-90 + 1 dtr	2.1×10^{-9}
Tc-99	4.7×10^{-11}
Th-230	2.5×10^{-9}
Th-232	7.7×10^{-10}
U-234	2.3×10^{-9}
U-238 + 2 dtrs	3.6×10^{-7}
TOTAL ILCR	**3.1×10^{-5}**
Chemicals	ILCR
Aroclor-1254	8.1×10^{-8}
Benzo(a)anthracene	1.7×10^{-5}
Benzo(a)pyrene	2.1×10^{-5}
Benzo(b)fluoranthene	4.4×10^{-6}
Beryllium	1.9×10^{-6}
bis(2-Ethylhexyl)phthalate	1.5×10^{-8}
Chrysene	1.6×10^{-5}
Dibenzo(a,h)anthracene	1.2×10^{-5}
Indeno(1,2,3-cd)pyrene	1.8×10^{-6}
Methylene chloride	1.5×10^{-10}
TOTAL ILCR	**7.1×10^{-5}**

TABLE D.5-6
(Continued)

Soil	
Chemicals	Hazard Quotients
2-Butanone	1.0×10^{-6}
4-Methyl-2-pentanone	4.6×10^{-7}
Acetone	4.6×10^{-6}
Anthracene	5.9×10^{-6}
Antimony	3.8×10^{-2}
Benzoic acid	1.1×10^{-7}
Beryllium	2.4×10^{-4}
bis(2-Ethylhexyl)phthalate	1.5×10^{-4}
Cadmium (food)	1.1×10^{-3}
Chromium	5.9×10^{-3}
Di-n-butylphthalate	1.5×10^{-5}
Fluoranthene	1.7×10^{-4}
Methylene chloride	9.4×10^{-7}
Molybdenum	2.9×10^{-4}
Nickel	2.2×10^{-3}
Phenol	2.9×10^{-6}
Pyrene	1.2×10^{-4}
Silver	2.8×10^{-3}
Thallium	7.3×10^{-4}
Toluene	1.1×10^{-8}
Total xylenes	8.2×10^{-10}
Uranium	1.7×10^{-2}
Zinc	1.1×10^{-4}
TOTAL HI	**6.9×10^{-2}**

[a]Radionuclide pathways include incidental ingestion of soil and external radiation exposure from soil. Chemical pathways include incidental ingestion of soil and dermal contact with soil.

progeny (3×10^{-5}). Radionuclides for which the risk exceeds 1×10^{-6} include Ra-226 plus progeny and Ra-228 plus progeny. The risk sum for radiological constituents is 3×10^{-5}.

Chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include the carcinogenic PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene) and beryllium. The total ILCR for the chemical carcinogens for ingestion of and dermal contact with soil is 7×10^{-5}. For the noncarcinogenic effects, all HI values are below 1.0, and the total HI is 7×10^{-2}.

Table D.5-7 presents the results for ingestion of and dermal contact with silo contents, and external radiation exposure from silo contents, assuming structural failure of the silos.

Radiological exposure pathways include ingestion of waste and exposure to penetrating external radiation from contaminated waste. The risks from the ingestion and external radiation pathways combined range from 5×10^{-7} (Th-232) to 2×10^{-2} (Ra-226 + 5 daughters). The dominant contribution is from external radiation exposure to soil contaminated by Ra-226 and its five short-lived progeny (2×10^{-2}). Radionuclides for which the risk exceeds 1×10^{-6} include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Th-228 plus progeny, Th-230, U-234, U-235 plus progeny, and U-238 plus progeny. The radiological risk sum for this pathway is 3×10^{-2}.

Prior to structural failure of the silos the potential risks to the receptor from the dose rates from the intact silos range from zero (the modeled dose rate is indistinguishable from background) at a location at the base of the K-65 berm to 2×10^{-2} at a location on top of the Silo 1 or 2 dome. The risk at a location immediately adjacent to the wall of Silo 3 is 1×10^{-4}.

Chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include beryllium. The ILCR for arsenic is greater than 1×10^{-4}. The total ILCR for chemical carcinogens for ingestion of and dermal contact with silo contents is 5×10^{-4}. For the noncarcinogenic effects, HI values for arsenic and uranium are greater than 1, and the total HI is 6×10^{0}. Target organs with HI values equal to or greater than 1×10^{0} include the skin (HI = 2×10^{0}), primarily due to arsenic, and the kidney (HI = 3×10^{0}), attributable largely to uranium.

Table D.5-8 presents the results for inhalation of VOCs, fugitive dust, and radon.

Radiological exposure includes inhalation of resuspended particulates and radon emissions. Particulates are assumed to be eroded from soil in the Operable Unit 4 Study Area and from Silo 3 waste following silo structural failure. Radon is assumed to be emitted from all of the silos under existing conditions and assuming silo structural failure. Under existing conditions with the silos intact the risks

TABLE D.5-7

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE GROUNDSKEEPER WORKER FROM RADIONUCLIDES AND CHEMICALS IN SILO 3 CONTENTS UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Silo 3 Contents	
Radionuclides	ILCR
Ac-227 + 7 dtrs	5.5×10^{-4}
Pa-231	2.4×10^{-5}
Pb-210 + 2 dtrs	1.4×10^{-4}
Ra-226 + 5 dtrs	1.9×10^{-2}
Ra-228 + 1 dtr	9.4×10^{-4}
Th-228 + 7 dtrs	5.9×10^{-3}
Th-230	3.5×10^{-5}
Th-232	5.4×10^{-7}
U-234	1.3×10^{-6}
U-235 + 1 dtr	2.3×10^{-5}
U-238 + 2 dtrs	5.4×10^{-5}
TOTAL ILCR	**2.7×10^{-2}**
Chemicals	ILCR
Arsenic	4.1×10^{-4}
Beryllium	6.4×10^{-5}
TOTAL ILCR	**4.7×10^{-4}**
Chemicals	Hazard Quotients
Antimony (CVS)[b]	7.2×10^{-3}
Arsenic (S)	2.2×10^{0}
Barium (CVS)	5.3×10^{-3}
Beryllium (ND)	8.4×10^{-3}
Cadmium (food) (K)	1.9×10^{-2}
Chromium (K)	1.1×10^{-1}
Cobalt (B)	6.9×10^{-2}
Manganese (CNS)	8.7×10^{-2}
Mercury (K)	8.0×10^{-3}

TABLE D.5-7
(Continued)

Silo 3 Contents	
Chemicals	Hazard Quotients
Nickel (CNS)	3.1×10^{-1}
Selenium (S)	7.1×10^{-3}
Silver (S)	5.3×10^{-3}
Thallium (CNS)	1.3×10^{-1}
Uranium (K)	2.6×10^{0}
Vanadium (ND)	7.2×10^{-1}
Zinc (B)	1.1×10^{-3}
TOTAL HI	**6.3×10^{0}**
Total HI for S	2.2×10^{0}
Total HI for K	2.7×10^{0}

[a]Radionuclide pathways include incidental ingestion of silo contents and external radiation exposure from silo contents following silo structural failure and release of silo contents. Chemical pathways include incidental ingestion of silo contents and dermal contact with silo contents following silo structural failure and release of silo contents.
[b]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^{0}$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
K: Target organ = kidney
ND: Target organ = not determined
S: Target organ = skin

TABLE D.5-8

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE GROUNDSKEEPER WORKER FROM RADIONUCLIDES AND CHEMICALS IN AIR UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	3.0×10^{-9}
Ra-226 + 5 dtrs	1.0×10^{-8}
Ra-228 + 1 dtr	9.6×10^{-10}
Rn-222 + 4 dtrs	7.2×10^{-6}
Sr-90 + 1 dtr	1.3×10^{-10}
Tc-99	8.6×10^{-12}
Th-228 + 7 dtrs[c]	1.5×10^{-8}
Th-230	1.9×10^{-7}
Th-232	6.9×10^{-9}
U-234	1.1×10^{-7}
U-238 + 2 dtrs	7.5×10^{-7}
TOTAL ILCR	**8.3×10^{-6}**
Chemicals	ILCR
Benzo(a)anthracene	2.2×10^{-9}
Benzo(a)pyrene	1.9×10^{-9}
Benzo(b)fluoranthene	3.0×10^{-9}
Beryllium	5.2×10^{-9}
Cadmium	2.5×10^{-8}
Chromium	5.9×10^{-7}
Chrysene	2.0×10^{-9}
Dibenzo(a,h)anthracene	1.3×10^{-9}
Indeno(1,2,3-c,d)pyrene	2.2×10^{-9}
Methylene chloride	2.1×10^{-14}
Nickel	1.9×10^{-8}
TOTAL ILCR	**6.5×10^{-7}**

TABLE D.5-8
(Continued)

Soil[b]	
Chemicals	Hazard Quotients
2-Butanone	3.0×10^{-11}
Methylene chloride	4.2×10^{-11}
Toluene	4.1×10^{-10}
TOTAL HI	**4.8×10^{-10}**
Silo 3 Contents[d]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	5.1×10^{-5}
Pa-231	3.1×10^{-5}
Pb-210 + 2 dtrs	1.8×10^{-5}
Ra-226 + 5 dtrs	1.1×10^{-5}
Ra-228 + 1 dtr	2.6×10^{-7}
Rn-222 + 4 dtrs	2.4×10^{-4}
Sr-90 + 1 dtr	1.2×10^{-10}
Tc-99	7.7×10^{-12}
Th-228 + 7 dtrs	6.3×10^{-5}
Th-230	1.7×10^{-3}
Th-232	2.2×10^{-5}
U-234	4.8×10^{-5}
U-235 + 1 dtr	2.8×10^{-6}
U-238 + 2 dtrs	8.7×10^{-5}
TOTAL ILCR	**2.3×10^{-3}**
Chemicals	ILCR
Arsenic	2.5×10^{-5}
Benzo(a)anthracene	2.0×10^{-9}
Benzo(a)pyrene	1.7×10^{-9}
Benzo(b)fluoranthene	2.7×10^{-9}
Beryllium	1.3×10^{-7}
Cadmium	3.3×10^{-7}
Chromium	8.7×10^{-6}

TABLE D.5-8
(Continued)

Silo 3 Contents[d]	
Chemicals	ILCR
Chrysene	1.8×10^{-9}
Dibenzo(a,h)anthracene	1.2×10^{-9}
Indeno(1,2,3-c,d)pylene	2.0×10^{-9}
Methylene chloride	2.1×10^{-14}
Nickel	1.9×10^{-6}
TOTAL ILCR	**3.6×10^{-5}**
Chemicals	Hazard Quotients
2-Butanone (R)[e]	3.0×10^{-11}
Barium (R)	2.7×10^{-3}
Cobalt (R)	1.4×10^{1}
Manganese (CNS)	6.9×10^{-2}
Mercury (K)	1.2×10^{-5}
Methylene chloride (L)	4.2×10^{-11}
Toluene (CNS)	4.1×10^{-10}
TOTAL HI	**1.4×10^{1}**
TOTAL HI for R	1.4×10^{1}

[a]Radionuclide pathways include inhalation of fugitive dust and radon. Chemical pathways include inhalation of fugitive dust and VOCs.
[b]Air contaminated by volatilization or fugitive dust from surface soil and berm fill (Silo 3 intact).
[c]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d]Air contaminated by volatilization or fugitive dust from Silo 3 contents (Silo-3 structural failure).
[e]Target organ information for inhalation exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^{0}$ are presented.

CNS: Target organ = central nervous system
K: Target organ = kidney
L: Target organ = liver
R: Target organ = respiratory system

from inhalation of resuspended particulates from soil and radon from the silos range from 9×10^{-12} (Tc-99) to 7×10^{-6} (Rn-222 plus progeny). The risk sum for radionuclides assuming the silos remain intact is 8×10^{-6}. Under conditions in which the silos suffer structural failure risks range from 8×10^{-12} (Tc-99) to 2×10^{-3} (Th-230). Assuming silo structural failure, the radiological risk sum is approximately 2×10^{-3}. Radionuclides for which the risk exceeds 1×10^{-6} under existing conditions with the silos intact include only Rn-222 plus progeny. Radionuclides for which the risk exceeds 1×10^{-6} under conditions assuming silo structural failure include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Rn-222 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, U-235 plus progeny, and U-238 plus progeny.

Under current conditions (Silo 3 intact), no chemical carcinogens result in ILCR values greater than 1×10^{-6}. The total ILCR is 7×10^{-7}. Under future conditions (Silo 3 structural failure), arsenic, chromium and nickel result in ILCR values between 1×10^{-6} and 1×10^{-4}. No chemical carcinogens result in ILCR values greater than 1×10^{-4}. The total ILCR is 4×10^{-5}. Virtually all of the cancer risk arises from direct inhalation of fugitive dust.

Under current conditions (Silo 3 intact) no chemical results in HI values greater than 1, and the total HI is 5×10^{-10}. Under future conditions (Silo 3 structural failure), cobalt results in an HI greater than 1. The total HI is 1×10^{1}. Target organs with HI values equal to or greater than 1×10^{0} are limited to the respiratory system (HI = 1×10^{1}), attributable almost entirely to cobalt.

D.5.3.1.3 Off-Property Resident Farmer

This section presents the ILCR and HI results for radionuclide and chemical COCs for the off-property resident farmer under current land use. (As noted in Section D.5.3.2.4, the results for the off-property farmer under the current and future land use scenarios are identical.) Because the presence or absence of access controls would have no effect on exposure frequency, duration or pathways, the off-property resident farmer was evaluated only without access controls.

Table D.5-9 presents the results for ingestion of drinking water, dermal exposure to water while bathing, inhalation of VOCs, and ingestion of vegetables, milk and meat, modeled from the impact of silo contents on groundwater from the underlying aquifer (assuming structural failure of the three silos).

Radiological exposure pathways include ingestion of contaminated groundwater as drinking water, ingestion of fruits and vegetables irrigated with contaminated groundwater, and ingestion of meat and milk from cattle raised on contaminated water and feed irrigated with contaminated groundwater. The risks from these exposure pathways are 4×10^{-6} (U-234), 4×10^{-7} (U-235 plus progeny), and 6×10^{-6} (U-238 plus progeny). The sum of radiological risks is 1×10^{-5}.

TABLE D.5-9

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE OFF-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN GROUNDWATER UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Groundwater	
Radionuclides	ILCR
U-234	4.1×10^{-6}
U-235 + 1 dtr	3.5×10^{-7}
U-238 + 2 dtrs	6.3×10^{-6}
TOTAL ILCR	**1.1×10^{-5}**
Chemical	Hazard Quotients
Uranium	1.2×10^{-1}
TOTAL HI	**1.2×10^{-1}**

[a]Radionuclide pathways include ingestion of groundwater as drinking water, ingestion of fruits and vegetables irrigated with groundwater, and ingestion of meat and milk from cattle drinking groundwater and eating feed crops irrigated with groundwater. Chemical pathways are the same as radionuclide pathways plus dermal contact with groundwater while bathing, and inhalation of VOCs from home water use.

No chemical carcinogens were identified as COCs in the groundwater; therefore, no chemical ILCR was calculated. Regarding noncancer effects, no chemical results in an HI greater than 1 (uranium, HI = 1×10^{-1}, is the only COC considered in the evaluation).

Table D.5-10 presents the results for inhalation of VOCs, fugitive dust and radon, and for ingestion of fruits and vegetables, milk and meat contaminated by pathways involving air deposition. The source of the airborne contaminants for current conditions (Silo 3 intact) is soil, and for future conditions (Silo 3 structural failure) is soil and silo contents.

Radiological exposure includes inhalation of resuspended particulates and radon emissions, ingestion of fruits and vegetables subject to contamination by air deposition on crops, and ingestion of meat and milk from cattle raised on feed subject to contamination by air deposition on feed crops. These exposure pathways are evaluated under existing conditions with the silos intact and under conditions assuming silo structural failure occurs allowing the Silo 3 waste to spread out in the Operable Unit 4 Study Area. Particulates are assumed to be eroded from soil in the Operable Unit 4 Study Area and from Silo 3 waste following silo structural failure. Radon is assumed to be emitted from all of the silos under existing conditions and assuming silo structural failure. Under existing conditions with the silos intact the risks from the inhalation and ingestion pathways subject to air deposition range from 5×10^{-9} (Ra-228 plus progeny) to 2×10^{-6} (Rn-222 plus progeny). With the silos intact the radiological risk sum from these pathways is 4×10^{-6}. Under conditions in which the silos suffer structural failure risks range from 2×10^{-8} (Tc-99 or Sr-90 plus progeny) to 2×10^{-3} (Th-230). Radionuclides for which the risk exceeds 1×10^{-6} under existing conditions with the silos intact include Rn-222 plus progeny and U-238 plus progeny. Radionuclides for which the risk exceeds 1×10^{-6} under conditions assuming silo structural failure include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Rn-222 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, U-235 plus progeny, and U-238 plus progeny. Assuming silo structural failure, the radiological risk sum is calculated to be 2×10^{-3}.

Under current conditions (Silo 3 intact), no chemical carcinogens result in ILCR values greater than 1×10^{-6}. The total ILCR is 1×10^{-6}. Under future conditions (Silo 3 structural failure), chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include arsenic, chromium, and nickel. No chemical carcinogen results in an ILCR greater than 1×10^{-4}. The total ILCR is 4×10^{-5}. Virtually all of the cancer risk arises from direct inhalation of fugitive dust.

Under current conditions (Silo 3 intact) no chemicals have HI values greater than 1. The total HI is 1×10^{-9}. Under future conditions (Silo 3 structural failure), cobalt has an HI greater than 1. The total HI is 5×10^{0}. Target organs with HI values equal to or greater than 1×10^{0} are limited to the respiratory system (HI = 5×10^{0}), attributable almost entirely to cobalt.

TABLE D.5-10

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE OFF-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN AIR UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	1.5×10^{-8}
Ra-226 + 5 dtrs	2.6×10^{-8}
Ra-228 + 1 dtr	4.6×10^{-9}
Rn-222 + 4 dtrs	2.3×10^{-6}
Sr-90 + 1 dtr	3.0×10^{-8}
Tc-99	2.2×10^{-8}
Th-228 + 7 dtrs[c]	1.8×10^{-8}
Th-230	2.8×10^{-7}
Th-232	9.9×10^{-9}
U-234	1.7×10^{-7}
U-238 + 2 dtrs	1.2×10^{-6}
TOTAL ILCR	**4.1×10^{-6}**
Chemicals	ILCR
Benzo(a)anthracene	3.2×10^{-9}
Benzo(a)pyrene	2.9×10^{-9}
Benzo(b)fluoranthene	4.4×10^{-9}
Beryllium	8.2×10^{-9}
Chrysene	3.2×10^{-9}
Cadmium	3.8×10^{-8}
Dibenzo(a,h)anthracene	2.0×10^{-9}
Chromium	9.1×10^{-7}
Indeno(1,2,3-c,d)pyrene	3.6×10^{-9}
Nickel	2.9×10^{-8}
TOTAL ILCR	**9.7×10^{-7}**

TABLE D.5-10
(Continued)

Soil[b]	
Chemicals	Hazard Quotients
Beryllium	2.9×10^{-12}
Cadmium	1.1×10^{-9}
Chromium	9.2×10^{-11}
Nickel	1.1×10^{-10}
TOTAL HI	**1.3×10^{-9}**
Silo 3 Contents[d]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	5.3×10^{-5}
Pa-231	3.1×10^{-5}
Pb-210 + 2 dtrs	6.3×10^{-5}
Ra-226 + 5 dtrs	1.7×10^{-5}
Ra-228 + 1 dtr	7.7×10^{-7}
Rn-222 + 4 dtrs	2.3×10^{-4}
Sr-90 + 1 dtr	2.1×10^{-8}
Tc-99	1.6×10^{-8}
Th-228 + 7 dtrs	6.2×10^{-5}
Th-230	1.6×10^{-3}
Th-232	2.3×10^{-5}
U-234	4.5×10^{-5}
U-235 + 1 dtr	2.6×10^{-6}
U-238 + 2 dtrs	8.5×10^{-5}
TOTAL ILCR	**2.2×10^{-3}**
Chemicals	ILCR
Arsenic	2.4×10^{-5}
Benzo(a)anthracene	2.4×10^{-9}
Benzo(a)pyrene	2.1×10^{-9}
Benzo(b)fluoranthene	3.2×10^{-9}
Beryllium	1.3×10^{-7}
Cadmium	3.3×10^{-7}

TABLE D.5-10
(Continued)

Silo 3 Contents[d]	
Chemicals	ILCR
Chromium	9.0×10^{-6}
Chrysene	2.4×10^{-9}
Dibenzo(a,h)anthracene	1.6×10^{-9}
Indeno(1,2,3-c,d)pyrene	2.4×10^{-9}
Nickel	1.8×10^{-6}
TOTAL ILCR	**3.5×10^{-5}**
Chemicals	Hazard Quotients
Antimony (R)[e]	1.6×10^{-10}
Arsenic (S)	5.1×10^{-8}
Barium (R)	9.3×10^{-4}
Beryllium (R)	1.9×10^{-11}
Cadmium (K)	4.6×10^{-9}
Chromium (R)	5.0×10^{-10}
Cobalt (R)	4.8×10^{0}
Manganese (CNS)	2.4×10^{-2}
Mercury (K)	3.8×10^{-6}
Nickel (R)	3.5×10^{-9}
Selenium (S)	7.5×10^{-10}
Silver (ND)	8.2×10^{-10}
Thallium (CNS)	1.2×10^{-8}
Vanadium (R)	1.8×10^{-9}
Zinc (R)	2.7×10^{-9}
TOTAL HI	**4.8×10^{0}**
Total HI for R	4.8×10^{0}

TABLE D.5-10
(Continued)

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[a]Radionuclide and chemical pathways include inhalation of fugitive dust, VOCs, and radon, and ingestion of fruits and vegetables and meat and milk from cattle subject to air deposition of contaminants on food and feed crops.
[b]Air contaminated by volatilization of fugitive dust from surface soil and berm fill (Silo 3 intact).
[c]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d]Air contaminated by volatilization or fugitive dust from Silo 3 contents (Silo 3 structural failure).
[e]Target organ information is provided for inhalation exposure for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

CNS: Target organ = central nervous system
K: Target organ = kidney
ND: Target organ = not determined
R: Target organ = respiratory system
S: Target organ = skin

D.5.3.1.4 Off-Property User of Surface Water

This section presents the ILCR and HI results for radionuclide and chemical COCs for the off-property user of surface water under the current land use scenario. (As noted in Section D.5.3.2.5, the results for the off-property user of surface water under the current and future land use scenarios are identical.) Since the presence or absence of access controls would have no effect on exposure frequency, duration or pathways, the off-property user of surface water was evaluated only once, in the scenario without access controls.

Table D.5-11 presents the results for ingestion of drinking water, dermal exposure to water while bathing, inhalation of VOCs, and ingestion of fruit and vegetables, milk, meat, and fish, modeled from the impact of soil (current conditions: Silo 3 intact) or Silo 3 contents (future conditions: Silo 3 structural failure) on surface water (the Great Miami River).

Radiological exposure pathways include ingestion of contaminated surface water from the river as drinking water, ingestion of fruits and vegetables irrigated with contaminated surface water, ingestion of meat and milk from cattle raised on contaminated surface water and feed irrigated with contaminated surface water, and ingestion of fish caught from the river. Under existing conditions in which the silos are intact the risks from these exposure pathways range from 2×10^{-13} (Th-232) to 3×10^{-8} (Tc-99). The sum of radiological risks is 4×10^{-8}. Under conditions assuming silo structural failure the risks from these exposure pathways range from 6×10^{-11} (Th-232) to 7×10^{-7} (U-238 plus progeny). The radiological risk sum under silo structural failure conditions is 1×10^{-6}.

Under both current conditions (Silo 3 intact) and future conditions (Silo 3 structural failure), no chemical carcinogens result in ILCR values of 1×10^{-6} or greater. The total ILCR is 1×10^{-9} for current conditions and 7×10^{-7} for future conditions.

Under both current conditions (Silo 3 intact) and future conditions (Silo 3 structural failure), no chemicals result in an HI value greater than 1. The total HI is 2×10^{-4} for current and 1×10^{-2} for future conditions.

D.5.3.2 Future Land Use

Risks are presented for both current conditions (i.e., the assumption that the silos remain intact, precluding direct contact with the silo contents) and future conditions (i.e., the assumption that the silos undergo structural failure, allowing direct contact with the silo contents as well as indirect contact such as escape of chemicals to the air, leaching to groundwater, or runoff into surface water). Future land use implies the absence of access controls.

TABLE D.5-11

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE OFF-PROPERTY USER OF SURFACE WATER FROM RADIONUCLIDES AND CHEMICALS IN SURFACE WATER UNDER CURRENT LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	7.7×10^{-11}
Ra-226 + 5 dtrs	7.0×10^{-11}
Ra-228 + 1 dtr	1.0×10^{-11}
Sr-90 + 1 dtr	1.0×10^{-9}
Tc-99	2.9×10^{-8}
Th-230	4.9×10^{-13}
Th-232	1.6×10^{-13}
U-234	1.3×10^{-9}
U-238 + 2 dtrs	8.8×10^{-9}
TOTAL ILCR	**4.0×10^{-8}**
Chemicals	ILCR
Aroclor-1254	9.5×10^{-13}
Benzo(a)anthracene	2.8×10^{-11}
Benzo(a)pyrene	2.5×10^{-10}
Benzo(b)fluoranthene	1.1×10^{-11}
Beryllium	7.2×10^{-11}
bis(2-Ethylhexyl)phthalate	5.3×10^{-14}
Chrysene	2.8×10^{-11}
Dibenzo(a,h)anthracene	1.1×10^{-11}
Indeno(1,2,3-cd)pyrene	4.3×10^{-10}
Methylene chloride	2.2×10^{-10}
TOTAL ILCR	**1.1×10^{-9}**
Chemicals	Hazard Quotients
2-Butanone	2.2×10^{-6}
4-Methyl-2-pentanone	1.4×10^{-7}

TABLE D.5-11
(Continued)

Soil[b]	
Chemicals	Hazard Quotients
Acetone	2.4×10^{-5}
Anthracene	7.1×10^{-11}
Antimony	8.9×10^{-6}
Benzoic acid	2.8×10^{-9}
Beryllium	3.3×10^{-9}
bis(2-Ethylhexyl)phthalate	1.9×10^{-10}
Cadmium (water)	1.3×10^{-6}
Chromium	7.7×10^{-8}
Di-n-butylphthalate	2.7×10^{-11}
Fluoranthene	1.4×10^{-10}
Methylene chloride	4.8×10^{-7}
Nickel	8.4×10^{-8}
Phenol	2.9×10^{-7}
Pyrene	2.6×10^{-10}
Silver	2.9×10^{-6}
Thallium	1.3×10^{-7}
Toluene	5.7×10^{-10}
Total xylenes	1.2×10^{-11}
Uranium	1.6×10^{-4}
TOTAL HI	**2.0×10^{-4}**
Silo 3 Contents[c]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	3.0×10^{-9}
Pa-231	7.8×10^{-10}
Pb-210 + 2 dtrs	4.5×10^{-8}
Ra-226 + 5 dtrs	2.3×10^{-8}
Ra-228 + 1 dtr	1.9×10^{-9}
Th-228 + 7 dtrs	3.5×10^{-10}

TABLE D.5-11
(Continued)

Silo 3 Contents[c]	
Radionuclides	ILCR
Th-230	3.4×10^{-9}
Th-232	5.6×10^{-11}
U-234	4.0×10^{-7}
U-235 + 1 dtr	2.4×10^{-8}
U-238 + 2 dtrs	6.6×10^{-7}
TOTAL ILCR	**1.2×10^{-6}**
Chemicals	ILCR
Arsenic	6.7×10^{-7}
Beryllium	1.7×10^{-9}
TOTAL ILCR	**6.7×10^{-7}**
Chemicals	Hazard Quotients
Antimony	8.5×10^{-7}
Arsenic	6.9×10^{-4}
Barium	4.7×10^{-8}
Beryllium	5.6×10^{-8}
Cadmium (water)	1.1×10^{-5}
Chromium	7.4×10^{-7}
Cobalt	1.5×10^{-6}
Manganese	3.5×10^{-6}
Mercury	1.8×10^{-4}
Nickel	5.9×10^{-6}
Selenium	1.2×10^{-6}
Silver	2.6×10^{-6}
Thallium	1.1×10^{-5}
Uranium	1.2×10^{-2}
Vanadium	6.3×10^{-6}
Zinc	5.9×10^{-7}
TOTAL HI	**1.3×10^{-2}**

TABLE D.5-11
(Continued)

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[a]Radionuclide and chemical pathways include ingestion of surface water as drinking water, ingestion of fruits and vegetables irrigated with surface water, ingestion of meat and milk from cattle drinking surface water and eating feed crops irrigated with surface water, and ingestion of fish from the river. Chemical pathways also include dermal contact with surface water while bathing and inhalation of VOCs from home water use.
[b]Surface water contaminated by runoff from surface soil and berm fill (Silo 3 intact).
[c]Surface water contaminated by runoff from Silo 3 contents (Silo 3 structural failure).

~~D.5.3.2.1 CT On-Property Resident Farmer~~

This section presents the ILCR and HI results for radionuclide and chemical COCs for the CT on-property resident farmer under future land use.

Table D.5-12 presents the results for ingestion of and dermal contact with soil, external radiation exposure from soil, and ingestion of fruits and vegetables, meat and milk from contamination through root uptake pathways.

Radiological exposure pathways include ingestion of contaminated soil, ingestion of fruits and vegetables, meat, and milk contaminated by root and animal uptake pathways, and penetrating external radiation exposure from contaminated soil. Under existing conditions in which the silos are intact the risks from these exposure pathways range from 5×10^{-9} (Th-232) to 1×10^{-4} (Ra-226 plus progeny). The dominant contribution to risk is from the penetrating radiation pathway from Ra-226 plus progeny in soil. Radionuclides for which the risk exceeds 1×10^{-6} include Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Sr-90 plus progeny, Tc-99, and U-238 plus progeny. The sum of radiological risks is approximately 2×10^{-4}.

Chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include Aroclor-1254, beryllium and several PAHs (benzo[a]anthracene, benzo(a)pyrene, benzo[b]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3-cd]pyrene). The total ILCR is 1×10^{-4}, attritutable almost entirely to benzo(a)pyrene. Ingestion of foodstuffs contaminated by root uptake is the predominant pathway.

For the noncarcinogenic effects, HI values greater than 1 are estimated for antimony, cadmium and silver. The total HI is 7×10^{0}. Target organs with HI values equal to or greater than 1×10^{0} include the skin (HI = 1×10^{0}), attributable solely to silver, the kidney (HI = 1×10^{0}), attributable almost entirely to cadmium, the cardiovascular system (HI = 3×10^{0}), attributable solely to antimony, and the blood (HI = 1×10^{0}), attributable largely to molybdenum and zinc. The foodstuff ingestion pathways are the predominant contributors to the HI values.

Table D.5-13 presents the results for ingestion of and dermal contact with Silo 3 contents, external radiation exposure from Silo 3 contents, and ingestion of fruits and vegetables, meat and milk from contamination through root uptake pathways.

Radiological exposure pathways include ingestion of contaminated silo waste, ingestion of fruits and vegetables, meat, and milk contaminated by root and animal uptake pathways, and penetrating external radiation exposure from contaminated silo waste. Under conditions assuming silo structural failure the risks from these exposure pathways range from 3×10^{-6} (Th-232) to 9×10^{-2} (Ra-226 plus progeny). The dominant contribution to risk is from the penetrating radiation pathway from Ra-226 plus progeny

TABLE D.5-12

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE CT ON-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN SOIL UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil	
Radionuclides	ILCR
Pb-210 + 2 dtrs	6.4×10^{-6}
Ra-226 + 5 dtrs	1.4×10^{-4}
Ra-228 + 1 dtr	1.3×10^{-5}
Sr-90 + 1 dtr	6.8×10^{-6}
Tc-99	3.4×10^{-6}
Th-230	1.5×10^{-8}
Th-232	4.6×10^{-9}
U-234	6.7×10^{-8}
U-238 + 2 dtrs	2.2×10^{-6}
TOTAL ILCR	**1.7×10^{-4}**
Chemicals	ILCR
Aroclor-1254	1.1×10^{-6}
Benzo(a)anthracene	1.2×10^{-5}
Benzo(a)pyrene	4.3×10^{-5}
Benzo(b)fluoranthene	1.2×10^{-5}
Beryllium	1.7×10^{-6}
bis(2-Ethylhexyl)phthalate	2.5×10^{-8}
Chrysene	1.1×10^{-5}
Dibenzo(a,h)anthracene	7.0×10^{-6}
Indeno(1,2,3-cd)pyrene	2.1×10^{-5}
Methylene chloride	1.2×10^{-7}
TOTAL ILCR	**1.1×10^{-4}**
Chemicals	Hazard Quotients
2-Butanone (ND)[b]	3.0×10^{-3}
4-Methyl-2-pentanone (K)	4.6×10^{-4}
Acetone (K)	2.7×10^{-2}

TABLE D.5-12
(Continued)

Soil	
Chemicals	Hazard Quotients
Anthracene (ND)	8.4×10^{-5}
Antimony (CVS)	3.3×10^{0}
Benzoic acid (ND)	4.0×10^{-5}
Beryllium (ND)	4.5×10^{-4}
bis(2-Ethylhexyl)phthalate (L)	6.6×10^{-4}
Cadmium (food) (K)	1.1×10^{0}
Chromium (K)	2.3×10^{-2}
Di-n-butylphthalate (ND)	7.3×10^{-5}
Fluoranthene (B)	3.8×10^{-4}
Methylene chloride (L)	2.1×10^{-3}
Molybdenum (B)	1.3×10^{-1}
Nickel (CNS)	9.1×10^{-2}
Phenol (F)	1.8×10^{-3}
Pyrene (K)	5.9×10^{-4}
Silver (S)	1.1×10^{0}
Thallium (CNS)	1.8×10^{-2}
Toluene (CNS)	3.7×10^{-5}
Total xylenes (CNS)	1.7×10^{-6}
Uranium (K)	5.4×10^{-2}
Zinc (B)	9.4×10^{-1}
TOTAL HI	**6.8×10^{0}**
Total HI for B	1.1×10^{0}
Total HI for CVS	3.3×10^{0}
Total HI for K	1.2×10^{0}
Total HI for S	1.1×10^{0}

TABLE D.5-12
(Continued)

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[a]Radionuclide and chemical pathways include ingestion of soil, ingestion of fruits and vegetables raised on contaminated soil, and ingestion of meat and milk from cattle eating feed crops raised on contaminated soil. Radionuclide pathways also include external radiation exposure from soil and chemical pathways also include dermal contact with soil.
[b]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
F: Target organ = fetus
K: Target organ = kidney
L: Target organ = liver
ND: Target organ = not determined
S: Target organ = skin

TABLE D.5-13

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE CT ON-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN SILO 3 CONTENTS UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Silo 3 Contents	
Radionuclides	ILCR
Ac-227 + 7 dtrs	2.8×10^{-3}
Pa-231	1.2×10^{-4}
Pb-210 + 2 dtrs	7.5×10^{-3}
Ra-226 + 5 dtrs	9.4×10^{-2}
Ra-228 + 1 dtr	4.9×10^{-3}
Th-228 + 7 dtrs	2.9×10^{-2}
Th-230	2.1×10^{-4}
Th-232	3.3×10^{-6}
U-234	4.0×10^{-5}
U-235 + 1 dtr	1.2×10^{-4}
U-238 + 2 dtrs	3.2×10^{-4}
TOTAL ILCR	**1.4×10^{-1}**
Chemicals	ILCR
Arsenic	7.7×10^{-3}
Beryllium	5.9×10^{-5}
TOTAL ILCR	**7.8×10^{-3}**
Chemicals	Hazard Quotients
Antimony (CVS)[b]	6.5×10^{-1}
Arsenic (S)	1.1×10^{2}
Barium (CVS)	1.1×10^{-1}
Beryllium (ND)	2.1×10^{-2}
Cadmium (food) (K)	1.9×10^{-1}
Chromium (K)	5.2×10^{-1}
Cobalt (B)	7.7×10^{-1}
Manganese (CNS)	2.6×10^{0}
Mercury (K)	7.6×10^{0}

TABLE D.5-13
(continued)

Silo 3 Contents	
Chemicals	Hazard Quotients
Nickel (CNS)	1.3×10^1
Selenium (S)	1.5×10^0
Silver (S)	2.1×10^0
Thallium (CNS)	4.1×10^0
Uranium (K)	9.8×10^0
Vanadium (ND)	2.2×10^0
Zinc (B)	9.7×10^0
TOTAL HI	**1.6×10^2**
Total HI for B	1.0×10^1
Total HI for CNS	2.0×10^1
Total HI for K	1.8×10^1
Total HI for ND	2.2×10^0
Total HI for S	1.1×10^2

[a]Radionuclide and chemical pathways include ingestion of silo waste, ingestion of fruits and vegetables raised on contaminated silo waste, and ingestion of meat and milk from cattle eating feed crops raised on contaminated silo waste. Radionuclide pathways also include external radiation exposure from silo waste and chemical pathways also include dermal contact with silo waste.

[b]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
K: Target organ = kidney
ND: Target organ = not determined
S: Target organ = skin

in silo waste. Radionuclides for which the risk exceeds 1×10^{-6} include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, U-235 plus progeny, and U-238 plus progeny. The radiological risk sum is 1×10^{-1}.

Prior to structural failure of the silos the potential risks to the receptor from the dose rates from the intact silos range from zero (the modeled dose rate is indistinguishable from background) at a location at the base of the K-65 berm to 2×10^{-2} at a location on top of the Silo 1 or 2 dome. The risk at a location immediately adjacent to the wall of Silo 3 is 2×10^{-4}.

Chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include beryllium. The only chemical with an ILCR exceeding 1×10^{-4} is arsenic. The total ILCR is 8×10^{-3}. Ingestion of foodstuffs contaminated by root uptake is the predominant pathway. For the noncarcinogenic effects, HI values greater than 1 are estimated for arsenic, manganese, mercury, nickel, selenium, silver, thallium, vanadium, uranium and zinc. The total HI is 2×10^{2}. Target organs with HI values equal to or greater than 1×10^{0} include the skin (HI = 1×10^{2}), attributable to arsenic, selenium and silver, the kidney (HI = 2×10^{1}), attributable largely to mercury and uranium, the central nervous system (HI = 2×10^{1}), attributable to manganese, nickel, and thallium, the blood (HI = 1×10^{1}), attributable largely to zinc, and target organ not determined (HI = 2×10^{0}), attributable largely to vanadium. The foodstuff ingestion pathways are the predominant contributors to the HI values.

Table D.5-14 presents the results for ingestion of drinking water, dermal exposure to water while bathing, inhalation of VOCs, and ingestion of vegetables, milk and meat, modeled from the impact of the silo contents on groundwater from the underlying aquifer (assuming structural failure of the silos).

Radiological exposure pathways include ingestion of contaminated groundwater as drinking water, ingestion of fruits and vegetables irrigated with contaminated groundwater, and ingestion of meat and milk from cattle raised on contaminated water and feed irrigated with contaminated groundwater. The risks from these exposure pathways are 2×10^{-6} (U-234), 2×10^{-7} (U-235 plus progeny), and 3×10^{-6} (U-238 plus progeny). The sum of these risks is 5×10^{-6}.

No chemical carcinogens were identified as COCs in the groundwater; therefore, no chemical ILCR was calculated. Regarding noncancer effects, no chemical has an HI greater than 1 (uranium, HI = 5×10^{-1}, is the only COC considered in the evaluation).

Table D.5-15 presents the results for inhalation of VOCs, fugitive dust and radon, and for ingestion of fruits and vegetables, milk and meat contaminated by pathways involving air deposition.

Radiological exposure includes inhalation of resuspended particulates and radon emissions, ingestion of fruits and vegetables subject to contamination by air deposition on crops, and ingestion of meat and

TABLE D.5-14

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE CT ON-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN GROUNDWATER UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Aquifer	
Radionuclides	ILCR
U-234	2.0×10^{-6}
U-235 + 1 dtr	1.7×10^{-7}
U-238 + 2 dtrs	3.0×10^{-6}
TOTAL ILCR	**5.2×10^{-6}**
Chemical	Hazard Quotients
Uranium	4.6×10^{-1}
TOTAL HI	**4.6×10^{-1}**

[a]Radionuclide pathways include ingestion of groundwater as drinking water, ingestion of fruits and vegetables irrigated with groundwater, ingestion of meat and milk from cattle drinking groundwater and eating feed crops irrigated with groundwater. Chemical pathways are the same as radionuclide pathways plus dermal contact with groundwater while bathing, and inhalation of VOCs from home water use.

TABLE D.5-15

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE CT ON-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN AIR UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	1.6×10^{-8}
Ra-226 + 5 dtrs	2.4×10^{-8}
Ra-228 + 1 dtr	4.1×10^{-9}
Rn-222 + 4 dtrs	1.1×10^{-5}
Sr-90 + 1 dtr	2.5×10^{-8}
Tc-99	2.0×10^{-8}
Th-228 + 7 dtrs[c]	2.2×10^{-8}
Th-230	2.8×10^{-7}
Th-232	1.0×10^{-8}
U-234	1.7×10^{-7}
U-238 + 2 dtrs	1.1×10^{-6}
TOTAL ILCR	**1.3×10^{-5}**
Chemicals	ILCR
Benzo(a)anthracene	3.2×10^{-9}
Benzo(a)pyrene	2.8×10^{-9}
Benzo(b)fluoranthene	4.4×10^{-9}
Beryllium	7.7×10^{-9}
Cadmium	3.7×10^{-8}
Chromium	8.8×10^{-7}
Chrysene	2.9×10^{-9}
Dibenzo(a,h)anthracene	1.9×10^{-9}
Indeno(1,2,3-c,d)pyrene	3.3×10^{-9}
Methylene chloride	3.2×10^{-14}
Nickel	2.9×10^{-8}
TOTAL ILCR	**9.7×10^{-7}**

TABLE D.5-15
(Continued)

Soil[b]	
Chemicals	Hazard Quotients
2-Butanone	1.4×10^{-10}
Beryllium	1.8×10^{-11}
Cadmium	7.0×10^{-9}
Chromium	6.1×10^{-10}
Methylene chloride	1.9×10^{-10}
Nickel	7.4×10^{-10}
Toluene	1.7×10^{-9}
TOTAL ILCR	**1.0×10^{-8}**
Silo 3 Contents[d]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	8.0×10^{-5}
Pa-231	4.8×10^{-5}
Pb-210 + 2 dtrs	9.2×10^{-5}
Ra-226 + 5 dtrs	2.5×10^{-5}
Ra-228 + 1 dtr	1.1×10^{-6}
Rn-222 + 4 dtrs	3.6×10^{-4}
Sr-90 + 1 dtr	2.3×10^{-8}
Tc-99	1.8×10^{-8}
Th-228 + 7 dtrs	9.5×10^{-5}
Th-230	2.5×10^{-3}
Th-232	3.4×10^{-5}
U-234	7.1×10^{-5}
U-235 + 1 dtr	4.2×10^{-6}
U-238 + 2 dtrs	1.3×10^{-4}
TOTAL ILCR	**3.4×10^{-3}**
Chemicals	ILCR
Arsenic	3.7×10^{-5}
Benzo(a)anthracene	3.0×10^{-9}
Benzo(a)pyrene	2.5×10^{-9}

TABLE D.5-15
(Continued)

Silo 3 Contents[d]	
Chemicals	ILCR
Benzo(b)fluoranthene	4.0×10^{-9}
Beryllium	2.0×10^{-7}
Cadmium	4.9×10^{-7}
Chromium	1.3×10^{-5}
Chrysene	2.7×10^{-9}
Dibenzo(a,h)anthracene	1.7×10^{-9}
Indeno(1,2,3-c,d)pyrene	3.0×10^{-9}
Methylene chloride	3.2×10^{-14}
Nickel	2.8×10^{-6}
TOTAL ILCR	**5.4×10^{-5}**
Chemicals	Hazard Quotients
2-Butanone (R)[e]	1.4×10^{-10}
Antimony (R)	3.7×10^{-9}
Arsenic (S)	1.2×10^{-6}
Barium (R)	1.1×10^{-2}
Beryllium (R)	4.7×10^{-10}
Cadmium (K)	9.4×10^{-8}
Chromium (R)	8.9×10^{-9}
Cobalt (R)	5.8×10^{1}
Manganese (CNS)	2.9×10^{-1}
Mercury (K)	4.9×10^{-5}
Methylene chloride (L)	1.9×10^{-10}
Nickel (R)	7.4×10^{-8}
Selenium (S)	1.2×10^{-8}
Silver (ND)	1.0×10^{-8}
Thallium (CNS)	1.7×10^{-7}
Toluene (CNS)	1.7×10^{-9}
Vanadium (R)	4.2×10^{-8}
Zinc (R)	3.5×10^{-8}
TOTAL HI	**5.8×10^{1}**
Total HI for R	5.8×10^{1}

TABLE D.5-15
(Continued)

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[a]Radionuclide and chemical pathways include inhalation of fugitive dust, VOCs, and radon ingestion of fruits and vegetables and meat and milk from cattle subject to air deposition of contaminants on food and feed crops.
[b]Air contaminated by volatilization or fugitive dust from surface soil and berm fill (Silo 3 intact).
[c]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d]Air contaminated by volatilization or fugitive dust from Silo 3 contents (Silo 3 structural failure).
[e]Target organ information for inhalation exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

CNS: Target organ = central nervous system
K: Target organ = kidney
L: Target organ = liver
ND: Target organ = not determined
R: Target organ = respiratory system
S: Target organ = skin

milk from cattle raised on feed subject to contamination by air deposition on feed crops. These exposure pathways are evaluated under existing conditions with the silos intact and under conditions assuming silo structural failure occurs allowing the Silo 3 waste to spread out in the Operable Unit 4 Study Area. Under existing conditions with the silos intact the risks from the inhalation and ingestion pathways subject to air deposition range from 4×10^{-9} (Ra-228 plus progeny) to 1×10^{-5} (Rn-222 plus progeny). The radiological risk sum with the silos intact is 1×10^{-5}. Under conditions in which the silos suffer structural failure risks range from 2×10^{-8} (Tc-99 or Sr-90 plus progeny) to 3×10^{-3} (Th-230). Radionuclides for which the risk exceeds 1×10^{-6} under existing conditions with the silos intact include Rn-222 plus progeny and U-238 plus progeny. Radionuclides for which the risk exceeds 1×10^{-6} under conditions assuming silo structural failure include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Rn-222 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, U-235 plus progeny, and U-238 plus progeny. Assuming silo structural failure, the sum of radiological risks is calculated to be approximately 3×10^{-3}.

Under current conditions (Silo 3 intact), no chemical carcinogens result in ILCR values greater than 1×10^{-6}. The total ILCR for current conditions is 1×10^{-6}. Under future conditions (Silo 3 structural failure), chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include arsenic, chromium and nickel. No chemical carcinogens result in an ILCR greater than 1×10^{-4}. The total ILCR for future conditions is 5×10^{-5}. Virtually all of the cancer risk arises from direct inhalation of fugitive dust.

Under current conditions (Silo 3 intact) no chemicals have HI values greater than 1. The total HI for current conditions is 1×10^{-8}. Under future conditions (Silo 3 structural failure), cobalt has an HI greater than 1. The total HI is 6×10^{1}. Target organs with HI values equal to or greater than 1×10^{0} are limited to the respiratory system (HI = 6×10^{1}), attributable almost entirely to cobalt.

D.5.3.2.2 RME On-Property Resident Farmer

This section presents the ILCR and HI results for radionuclide and chemical COCs for the RME on-property resident farmer under future land use.

Table D.5-16 presents the results for ingestion of and dermal contact with soil, external radiation exposure from soil, and ingestion of fruits and vegetables, meat and milk from contamination through root uptake pathways.

Radiological exposure pathways include ingestion of contaminated soil, ingestion of fruits and vegetables, meat, and milk contaminated by root and animal uptake pathways, and penetrating external radiation exposure from contaminated soil. Under existing conditions in which the silos are intact the risks from these exposure pathways range from 2×10^{-7} (Th-232) to 1×10^{-3} (Ra-226 plus progeny). The dominant contribution to risk is from the penetrating radiation pathway from Ra-226 plus progeny

TABLE D.5-16

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE RME ON-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN SOIL UNDER FUTURE LAND USE WITHOUT ACCESS CONTROL - ALL PATHWAYS[a]

Soil	
Radionuclides	ILCR
Pb-210 + 2 dtrs	1.2×10^{-4}
Ra-226 + 5 dtrs	1.4×10^{-3}
Ra-228 + 1 dtr	1.3×10^{-4}
Sr-90 + 1 dtr	1.0×10^{-4}
Tc-99	5.0×10^{-5}
Th-230	6.4×10^{-7}
Th-232	2.1×10^{-7}
U-234	1.1×10^{-6}
U-238 + 2 dtrs	2.7×10^{-5}
TOTAL ILCR	**1.8×10^{-3}**
Chemicals	ILCR
Aroclor-1254	2.0×10^{-5}
Benzo(a)anthracene	6.6×10^{-4}
Benzo(a)pyrene	1.2×10^{-3}
Benzo(b)fluoranthene	3.1×10^{-4}
Beryllium	9.0×10^{-5}
bis(2-Ethylhexyl)phthalate	7.8×10^{-7}
Chrysene	6.1×10^{-4}
Dibenzo(a,h)anthracene	4.3×10^{-4}
Indeno(1,2,3-cd)pyrene	3.8×10^{-4}
Methylene chloride	1.8×10^{-6}
TOTAL ILCR	**4.2×10^{-3}**
Chemicals	Hazard Quotients
2-Butanone (ND)[b]	6.0×10^{-3}
4-Methyl-2-pentanone (K)	9.2×10^{-4}

TABLE D.5-16
(Continued)

Soil	
Chemicals	Hazard Quotients
Acetone (K)	5.3×10^{-2}
Anthracene (ND)	2.3×10^{-4}
Antimony (CVS)	7.4×10^{0}
Benzoic acid (ND)	8.0×10^{-5}
Beryllium (ND)	4.2×10^{-3}
bis(2-Ethylhexyl)phthalate (L)	2.8×10^{-3}
Cadmium (food) (K)	2.2×10^{0}
Chromium (K)	1.3×10^{-1}
Di-n-butylphthalate (ND)	3.0×10^{-4}
Fluoranthene (B)	2.4×10^{-3}
Methylene chloride (L)	4.1×10^{-3}
Molybdenum (B)	2.6×10^{-1}
Nickel (CNS)	2.1×10^{-1}
Phenol (F)	3.6×10^{-3}
Pyrene (K)	3.4×10^{-3}
Silver (S)	2.2×10^{0}
Thallium (CNS)	7.3×10^{-2}
Toluene (CNS)	7.4×10^{-5}
Total xylenes (CNS)	2.7×10^{-8}
Uranium (K)	3.4×10^{-1}
Zinc (B)	1.8×10^{0}
TOTAL HI	**1.5×10^{1}**
Total HI for B	2.1×10^{0}
Total HI for CVS	7.4×10^{0}
Total HI for K	2.7×10^{0}
Total HI for S	2.2×10^{0}

TABLE D.5-16
(Continued)

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[a]Radionuclide and chemical pathways include ingestion of soil, ingestion of fruits and vegetables raised on contaminated soil, and ingestion of meat and milk from cattle eating feed crops raised on contaminated soil. Radionuclide pathways also include external radiation exposure from soil and chemical pathways also include dermal contact with soil.
[b]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
F: Target organ = fetus
K: Target organ = kidney
L: Target organ = liver
ND: Target organ = not determined
S: Target organ = skin

in soil. Radionuclides for which the risk exceeds 1×10^{-6} include Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Sr-90 plus progeny, Tc-99, U-234, and U-238 plus progeny. The sum of radiological risks is 2×10^{-3}.

Chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include Aroclor-1254, beryllium and methylene chloride. Several PAHs (benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3-cd]pyrene) have an ILCR exceeding 1×10^{-4}. The total ILCR is 4×10^{-3}. Ingestion of foodstuffs contaminated by root uptake is the predominant pathway.

For the noncarcinogenic effects, HI values greater than 1 are estimated for antimony, cadmium, silver and zinc. The total HI is 2×10^{1}. Target organs with HI values equal to or greater than 1×10^{0} include the skin (HI = 2×10^{0}), attributable solely to silver, the kidney (HI = 3×10^{0}), attributable largely to cadmium, chromium, and uranium, the cardiovascular system (HI = 7×10^{0}), attributable solely to antimony, and the blood (HI = 2×10^{0}), attributable largely to zinc. The foodstuff ingestion pathways are the predominant contributors to the HI values.

Table D.5-17 presents the results for ingestion of and dermal contact with Silo 3 contents, external radiation exposure from Silo 3 contents, and ingestion of fruits and vegetables, meat and milk from contamination through root uptake pathways.

Radiological exposure pathways include ingestion of contaminated silo waste, ingestion of fruits and vegetables, meat, and milk contaminated by root and animal uptake pathways, and penetrating external radiation exposure from contaminated silo waste. Under conditions assuming silo structural failure the risks from these exposure pathways range from 1×10^{-4} (Th-232) to 1×10^{0} (Ra-226 plus progeny). The dominant contribution to risk is from the penetrating radiation pathway from Ra-226 plus progeny in silo waste. Radionuclides for which the risk exceeds 1×10^{-6} include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, U-235 plus progeny, and U-238 plus progeny. The radiological risk sum is 8×10^{-1} applying the one-hit equation.

Prior to structural failure of the silos the potential risks to the receptor from the dose rates from the intact silos range from zero (the modeled dose rate is indistinguishable from background) at a location at the base of the K-65 berm to 3×10^{-1} at a location on top of the Silo 1 or 2 dome. The risk at a location immediately adjacent to the wall of Silo 3 is 2×10^{-3}.

No chemical carcinogens result in ILCR values between 1×10^{-6} and 1×10^{-4}. Chemicals with an ILCR exceeding 1×10^{-4} include arsenic and beryllium. The total ILCR is 2×10^{-1}. Ingestion of foodstuffs contaminated by root uptake is the predominant pathway. For the noncarcinogenic effects,

TABLE D.5-17

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE RME ON-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN SILO 3 CONTENTS UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Silo 3 Contents	
Radionuclides	ILCR
Ac-227 + 7 dtrs	3.1×10^{-2}
Pa-231	2.1×10^{-3}
Pb-210 + 2 dtrs	1.4×10^{-1}
Ra-226 + 5 dtrs	9.8×10^{-1}
Ra-228 + 1 dtr	4.9×10^{-2}
Th-228 + 7 dtrs	3.0×10^{-1}
Th-230	9.1×10^{-3}
Th-232	1.4×10^{-4}
U-234	8.7×10^{-4}
U-235 + 1 dtr	1.2×10^{-3}
U-238 + 2 dtrs	4.1×10^{-3}
TOTAL ILCR	**7.8×10^{-1}**
Chemicals	ILCR
Arsenic	1.5×10^{-1}
Beryllium	3.1×10^{-3}
TOTAL ILCR	**1.5×10^{-1}**
Chemicals	Hazard Quotients
Antimony (CVS)[b]	1.4×10^{0}
Arsenic (S)	2.9×10^{2}
Barium (CVS)	2.9×10^{-1}
Beryllium (ND)	1.4×10^{-1}
Cadmium (food) (K)	3.8×10^{1}
Chromium (K)	2.4×10^{0}
Cobalt (B)	2.3×10^{0}
Manganese (CNS)	6.1×10^{0}
Mercury (K)	1.5×10^{1}

TABLE D.5-17
(Continued)

Silo 3 Contents	
Chemicals	Hazard Quotients
Nickel (CNS)	2.9×10^1
Selenium (S)	3.2×10^0
Silver (S)	4.1×10^0
Thallium (CNS)	1.3×10^0
Uranium (K)	5.1×10^1
Vanadium (ND)	1.3×10^1
Zinc (B)	1.9×10^1
TOTAL HI	**4.8×10^2**
Total HI for B	2.1×10^1
Total HI for CNS	8.7×10^1
Total HI for CVS	1.7×10^0
Total HI for K	1.1×10^2
Total HI for ND	1.3×10^1
Total HI for S	3.0×10^2

[a]Radionuclide and chemical pathways include ingestion of silo waste, ingestion of fruits and vegetables raised on contaminated silo waste, and ingestion of meat and milk from cattle eating feed crops raised on contaminated silo waste. Radionuclide pathways also include external radiation exposure from silo waste and chemical pathways also include dermal contact with silo waste.

[b]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
K: Target organ = kidney
ND: Target organ = not determined
S: Target organ = skin

HI values greater than 1 are estimated for antimony, arsenic, cadmium, chromium, cobalt, manganese, mercury, nickel, selenium, silver, thallium, vanadium, uranium and zinc. The total HI is 4×10^2. Target organs with HI values equal to or greater than 1×10^0 include the cardiovascular system (HI = 2×10^0), attributable largely to antimony, the skin (HI = 3×10^2), attributable to arsenic, silver, and selenium, target organ not determined (HI = 1×10^1), attributable almost entirely to vanadium, the kidney (HI = 1×10^2), attributable to cadmium, chromium, mercury, and uranium, the central nervous system (HI = 9×10^1), attributable to nickel, thallium, and manganese, and the blood (HI = 2×10^1), attributable to zinc and cobalt. The foodstuff ingestion pathways are the predominant contributors to the HI values.

Table D.5-18 presents the results for ingestion of drinking water, dermal exposure to water while bathing, inhalation of VOCs, and ingestion of vegetables, milk and meat, modeled from the impact of the silo contents on groundwater from the underlying aquifer (assuming structural failure of silos). In addition, the second part of Table D.5-18 presents the results for ingestion of drinking water modeled from the effects of silo contents on groundwater from perched water in the sand lens directly beneath Operable Unit 4.

Radiological exposure pathways include ingestion of contaminated groundwater as drinking water, ingestion of fruits and vegetables irrigated with contaminated groundwater, and ingestion of meat and milk from cattle raised on contaminated water and feed irrigated with contaminated groundwater. The risks from these exposure pathways are 3×10^{-5} (U-234), 2×10^{-6} (U-235 plus progeny), and 4×10^{-5} (U-238 plus progeny). The sum of these risks is 7×10^{-5}.

The radiological risks from the ingestion of perched water from the sand lens as drinking water range from 2×10^{-15} (Th-232) to 1.0×10^0 (Pb-210 plus progeny). Radionuclides for which the risk exceeds 1×10^{-6} include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Th-228 plus progeny, U-234, and U-238 plus progeny. The risk associated with Pb-210 plus progeny dominate all other risks, leaving the sum of risks unity.

With regard to groundwater from the aquifer, no chemical carcinogens were identified as COCs in the groundwater; therefore, no chemical ILCR was calculated. Regarding noncancer effects, no chemical has an HI greater than 1 (uranium, HI = 8×10^{-1}, is the only COC considered in the evaluation).

With regard to groundwater from the perched water in the sand lens, no chemical carcinogen results in an ILCR between 1×10^{-6} and 1×10^{-4}, and arsenic has an ILCR greater than 1×10^{-4}. The total ILCR is 1×10^{-2}, attributable almost entirely to arsenic. For noncancer effects, arsenic, cadmium, thallium and vanadium result in HI values greater than 1. The total HI is 5×10^1. Target organs with HI values equal to or greater than 1×10^0 include the skin (HI = 4×10^1), attributable largely to arsenic, target organ not determined (HI = 2×10^0), attributable almost entirely to vanadium, the

TABLE D.5-18

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE RME ON-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN GROUNDWATER UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Aquifer[b]	
Radionuclides	ILCR
U-234	2.8×10^{-5}
U-235 + 1 dtr	2.4×10^{-6}
U-238 + 2 dtrs	4.3×10^{-5}
TOTAL ILCR	**7.3×10^{-5}**
Chemicals	Hazard Quotients
Uranium	8.5×10^{-1}
TOTAL HI	**8.5×10^{-1}**
Perched Water[b]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	4.8×10^{-4}
Pa-231	8.9×10^{-5}
Pb-210 + 2 dtrs[c]	1.0×10^{0}
Ra-226 + 5 dtrs	1.9×10^{-3}
Ra-228 + 1 dtr	1.7×10^{-4}
Th-228 + 7 dtrs[d]	8.3×10^{-5}
Th-232	1.6×10^{-15}
U-234	7.9×10^{-6}
U-235 + 1 dtr	3.5×10^{-7}
U-238 + 2 dtrs	1.3×10^{-5}
TOTAL ILCR	**1.0×10^{0}**
Chemicals	ILCR
Arsenic	1.3×10^{-2}
Beryllium	8.0×10^{-7}
TOTAL ILCR	**1.3×10^{-2}**

TABLE D.5-18
(Continued)

Perched Water[b]	
Chemicals	Hazard Quotients
Antimony (CVS)[e]	5.9×10^{-2}
Arsenic (S)	3.4×10^{1}
Barium (CVS)	7.8×10^{-6}
Beryllium (ND)	4.9×10^{-5}
Boron (T)	1.2×10^{-2}
Cadmium (water) (K)	5.9×10^{0}
Chromium (K)	1.5×10^{-5}
Cobalt (B)	3.1×10^{-1}
Manganese (CNS)	3.0×10^{-5}
Mercury (K)	1.2×10^{-1}
Molybdenum (B)	5.7×10^{-3}
Nickel (CNS)	4.7×10^{-2}
Selenium (S)	7.3×10^{-1}
Silver (S)	2.9×10^{-2}
Thallium (CNS)	6.0×10^{0}
Uranium (K)	3.5×10^{-1}
Vanadium (ND)	2.3×10^{0}
Zinc (B)	4.3×10^{-3}
TOTAL HI	**5.0×10^{1}**
Total HI for CNS	6.0×10^{0}
Total HI for K	6.4×10^{0}
Total HI for ND	2.3×10^{0}
Total HI for S	3.5×10^{1}

[a]Radionuclide pathways include ingestion of groundwater as drinking water, ingestion of fruits and vegetables irrigated with groundwater, and ingestion of meat and milk from cattle drinking groundwater and eating feed crops irrigated with groundwater. Chemical pathways

TABLE D.5-18
(Continued)

[c]Impact of Po-210 is contained within Pb-210 + 2 dtrs.
[d]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[e]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
K: Target organ = kidney
ND: Target organ = not determined
S: Target organ = skin
T: Target organ = testis

kidney (HI = 6 x 10^0), attributable largely to cadmium, and the central nervous system (HI = 6 x 10^0), attributable largely to thallium.

Table D.5-19 presents the results for inhalation of VOCs, fugitive dust and radon, and for ingestion of fruits and vegetables, milk and meat contaminated by pathways involving air deposition.

Radiological exposure includes inhalation of resuspended particulates and radon emissions, ingestion of fruits and vegetables subject to contamination by air deposition on crops, and ingestion of meat and milk from cattle raised on feed subject to contamination by air deposition on feed crops. These exposure pathways are evaluated under existing conditions with the silos intact and under conditions assuming silo structural failure occurs. Under existing conditions with the silos intact the risks range from 6 x 10^{-8} (Ra-228 plus progeny) to 1 x 10^{-4} (Rn-222 plus progeny). The radiological risk sum is approximately 2 x 10^{-4}, assuming the silos remain intact. Under conditions in which the silos suffer structural failure risks range from 3 x 10^{-7} (Tc-99 or Sr-90 plus progeny) to 3 x 10^{-2} (Th-230). Radionuclides for which the risk exceeds 1 x 10^{-6} under existing conditions with the silos intact include Rn-222 plus progeny, Th-230, U-234, and U-238 plus progeny. Radionuclides for which the risk exceeds 1 x 10^{-6} under conditions assuming silo structural failure include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Rn-222 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, U-235 plus progeny, and U-238 plus progeny. The radiological risk sum assuming structural failure is calculated to be approximately 5 x 10^{-2}.

Under current conditions (Silo 3 intact), chromium results in an ILCR between 1 x 10^{-6} and 1 x 10^{-4}. No chemical carcinogen results in an ILCR greater than 1 x 10^{-4}. The total ILCR for current conditions is 1 x 10^{-5}, attributable almost entirely to chromium. Under future conditions (Silo 3 structural failure), chemical carcinogens resulting in ILCR values between 1 x 10^{-6} and 1 x 10^{-4} include beryllium, cadmium and nickel. Arsenic and chromium have ILCR values greater than 1 x 10^{-4}. The total ILCR is 7 x 10^{-4}. Virtually all of the cancer risk arises from direct inhalation of fugitive dust.

Under current conditions (Silo 3 intact), no chemicals result in an HI greater than 1. The total HI is 4 x 10^{-7}. Under future conditions (Silo 3 structural failure), cobalt has an HI value greater than 1. The total HI is 1 x 10^2. Target organs with HI values equal to or greater than 1 x 10^0 are limited to the respiratory system (HI = 1 x 10^2), attributable almost entirely to cobalt.

D.5.3.2.3 <u>On-Property Resident Child</u>

This section presents the ILCR and HI results for radionuclide and chemical COCs for the on-property resident child under future land use, as well as the results for effects on exposure to lead on blood lead concentrations.

TABLE D.5-19

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE RME ON-PROPERTY RESIDENT FARMER FROM RADIONUCLIDES AND CHEMICALS IN AIR UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	2.2×10^{-7}
Ra-226 + 5 dtrs	3.5×10^{-7}
Ra-228 + 1 dtr	5.8×10^{-8}
Rn-222 + 4 dtrs	1.4×10^{-4}
Sr-90 + 1 dtr	3.9×10^{-7}
Tc-99	2.9×10^{-7}
Th-228 + 7 dtrs[c]	3.0×10^{-7}
Th-230	3.7×10^{-6}
Th-232	1.4×10^{-7}
U-234	2.3×10^{-6}
U-238 + 2 dtrs	1.5×10^{-5}
TOTAL ILCR	**1.6×10^{-4}**
Chemicals	ILCR
Benzo(a)anthracene	4.4×10^{-8}
Benzo(a)pyrene	3.7×10^{-8}
Benzo(b)fluoranthene	6.0×10^{-8}
Beryllium	1.0×10^{-7}
Chromium	1.2×10^{-5}
Chrysene	4.0×10^{-8}
Dibenzo(a,h)anthracene	2.5×10^{-8}
Methylene chloride	4.3×10^{-13}
Nickel	3.8×10^{-7}
TOTAL ILCR	**1.3×10^{-5}**

TABLE D.5-19
(Continued)

Soil[b]	
Chemicals	Hazard Quotients
2-Butanone	2.4×10^{-10}
Beryllium	9.4×10^{-10}
Cadmium (food)	1.9×10^{-7}
Chromium	1.8×10^{-8}
Methylene chloride	3.2×10^{-10}
Nickel	1.5×10^{-7}
Toluene	3.0×10^{-9}
TOTAL HI	**3.6×10^{-7}**
Silo 3 Contents[d]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	1.1×10^{-3}
Pa-231	6.5×10^{-4}
Pb-210 + 2 dtrs	1.3×10^{-3}
Ra-226 + 5 dtrs	3.6×10^{-4}
Ra-228 + 1 dtr	1.6×10^{-5}
Rn-222 + 4 dtrs	4.8×10^{-3}
Sr-90 + 1 dtr	3.5×10^{-7}
Tc-99	2.6×10^{-7}
Th-228 + 7 dtrs	1.3×10^{-3}
Th-230	3.3×10^{-2}
Th-232	4.5×10^{-4}
U-234	9.6×10^{-4}
U-235 + 1 dtr	5.5×10^{-5}
U-238 + 2 dtrs	1.8×10^{-2}
TOTAL ILCR	**6.2×10^{-2}**
Chemicals	ILCR
Arsenic	5.0×10^{-4}
Benzo(a)anthracene	4.0×10^{-8}
Benzo(a)pyrene	3.4×10^{-8}

TABLE D.5-19
(Continued)

Silo 3 Contents[d]	
Chemicals	ILCR
Benzo(b)fluoranthene	5.4×10^{-8}
Beryllium	2.7×10^{-6}
Cadmium	6.6×10^{-6}
Chromium	1.7×10^{-4}
Chrysene	3.6×10^{-8}
Dibenzo(a,h)anthracene	2.3×10^{-8}
Indeno(1,2,3-c,d)pyrene	4.1×10^{-8}
Methylene chloride	4.3×10^{-13}
Nickel	3.8×10^{-5}
TOTAL ILCR	**7.2×10^{-4}**
Chemicals	Hazard Quotients
2-Butanone (R)[e]	2.4×10^{-10}
Antimony (R)	7.3×10^{-9}
Arsenic (S)	2.4×10^{-6}
Barium (R)	1.9×10^{-2}
Beryllium (R)	9.4×10^{-10}
Cadmium (K)	1.9×10^{-7}
Chromium (R)	1.8×10^{-8}
Cobalt (R)	1.0×10^{2}
Manganese (CNS)	4.9×10^{-1}
Mercury (K)	8.5×10^{-5}
Methylene chloride (L)	3.2×10^{-10}
Nickel (R)	1.5×10^{-7}
Selenium (S)	2.4×10^{-8}
Silver (ND)	2.0×10^{-8}
Thallium (CNS)	3.3×10^{-7}
Toluene (CNS)	3.0×10^{-9}
Vanadium (R)	8.4×10^{-8}

TABLE D.5-19
(Continued)

Silo 3 Contents[d]	
Chemicals	Hazard Quotients
Zinc (R)	6.7×10^{-8}
TOTAL HI	**1.0×10^{2}**
Total HI for R	1.0×10^{2}

[a]Radionuclide and chemical pathways include inhalation of fugitive dust, VOCs, and radon, and ingestion of fruits and vegetables and meat and milk from cattle subject to air deposition of contaminants on food and feed crops.
[b]Air contaminated by volatilization or fugitive dust from surface soil and berm fill (Silo 3 intact).
[c]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d]Air contaminated by volatilization or fugitive dust from Silo 3 contents (Silo 3 structural failure).
[e]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^{0}$ are presented.

CNS: Target organ = central nervous system
K: Target organ = kidney
L: Target organ = liver
ND: Target organ = not determined
R: Target organ = respiratory system
S: Target organ = skin

Table D.5-20 presents the results for ingestion of and dermal contact with soil, external radiation exposure from soil, and ingestion of fruits and vegetables, meat and milk from contamination through root uptake pathways.

Radiological exposure pathways include ingestion of contaminated soil, ingestion of fruits and vegetables, meat, and milk contaminated by root and animal uptake pathways, and penetrating external radiation exposure from contaminated soil. Under existing conditions in which the silos are intact the risks from these exposure pathways range from 8×10^{-9} (Th-232) to 1×10^{-4} (Ra-226 plus progeny). The dominant contribution to risk is from the penetrating radiation pathway from Ra-226 plus progeny in soil. Radionuclides for which the risk exceeds 1×10^{-6} include Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Sr-90 plus progeny, Tc-99, and U-238 plus progeny. The sum of the calculated risks for radionuclides is approximately 2×10^{-4}.

Chemical carcinogens resulting in ILCR values between 1×10^{-6} and 1×10^{-4} include Aroclor-1254, beryllium and dibenzo(a,h)anthracene. Several PAHs (benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, chrysene, indeno[1,2,3-cd]pyrene) have an ILCR exceeding 1×10^{-4}. The total ILCR is 1×10^{-1}. Ingestion of foodstuffs contaminated by root uptake is the predominant pathway.

For the noncarcinogenic effects, HI values greater than 1 are estimated for antimony, cadmium, chromium, molybdenum, silver and zinc. The total HI is 1×10^{2}. Target organs with HI values equal to or greater than 1×10^{0} include the kidney (HI = 5×10^{1}), attributable largely to cadmium and chromium, the cardiovascular system (HI = 3×10^{1}), attributable solely to antimony, the blood (HI = 1×10^{1}), attributable almost entirely to molybdenum and zinc, the central nervous system (HI = 1×10^{0}), attributable largely to nickel and thallium, and the skin (HI = 2×10^{1}), attributable solely to silver. The foodstuff ingestion pathways are the predominant contributors to the HI values.

Table D.5-21 presents the results for ingestion of and dermal contact with Silo 3 contents, external radiation exposure from Silo 3 contents, and ingestion of fruits and vegetables, meat and milk from contamination through root uptake pathways.

Radiological exposure pathways include ingestion of contaminated silo waste, ingestion of fruits and vegetables, meat, and milk contaminated by root and animal uptake pathways, and penetrating external radiation exposure from contaminated silo waste. Under conditions assuming silo structural failure the risks from these exposure pathways range from 5×10^{-6} (Th-232) to 7×10^{-2} (Ra-226 plus progeny). The dominant contribution to risk is from the penetrating radiation pathway from Ra-226 plus progeny in silo waste. Radionuclides for which the risk exceeds 1×10^{-6} include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, U-235 plus progeny, and U-238 plus progeny. The sum of the radiological risks is 1×10^{-1}.

TABLE D.5-20

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE ON-PROPERTY RESIDENT CHILD FROM RADIONUCLIDES AND CHEMICALS IN SOIL UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil	
Radionuclides	ILCR
Pb-210 + 2 dtrs	9.6×10^{-6}
Ra-226 + 5 dtrs	1.1×10^{-4}
Ra-228 + 1 dtr	1.0×10^{-5}
Sr-90 + 1 dtr	1.9×10^{-5}
Tc-99	9.8×10^{-6}
Th-230	2.4×10^{-8}
Th-232	7.6×10^{-9}
U-234	1.2×10^{-7}
U-238 + 2 dtrs	2.2×10^{-6}
TOTAL ILCR	**1.6×10^{-4}**
Chemicals	ILCR
Aroclor-1254	9.0×10^{-6}
Benzo(a)anthracene	1.4×10^{-4}
Benzo(a)pyrene	4.1×10^{-4}
Benzo(b)fluoranthene	1.3×10^{-4}
Beryllium	1.6×10^{-5}
bis(2-Ethylhexyl)phthalate	2.0×10^{-7}
Chrysene	1.3×10^{-4}
Dibenzo(a,h)anthracene	9.5×10^{-5}
Indeno(1,2,3-cd)pyrene	2.4×10^{-4}
Methylene chloride	6.1×10^{-7}
TOTAL ILCR	**1.2×10^{-3}**
Chemicals	Hazard Quotients
2-Butanone (ND)[b]	2.3×10^{-2}
4-Methyl-2-pentanone (K)	3.5×10^{-3}
Acetone (K)	2.1×10^{-1}

TABLE D.5-20
(Continued)

Soil	
Chemicals	Hazard Quotients
Anthracene (ND)	7.7×10^{-4}
Antimony (CVS)	2.8×10^{1}
Benzoic acid (ND)	3.1×10^{-4}
Beryllium (ND)	8.9×10^{-3}
bis(2-Ethylhexyl)phthalate (L)	8.3×10^{-3}
Cadmium (food) (K)	1.1×10^{1}
Chromium (K)	3.5×10^{1}
Di-n-butyl phthalate (ND)	9.0×10^{-4}
Fluoranthene (B)	6.1×10^{-3}
Methylene chloride (L)	1.6×10^{-2}
Molybdenum (B)	1.4×10^{0}
Nickel (CNS)	8.1×10^{-1}
Phenol (F)	1.4×10^{-2}
Pyrene (K)	7.1×10^{-3}
Silver (S)	2.5×10^{1}
Thallium (CNS)	2.1×10^{-1}
Toluene (CNS)	2.9×10^{-4}
Total xylenes (CNS)	1.3×10^{-5}
Uranium (K)	8.7×10^{-1}
Zinc (B)	9.0×10^{0}
TOTAL HI	**1.1×10^{2}**
Total HI for B	1.0×10^{1}
Total HI for CNS	1.0×10^{0}
Total HI for CVS	2.8×10^{1}
Total HI for K	4.7×10^{1}
Total HI for S	2.5×10^{1}

TABLE D.5-20
(Continued)

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[a]Radionuclide and chemical pathways include ingestion of soil, ingestion of fruits and vegetables raised on contaminated soil, and ingestion of meat and milk from cattle eating feed crops raised on contaminated soil. Radionuclide pathways also include external radiation exposure from soil and chemical pathways also include dermal contact with soil.
[b]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
F: Target organ = fetus
K: Target organ = kidney
L: Target organ = liver
ND: Target organ = not determined
S: Target organ = skin

TABLE D.5-21

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE ON-PROPERTY RESIDENT CHILD FROM RADIONUCLIDES AND CHEMICALS IN SILO 3 CONTENTS UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Silo 3 Contents	
Radionuclides	ILCR
Ac-227 + 7 dtrs	2.2×10^{-3}
Pa-231	1.2×10^{-4}
Pb-210 + 2 dtrs	1.1×10^{-2}
Ra-226 + 5 dtrs	7.4×10^{-2}
Ra-228 + 1 dtr	3.8×10^{-3}
Th-228 + 7 dtrs	2.2×10^{-2}
Th-230	3.4×10^{-4}
Th-232	5.3×10^{-6}
U-234	7.0×10^{-5}
U-235 + 1 dtr	9.5×10^{-5}
U-238 + 2 dtrs	3.2×10^{-4}
TOTAL ILCR	**1.1×10^{-1}**
Chemicals	ILCR
Arsenic	4.2×10^{-2}
Beryllium	5.7×10^{-4}
TOTAL ILCR	**4.3×10^{-2}**
Chemicals	Hazard Quotients
Antimony (CVS)[b]	5.3×10^{0}
Arsenic (S)	9.3×10^{2}
Barium (CVS)	1.2×10^{0}
Beryllium (ND)	3.1×10^{-1}
Cadmium (food) (K)	2.0×10^{2}
Chromium (K)	6.7×10^{0}
Cobalt (B)	8.0×10^{0}
Manganese (CNS)	2.4×10^{1}
Mercury (K)	3.0×10^{1}

TABLE D.5-21
(Continued)

Silo 3 Contents	
Chemicals	Hazard Quotients
Nickel (CNS)	1.1×10^2
Selenium (S)	1.6×10^1
Silver (S)	4.6×10^1
Thallium (CNS)	3.6×10^1
Uranium (K)	1.3×10^2
Vanadium (ND)	2.9×10^1
Zinc (B)	9.3×10^1
TOTAL HI	**1.7×10^3**
Total HI for B	1.0×10^2
Total HI for CNS	1.7×10^2
Total HI for CVS	6.5×10^0
Total HI for K	3.7×10^2
Total HI for ND	2.9×10^1
Total HI for S	9.9×10^2

[a]Radionuclide and chemical pathways include ingestion of silo waste, ingestion of fruits and vegetables raised on contaminated silo waste, and ingestion of meat and milk from cattle eating feed crops raised on contaminated silo waste. Radionuclide pathways also include external radiation exposure from silo waste and chemical pathways also include dermal contact with silo waste.
[b]Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^0$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
K: Target organ = kidney
ND: Target organ = not determined
S: Target organ = skin

Prior to structural failure of the silos the potential risks to the receptor from the dose rates from the intact silos range from zero (the modeled dose rate is indistinguishable from background) at a location at the base of the K-65 berm to 9 x 10^{-3} at a location on top of the Silo 1 or 2 dome. The risk at a location immediately adjacent to the wall of Silo 3 is 7 x 10^{-5}.

No chemical carcinogens result in ILCR values between 1 x 10^{-6} and 1 x 10^{-4}. Chemicals with an ILCR exceeding 1 x 10^{-4} include arsenic and beryllium. The total ILCR is 4 x 10^{-2}. Ingestion of foodstuffs contaminated by root uptake is the predominant pathway. For the noncarcinogenic effects, HI values greater than 1 are estimated for antimony, arsenic, barium, cadmium, chromium, cobalt, manganese, mercury, nickel, selenium, silver, thallium, vanadium, uranium and zinc. The total HI is 2 x 10^{3}. Target organs with HI values equal to or greater than 1 x 10^{0} include the cardiovascular system (HI = 6 x 10^{0}), attributable to antimony and barium, the skin (HI = 1 x 10^{3}), attributable to arsenic, silver, and selenium, target organ not determined (HI = 3 x 10^{1}), attributable almost entirely to vanadium, the kidney (HI = 4 x 10^{2}), attributable to cadmium, chromium, mercury, and uranium, the central nervous system (HI = 2 x 10^{2}), attributable to nickel, thallium and manganese, and the blood (HI = 1 x 10^{2}), attributable to zinc and cobalt. The foodstuff ingestion pathways are the predominant contributors to the HI values.

Table D.5-22 presents the results for ingestion of drinking water, dermal exposure to water while bathing, inhalation of VOCs, and ingestion of vegetables, milk and meat, modeled from the impact of the silo contents on groundwater from the underlying aquifer (assuming structural failure of the silos).

Radiological exposure pathways include ingestion of contaminated groundwater as drinking water, ingestion of fruits and vegetables irrigated with contaminated groundwater, and ingestion of meat and milk from cattle raised on contaminated water and feed irrigated with contaminated groundwater. The risks from these exposure pathways are 8 x 10^{-6} (U-234), 7 x 10^{-7} (U-235 plus progeny), and 1 x 10^{-5} (U-238 plus progeny). The sum of the radionuclide risks is 2 x 10^{-5}.

No chemical carcinogens were identified as COCs in the groundwater; therefore, no chemical ILCR was calculated. Regarding noncancer effects, uranium, the only COC evaluated, has an HI of 3 x 10^{0}. The target organ for ingestion of uranium is the kidney.

Table D.5-23 presents the results for ingestion of and dermal contact with surface water.

Radiological exposure includes ingestion of surface water while in Paddys Run. The risks from this pathway under current conditions with the silos intact range from 5 x 10^{-14} (Th-232) to 3 x 10^{-9} (U-238 plus progeny). With the silos intact, the risk sum for radionuclides is 4 x 10^{-9} The risks from this pathway under conditions in which the silos suffer structural failure range from 4 x 10^{-11} (Th-232) to 5 x 10^{-7} (U-238 plus progeny). Assuming the silo structures fail, the sum of radiological risks is

TABLE D.5-22

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE ON-PROPERTY RESIDENT CHILD FROM RADIONUCLIDES AND CHEMICALS IN GROUNDWATER UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Aquifer	
Radionuclides	ILCR
U-234	7.6×10^{-6}
U-235 + 1 dtr	6.6×10^{-7}
U-238 + 2 dtrs	1.2×10^{-5}
TOTAL ILCR	**2.0×10^{-5}**
Chemicals	Hazard Quotients
Uranium	3.1×10^{0}
TOTAL HI	**3.1×10^{0}**

[a]Radionuclide pathways include ingestion of groundwater as drinking water, ingestion of fruits and vegetables irrigated with groundwater, and ingestion of meat and milk from cattle drinking groundwater and eating feed crops irrigated with groundwater. Chemical pathways are the same as radionuclide pathways plus dermal contact with groundwater while bathing, and inhalation of VOCs from home water use.

TABLE D.5-23

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE ON-PROPERTY RESIDENT CHILD FROM RADIONUCLIDES AND CHEMICALS IN SURFACE WATER UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	1.6×10^{-11}
Ra-226 + 5 dtrs	1.8×10^{-11}
Ra-228 + 1 dtr	2.8×10^{-12}
Sr-90 + 1 dtr	8.4×10^{-11}
Tc-99	8.6×10^{-11}
Th-230	1.6×10^{-13}
Th-232	5.1×10^{-14}
U-234	4.7×10^{-10}
U-238 + 2 dtrs	3.1×10^{-9}
TOTAL ILCR	**3.8×10^{-9}**
Chemicals	ILCR
Aroclor-1254	2.0×10^{-10}
Benzo(a)anthracene	1.3×10^{-8}
Benzo(a)pyrene	1.0×10^{-7}
Benzo(b)fluoranthene	7.0×10^{-9}
Beryllium	2.5×10^{-10}
bis(2-Ethylhexyl)phthalate	4.2×10^{-12}
Chrysene	1.2×10^{-8}
Dibenzo(a,h)anthracene	4.8×10^{-9}
Indeno(1,2,3-cd)pyrene	2.4×10^{-9}
Methylene chloride	1.8×10^{-11}
TOTAL ILCR	**1.4×10^{-7}**
Chemicals	Hazard Quotients
2-Butanone	3.4×10^{-7}
4-Methyl-2-pentanone	5.9×10^{-8}
Acetone	1.7×10^{-6}

TABLE D.5-23
(Continued)

Soil[b]	
Chemicals	Hazard Quotients
Anthracene	1.4×10^{-7}
Antimony	1.6×10^{-4}
Benzoic acid	1.1×10^{-8}
Beryllium	1.3×10^{-7}
bis(2-Ethylhexyl)phthalate	1.8×10^{-7}
Cadmium (food)	1.1×10^{-5}
Cadmium (water)	2.3×10^{-5}
Chromium	2.8×10^{-6}
Di-n-butylphthalate	4.4×10^{-8}
Fluoranthene	7.2×10^{-7}
Methylene chloride	4.8×10^{-7}
Nickel	2.4×10^{-6}
Phenol	4.7×10^{-7}
Pyrene	5.4×10^{-7}
Silver	1.1×10^{-5}
Thallium	1.1×10^{-6}
Toluene	1.6×10^{-8}
Total xylenes	1.2×10^{-9}
Uranium	6.4×10^{-3}
TOTAL HI	**6.6×10^{-3}**
Silo 3 Contents[c]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	2.0×10^{-9}
Pa-231	5.7×10^{-10}
Pb-210 + 2 dtrs	1.9×10^{-8}
Ra-226 + 5 dtrs	1.2×10^{-8}
Ra-228 + 1 dtr	1.1×10^{-9}
Th-228 + 7 dtrs	2.3×10^{-10}

TABLE D.5-23
(Continued)

Silo 3 Contents[c]	
Radionuclides	ILCR
Th-230	2.3×10^{-9}
Th-232	3.6×10^{-11}
U-235 + 1 dtr	1.8×10^{-8}
U-238 + 2 dtrs	4.8×10^{-7}
TOTAL ILCR	**5.4×10^{-7}**
Chemicals	ILCR
Arsenic	3.6×10^{-7}
Beryllium	1.3×10^{-9}
TOTAL ILCR	**3.6×10^{-7}**
Chemicals	Hazard Quotients
Antimony	1.4×10^{-5}
Arsenic	9.1×10^{-3}
Barium	1.6×10^{-6}
Beryllium	2.3×10^{-6}
Cadmium (food)	9.6×10^{-5}
Cadmium (water)	1.9×10^{-4}
Chromium	2.6×10^{-5}
Cobalt	4.5×10^{-5}
Manganese	1.6×10^{-4}
Mercury	2.4×10^{-4}
Nickel	1.7×10^{-4}
Selenium	9.7×10^{-6}
Silver	1.0×10^{-5}
Thallium	9.5×10^{-5}
Uranium	4.9×10^{-1}
Vanadium	2.5×10^{-4}
Zinc	2.5×10^{-7}
TOTAL HI	**5.0×10^{-1}**

TABLE D.5-23
(Continued)

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[a]Radionuclide pathways include ingestion of surface water in Paddys Run. Chemical pathways include ingestion and dermal contact with surface water in Paddys Run.
[b]Surface water contaminated by runoff from surface soil and berm fill.
[c]Surface water contaminated by runoff from Silo 3 contents.

calculated to be 8×10^{-7}.

No chemical has an ILCR greater than 1×10^{-6} under either current conditions (Silo 3 intact) or future conditions (Silo 3 structural failure). The total ILCR for current conditions is 1×10^{-7}, and future conditions, 4×10^{-7}. No chemical has an HI greater than 1 under either current conditions (Silo 3 intact) or future conditions (Silo 3 structural failure). The total HI values are 6×10^{-3} for current conditions and 5×10^{-1} for future conditions.

Table D.5-24 presents the results for ingestion of sediment and dermal contact with sediment contaminated by the chemicals which gained access to perched water from leachate B (assuming structural failure of the silos).

Radiological exposure includes ingestion of sediment while in Paddys Run. This pathway addresses the potential impact of perched water in the sand lens beneath the silos on sediment in Paddys Run assuming that this water seeps from the sand lens directly into the streambed. Sediment exposure point concentrations are conservatively estimated based on transport modeling from the silo waste source terms. The risks from this pathway range from 8×10^{-17} (Th-232) to 1.0×10^{0} (Pb-210 plus progeny). Radionuclides for which the risk exceeds 1×10^{-6} include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, and Ra-226 plus progeny. The calculated sum of radiological risks is due almost entirely to the contribution from Pb-210 and progeny.

The only chemical carcinogen with an ILCR greater than 1×10^{-6} is arsenic, which has an ILCR greater than 1×10^{-4}. The total ILCR is 2×10^{-4}, which is attributable almost entirely to arsenic. For noncancer effects, arsenic, thallium and vanadium have HI values greater than 1. The total HI is 1×10^{1}. Target organs with HI values equal to or greater than 1×10^{0} include the skin (HI = 5×10^{0}), attributable largely to arsenic, target organ not determined (HI = 2×10^{0}), attributable almost entirely to vanadium, and the central nervous system (HI = 5×10^{0}), attributable largely to thallium.

Table D.5-25 presents the results for inhalation of VOCs, fugitive dust and radon, and for ingestion of fruits and vegetables, milk and meat contaminated by pathways involving air deposition.

Radiological exposure includes inhalation of resuspended particulates and radon emissions, ingestion of fruits and vegetables subject to contamination by air deposition on crops, and ingestion of meat and milk from cattle raised on feed subject to contamination by air deposition on feed crops. These exposure pathways are evaluated under existing conditions with the silos intact and under conditions assuming silo structural failure occurs. Under existing conditions with the silos intact the risks range from 4×10^{-9} (Ra-228 plus progeny) to 4×10^{-6} (Rn-222 plus progeny). The radiological risk sum is 5×10^{-6}. Under conditions in which the silos suffer structural failure risks range from 5×10^{-8}

TABLE D.5-24

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE ON-PROPERTY RESIDENT CHILD FROM RADIONUCLIDES AND CHEMICALS IN SEDIMENT UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Sediment	
Radionuclides	ILCR
Ac-227 + 7 dtrs	1.0×10^{-5}
Pa-231	2.3×10^{-6}
Pb-210 + 2 dtrs[a]	1.0×10^{0}
Ra-226 + 5 dtrs	1.0×10^{-5}
Ra-228 + 1 dtr	8.9×10^{-7}
Th-228 + 7 dtrs[b]	4.4×10^{-7}
Th-232	7.7×10^{-17}
U-234	1.2×10^{-10}
U-235 + 1 dtr	5.3×10^{-12}
U-238 + 2 dtrs	2.1×10^{-10}
TOTAL ILCR	**1.0×10^{0}**
Chemicals	ILCR
Arsenic	2.1×10^{-4}
Beryllium	8.4×10^{-8}
TOTAL ILCR	**2.1×10^{-4}**
Chemicals	Hazard Quotients
Antimony (CVS)[c]	8.7×10^{-3}
Arsenic (S)	4.6×10^{0}
Barium (CVS)	5.5×10^{-6}
Beryllium (ND)	4.6×10^{-5}
Boron (T)	1.7×10^{-6}
Cadmium (Water) (K)	9.3×10^{-1}
Chromium (K)	1.4×10^{-5}
Cobalt (B)	8.8×10^{-1}
Manganese (CNS)	2.9×10^{-6}
Mercury (K)	1.5×10^{-5}

TABLE D.5-24
(Continued)

Sediment	
Chemicals	Hazard Quotients
Molybdenum (B)	1.8×10^{-4}
Nickel (CNS)	1.6×10^{-2}
Selenium (S)	2.6×10^{-1}
Silver (S)	3.6×10^{-4}
Thallium (CNS)	4.5×10^{0}
Uranium (K)	4.5×10^{-4}
Vanadium (ND)	1.6×10^{0}
Zinc (B)	1.3×10^{-4}
TOTAL HI	**1.3×10^{1}**
Total HI for CNS	4.5×10^{0}
Total HI for ND	1.6×10^{0}
Total HI for S	4.9×10^{0}

[a] Impact of Po-210 is contained within Pb-210 + dtrs.
[b] Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[c] Target organ information for oral exposure is provided for all chemicals. HI values are summed for common target organs; HI sums $\geq 1 \times 10^{0}$ are presented.

B: Target organ = blood
CNS: Target organ = central nervous system
CVS: Target organ = cardiovascular system
K: Target organ = kidney
ND: Target organ = not determined
S: Target organ = skin
T: Target organ = testis

TABLE D.5-25

INCREMENTAL LIFETIME CANCER RISKS AND HAZARD QUOTIENTS TO THE ON-PROPERTY RESIDENT CHILD FROM RADIONUCLIDES AND CHEMICALS IN AIR UNDER FUTURE LAND USE WITHOUT ACCESS CONTROLS - ALL PATHWAYS[a]

Soil[b]	
Radionuclides	ILCR
Pb-210 + 2 dtrs	1.6×10^{-8}
Ra-226 + 5 dtrs	2.0×10^{-8}
Ra-228 + 1 dtr	4.1×10^{-9}
Rn-222 + 4 dtrs	4.3×10^{-6}
Sr-90 + 1 dtr	7.0×10^{-8}
Tc-99	5.9×10^{-8}
Th-228 + 7 dtrs[c]	9.2×10^{-9}
Th-230	1.1×10^{-7}
Th-232	4.3×10^{-9}
U-234	7.1×10^{-8}
U-238 + 2 dtrs	4.8×10^{-7}
TOTAL ILCR	**5.1×10^{-6}**
Chemicals	ILCR
Benzo(a)anthracene	6.1×10^{-9}
Benzo(a)pyrene	5.3×10^{-9}
Benzo(b)fluoranthene	8.3×10^{-9}
Beryllium	1.4×10^{-8}
Cadmium	6.9×10^{-8}
Chromium	1.7×10^{-6}
Chrysene	5.6×10^{-9}
Dibenzo(a,h)anthracene	3.6×10^{-9}
Indeno(1,2,3-c,d)pyrene	6.3×10^{-9}
Methylene chloride	6.2×10^{-14}
Nickel	5.4×10^{-8}
TOTAL ILCR	**1.8×10^{-6}**

TABLE D.5-25
(continued)

Soil[b]	
Chemicals	Hazard Quotients
2-Butanone	4.5×10^{-10}
Beryllium	1.4×10^{-10}
Cadmium	7.4×10^{-8}
Chromium	6.0×10^{-9}
Methylene chloride	5.8×10^{-10}
Nickel	6.3×10^{-9}
Toluene	4.8×10^{-9}
TOTAL HI	**9.2×10^{-8}**
Silo 3 Contents[d]	
Radionuclides	ILCR
Ac-227 + 7 dtrs	3.6×10^{-5}
Pa-231	2.1×10^{-5}
Pb-210 + 2 dtrs	9.2×10^{-5}
Ra-226 + 5 dtrs	2.0×10^{-5}
Ra-228 + 1 dtr	1.1×10^{-6}
Rn-222 + 4 dtrs	1.5×10^{-4}
Sr-90 + 1 dtr	6.4×10^{-8}
Tc-99	5.3×10^{-8}
Th-228 + 7 dtrs	6.0×10^{-5}
Th-230	9.9×10^{-4}
Th-232	1.4×10^{-5}
U-234	3.0×10^{-5}
U-235 + 1 dtr	1.7×10^{-6}
U-238 + 2 dtrs	5.5×10^{-5}
TOTAL ILCR	**1.5×10^{-3}**
Chemicals	ILCR
Arsenic	7.0×10^{-5}
Benzo(a)anthracene	5.6×10^{-9}
Benzo(a)pyrene	4.8×10^{-9}

TABLE D.5-25
(continued)

Silo 3 Contents[d]	
Chemicals	ILCR
Benzo(b)fluoranthene	7.6×10^{-9}
Beryllium	3.7×10^{-7}
Cadmium	9.3×10^{-7}
Chromium	2.4×10^{-5}
Chrysene	5.1×10^{-9}
Dibenzo(a,h)anthracene	3.3×10^{-9}
Indeno(1,2,3-c,d)pyrene	5.8×10^{-9}
Methylene chloride	6.2×10^{-14}
Nickel	5.4×10^{-6}
TOTAL ILCR	**1.0×10^{-4}**
Chemicals	Hazard Quotients
2-Butanone (R)[e]	4.5×10^{-10}
Antimony (R)	2.9×10^{-8}
Arsenic (S)	9.0×10^{-6}
Barium (R)	3.2×10^{-2}
Beryllium (R)	3.6×10^{-9}
Cadmium (K)	9.9×10^{-7}
Chromium (R)	8.7×10^{-8}
Cobalt (R)	1.6×10^{2}
Manganese (CNS)	8.1×10^{-1}
Mercury (K)	1.4×10^{-4}
Methylene chloride (L)	5.8×10^{-10}
Nickel (R)	6.3×10^{-7}
Selenium (S)	1.4×10^{-7}
Silver (ND)	2.3×10^{-7}
Thallium (CNS)	1.3×10^{-6}
Toluene (CNS)	4.8×10^{-9}
Vanadium (R)	3.2×10^{-7}
Zinc (R)	4.3×10^{-7}

TABLE D.5-25
(continued)

Silo 3 Contents[d]	
Chemicals	Hazard Quotients
TOTAL HI	**1.6×10^2**
Total HI for R	1.6×10^2

[a]Radionuclide and chemical pathways include inhalation of fugitive dust, VOCs, and radon, and ingestion of fruits and vegetables and meat and milk from cattle subject to air deposition of contaminants on food and feed crops.
[b]Air contaminated by volatilization or fugitive dust from surface soil and berm fill (Silo 3 intact).
[c]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d]Air contaminated by volatilization or fugitive dust from Silo 3 contents (Silo 3 structural failure).
[e]Target organ information for inhalation exposure is provided for all chemicals. HI values are summed for common target organs; HI $\geq 1 \times 10^0$ are presented.

CNS: Target organ = central nervous system
K: Target organ = kidney
L: Target organ = liver
ND: Target organ = not determined
R: Target organ = respiratory system
S: Target organ = skin

(Tc-99) to 1 x 10^{-3} (Th-230). Radionuclides for which the risk exceeds 1 x 10^{-6} under existing conditions with the silos intact include only Rn-222 plus progeny. Radionuclides for which the risk exceeds 1 x 10^{-6} under conditions assuming silo structural failure include Ac-227 plus progeny, Pa-231, Pb-210 plus progeny, Ra-226 plus progeny, Ra-228 plus progeny, Rn-222 plus progeny, Th-228 plus progeny, Th-230, Th-232, U-234, U-235 plus progeny, and U-238 plus progeny. The sum of radiological risks is approximately 2 x 10^{-3}, assuming silo structural failure.

Under current conditions (Silo 3 intact), chromium results in an ILCR between 1 x 10^{-6} and 1 x 10^{-4}. No chemical carcinogen results in an ILCR greater than 1 x 10^{-4}. The total ILCR for current conditions is 2 x 10^{-6}, which is attributable largely to chromium. Under future conditions (Silo 3 structural failure), chemical carcinogens resulting in ILCR values between 1 x 10^{-6} and 1 x 10^{-4} include arsenic, chromium and nickel. No chemical carcinogens result in ILCR values greater than 1 x 10^{-4}. The total ILCR for future conditions is 1 x 10^{-4}. Virtually all of the cancer risk arises from direct inhalation of fugitive dust; the risk associated with foliar deposition and ingestion pathways is negligible.

Under current conditions (Silo 3 intact), no chemical results in an HI greater than 1. The total HI for current conditions is 9 x 10^{-8}. Under future conditions (Silo 3 structural failure), cobalt has an HI value greater than 1. The total HI for future conditions is 2 x 10^{2}. Target organs with HI values equal to or greater than 1 x 10^{0} are limited to the respiratory system (HI = 2 x 10^{2}), attributable almost entirely to cobalt.

The EPA UBK lead model can be applied only to the on-property resident child age 1-6 years for the future land use scenario, because all other potential receptors are greater than 0-6 years of age. Background blood lead concentrations, which reflect the body burden of lead at birth and excretory processes over the 7-year evaluation period, were estimated by setting the lead concentrations in all media equal to zero. In order to estimate the pathway-specific contribution to blood lead concentration, the lead concentrations in the media and pathways not being evaluated were set equal to zero. The background blood lead concentrations were subtracted from the blood lead concentrations generated for the pathway of interest to estimate the contribution to blood lead concentration from the pathway of interest. The estimation of pathway-specific contribution to blood lead concentration is not precise because the relationship between lead intake and blood lead concentration is not linear.

The future land use scenario assumes that the silos have failed, and that the silo contents contribute to the same exposure pathways associated with surface soil. Potential pathways of exposure to lead include:

- Soil/silo contents: inhalation of lead in fugitive dust, incidental ingestion of lead in soil, ingestion of lead in fruits and vegetables, and ingestion of lead in meat and milk

- Groundwater: ingestion of drinking water, ingestion of fruits and vegetables, ingestion of meat and milk

- Surface water/sediment: incidental ingestion of surface water and sediment while playing.

Although dermal contact with lead from any of the sources listed above is possible, the EPA UBK model ignores dermal exposure because dermal uptake of lead is negligible. Furthermore, lead was determined not to be a constituent of concern in groundwater; therefore, the only pathways evaluated include those for lead in soil/silo contents and for lead in surface water and sediment.

The concentration of lead in air arising from fugitive dust from the surface soil and silo contents was estimated at 0.39 $\mu g/m^3$. By applying the model described in Section D.5.2, and setting a hypothetical noncancer toxicity value for lead equal to 1 mg/kg/day, unit toxicity factors of 1.06×10^{-1}, 5.46×10^{-6}, 8.01×10^{-7} and 3.10×10^{-8} were estimated for inhalation of fugitive dust, ingestion of fruits and vegetables, ingestion of milk and ingestion of meat, respectively. Because the unit toxicity factor for inhalation of fugitive dust was more than 4 orders of magnitude greater than the sum of the unit toxicity factors for the ingestion pathways (vegetables and fruits, milk, meat), the contribution from ingestion was ignored in running the EPA UBK model.

Since the EPA UBK model permits neither adjustment of body weight nor input of inhaled dose of lead, the model default respiratory rate was not altered in the estimation of the air-pathway-specific contribution to blood lead concentration. Because the receptor of interest is located on-property and could be subjected to the same lead concentration in indoor and outdoor air, the lead concentration of indoor air was assumed to be 0.39 $\mu g/m^3$. Calculated as described above, the increment in blood lead concentration attributed to exposure to contaminated air ranged from 0.07 µg/dL for 0.5-1 years to 0.25 µg/dL for 6-7 years.

By applying the model described in Section D.5.2, setting the concentration of lead in soil equal to 1 mg/kg, and setting a hypothetical noncancer toxicity value for lead equal to 1 mg/kg/day, unit toxicity factors of 1.28×10^{-5}, 8.64×10^{-5}, 1.62×10^{-5} and 6.26×10^{-7} were estimated for ingestion of soil, ingestion of fruits and vegetables, ingestion of milk and ingestion of meat, respectively. These unit toxicity factors were then used as the intake variables in contaminant intake equations D.3-2 (soil ingestion), D.3-8 (ingestion of fruits and vegetables) and D.3-12 (ingestion of milk and meat). These equations were rearranged and solved for the term representing the concentration of lead in each of these media. Because the concentration of lead in soil was assigned a value of 1 mg/kg, the media concentration values obtained are concentration factors which, when multiplied by the actual concentration of lead in the soil, yield the actual concentration of lead in each medium. The concentration factors obtained are 1.00, 0.0133, 0.000282 and 0.000338 for lead in soil, fruits and vegetables, milk, and meat, respectively.

The concentration of lead in the surface soil and berm fill was estimated at 13.6 mg/kg. Using the concentration factors derived above, corresponding lead concentrations in the fruits and vegetables, milk, and meat were 0.181 mg/kg, 0.00384 mg/L, and 0.00460 mg/kg, respectively. From the contaminant intake equations listed above, and the exposure parameters presented in Table D.3-12, lead intakes of 0.174, 1.17, 0.221 and 0.00853 µg/kg/day were calculated for ingestion of soil, fruits and vegetables, milk, and meat, respectively, for the on-property resident child. Together, the dietary components contribute 1.40 µg/day of ingested lead. The contribution of airborne lead in dust from soil to lead concentrations in ingested foodstuffs is considered to be negligible compared with root uptake.

As noted above, the contribution to ingested lead from contaminated soil includes 0.174 µg/day from direct ingestion of soil and 1.40 µg/day from dietary components. Lead intake from the dietary components was input directly into the EPA UBK model; lead intake from the contaminated soil was input as daily ingestion of 1 g of soil containing 0.174 µg of lead per g of soil. Calculated as described above, the increment in blood lead concentration attributed to ingestion of contaminated soil and dietary components ranged from 0.21 to 0.23 µg/dL.

The concentration of lead in the silo contents was estimated at 2377 mg/kg. Using the concentration factors derived above, corresponding lead concentrations in the fruits and vegetables, milk, and meat were 31.6 mg/kg, 0.670 mg/L, and 0.803 mg/kg, respectively. From the contaminant intake equations listed above, and the exposure parameters presented in Table D.3-12, lead intakes of 30.4, 205, 38.5 and 1.49 µg/kg/day were calculated for ingestion of silo contents, fruits and vegetables, milk, and meat, respectively, for the on-property resident child. Together, the dietary components contribute 245 µg/day of ingested lead. The contribution of airborne lead in dust from silo contents to lead concentrations in ingested foodstuffs is considered to be negligible.

As noted above, the contribution to ingested lead from silo contents includes 30.4 µg/day from direct ingestion of silo contents and 245 µg/day from dietary components. Lead intake from the dietary components was input directly; lead intake from the contaminated silo contents was input as daily ingestion of 1 g of "soil" containing 30.4 µg of lead per g of "soil." The increment in blood lead concentration attributed to ingestion of contaminated silo contents and dietary components, calculated as described above, ranged from 37.93 to 39.94 µg/dL.

The concentration of lead in surface water arising from runoff from the surface soil is estimated at 0.000054 mg/L. Incidental ingestion of 0.000342 L of surface water per day while swimming or playing was estimated from the parameters for ingestion of 0.05 L/hour, 0.5 hours/day, and 5 days/year (Table D.3-12). Both the lead concentration in water and the incidental surface water ingestion rate of 0.000342 L/day were directly input into the EPA UBK model. Modeled blood lead concentrations were indistinguishable from background.

The concentration of lead in surface water arising from runoff from the silo contents is estimated at 0.0046 mg/L. Incidental ingestion of 0.000342 L of surface water per day while swimming or playing was estimated from the parameters of 0.05 L/hour, 0.5 hours/day, and 5 days/year (Table D.3-12). Both the lead concentration in water and the incidental surface water ingestion rate of 0.000342 L/day were directly input into the EPA UBK model. Modeled blood lead concentrations were indistinguishable from background.

The concentration of lead in the sediment arising from the perched water in the sand lens is estimated at 0.306 mg/kg. Incidental ingestion of 0.192 g of sediment per day was estimated from the parameters for ingestion of 0.2 g of soil/day, 350 days/year (Table D.3-12). Both the lead concentration in sediment and the daily sediment ingestion rate of 0.192 g of sediment per day were directly input into the EPA UBK model. The increment in blood lead concentration attributed to ingestion of sediment, calculated as described above, ranged from 0.0 to 0.01 µg/dL.

D.5.3.2.4 Off-Property Resident Farmer

The ILCR and HI results for radionuclide and chemical COCs for the off-property resident farmer under the future and current land use scenarios are identical. Therefore, please see Section D.5.3.1.3 for the ILCR and HI results for the off-property resident farmer under the future land use scenario.

D.5.3.2.5 Off-Property User of Surface Water

The ILCR and HI results for radionuclide and chemical COCs for the off-property user of surface water under the future and current land use scenarios are identical. Therefore, please see Section D.5.3.1.4 for the ILCR and HI results for the off-property user of surface water under the future land use scenario.

D.6.0 UNCERTAINTIES

This section contains the evaluation of uncertainties inherent in the risk assessment process. Uncertainty is a factor in each step of the exposure and toxicity assessment process, and can involve variations in sample analytical results, the values of variables used as input to a given model, the accuracy with which the model itself represents actual environmental or biological processes, the manner in which the exposure scenario is developed, and the high-to-low dose and interspecies extrapolations for dose-response relationships. Each of these categories of potential uncertainty is discussed in this section.

D.6.1 TERMINOLOGY

Generally, risk assessments carry two types of uncertainty, and each merits consideration. Measurement uncertainty refers to the usual variance that accompanies scientific measurements (such as the range of an exposure estimate) and reflects the accumulated variances of the individual measured values used to develop the estimate. A different kind of uncertainty arises if information needed to complete the database for the assessment is unavailable. In some instances, the impact is significant, such as the absence of information on the effects of human exposure to a chemical or on the biological mechanism of action of an agent (EPA 1992c). In other instances, the overall impact can be minimized using the information available coupled with reasonable assumptions to place an upper bound on the uncertainty in the risk assessment.

Once the risk assessment is completed, its results must be reviewed and evaluated to identify the type and degree of uncertainty involved. The results of the evaluation should be considered when using the risk assessment results for remedial decision making. Decision-makers, as well as the general public, who rely only on a simplified numerical presentation without considering uncertainties, limitations, and assumptions inherent in the risk assessment process can be misled.

For example, a small impact of 1×10^{-6} lifetime risk of cancer may be calculated for an individual from exposure to a particular source of contamination. However, if the uncertainty in this number is orders of magnitude, the real risk from this source of contamination may in fact be higher than the risk from another contaminated source that has a calculated risk of 1×10^{-5} lifetime risk of cancer but has a small degree of uncertainty. Alternatively, an upper bound lifetime risk of 1×10^{-2} may be calculated and appear to represent an unacceptable risk. However, the actual risk may be one, two, or even three orders of magnitude smaller. This situation often occurs when, due to limited information and uncertainty in the calculational parameters, conservative assumptions on lifestyles and land use scenarios, and maximum or near-maximum values for almost all modeling and exposure variables are used throughout the calculation in order to ensure that the risks are not underestimated. Health risk assessments for an RME individual for Operable Unit 4 are based on such conservatism. Although it is possible that such an exposure, dose, or sensitivity combination might occur in a given population

of interest, the probability of the RME individual receiving this combination of events and conditions is usually small, and often so small that such a combination will not occur in an actual receptor population. Characterization of risk based on overly conservative model parameters, scenarios, and assumptions does not convey "real world" information (EPA 1992c) and is often misleading. A risk estimate for an RME individual may be mistakenly viewed as an average risk to all individuals (EPA 1992c). Currently, Superfund risk assessments based on the "Risk Assessment Guidance for Superfund" (EPA 1989a) yield calculated risks only for RME individuals, with risk estimates actually exceeding the high end risk.

The new EPA guidance on risk assessment issued in February 1992 (EPA 1992c) urges risk assessors to address or provide descriptions of individual risk to include the "high end" portions and "central tendency" of the risk distribution. This corresponds to the reasonable conservatism and non-conservatism, respectively, of the scenarios for the risk assessment. The high end of the risk distribution is, conceptually, above the 90th percentile of the actual (either measured or estimated) distribution, but not higher than the risk to an individual in the population who has the highest risk. If only limited information on the distribution of the exposure or dose factors is available, the assessor should approach estimating the high end risk by identifying the most sensitive parameters and using maximum or near-maximum values for one or a few of these variables, leaving others at their mean values (EPA 1992c). The risk descriptor addressing CT may be either the arithmetic mean risk ("Average Estimate") or the median risk ("Median Estimate"). The Average and Median Estimates can be derived by using average and median values, respectively, for all of the factors in the risk assessment (EPA 1992c).

In an attempt to incorporate the new concepts of Average and Medium Estimates for health risk calculations, the risk assessment for Operable Unit 4 includes an exposure scenario for average (or "typical") lifestyle conditions (e.g., average duration/frequency of exposure) for resident farmers. Based on the future land use scenario, resident farmers comprise the most important subgroups for exposures. This additional "typical" scenario does not provide a full CT risk descriptor because most of the exposure and modeling parameters use maximum or near-maximum values, leading to an estimated risk considerably higher than the 90th percentile of the actual range (i.e., the high end risk). Nevertheless, this attempt to characterize risk based on the new EPA risk assessment presents a more realistic estimate of risk within the range of different exposure conditions. Efforts to incorporate the guidance will continue as more exposure data at the FEMP become available and the additional guidance on estimating CT is completed by EPA. The ultimate goal of the risk assessment process is to provide an objective, realistic, and balanced risk estimate for risk management at the FEMP.

D.6.2 SOURCES OF UNCERTAINTY

As noted previously, uncertainties are associated with the information and data used in each phase of the Operable Unit 4 baseline risk assessment. These uncertainties are due to a number of factors,

including the conservative bias of parameters, parameter variability (random errors or natural variations), and the necessity of using computer models to predict complex environmental interactions. Uncertainties also arise from the use of animal data to predict the toxic effects and the toxic potency in humans. As EPA has pointed out in their guidance for human health risk assessments, "it is more important to identify the key site-related variables and assumptions that contribute most to the uncertainty than to precisely quantify the degree of uncertainty in the risk assessment" (EPA 1989a). Uncertainties associated with information and data are evaluated in this section to provide the spectrum of information in regard to the overall quality of the risk assessment results.

D.6.2.1 Exposure Assessment

Uncertainties in the exposure assessment are traceable to two major steps in the process. The first source is the process used to determine the constituents of concern and estimate exposure point concentrations. The second major source of uncertainty in the exposure assessment is the selection of exposure parameters used to describe the behavior of various hypothetical receptors.

D.6.2.1.1 Constituents of Concern Selection

The selection of which contaminants to evaluate is a potential source of uncertainty in any risk assessment for the generic reasons previously discussed. The selection of constituents of concern (COC) for Operable Unit 4 is less uncertain than for other operable units because the primary source term in the operable unit is the waste contained inside Silos 1, 2, and 3. The nature of this waste, which contains significant quantities and concentrations of radionuclides and chemicals, dictates that virtually all of these chemicals and radionuclides must be selected as COCs. Additional uncertainty arises from the fact that the soil samples may not be representative of conditions at the surface of the soil. Samples for nonradioactive chemicals were taken from depths of 0 to 2 feet from the waste pit runoff sampling program, and from 0 to 5 feet from the K-65 berm sampling program. The cumulative impact of these uncertainties on the results of the exposure and risk assessments is unclear. However, these uncertainties concerning the representativeness of the soil data for Operable Unit 4 can be expected to have a small impact on the risk assessment compared to other uncertainties in the risk assessment process because the levels of contamination in the soils are comparatively low.

D.6.2.1.2 Exposure Point Concentrations

The material in the silos is heterogeneous in nature. To obtain samples from the most contaminated areas, samples were often collected from the locations having the highest radiation measurement results. Selection of sampling locations in this way leads to a conservative bias for certain radionuclides and uncertainty in the representativeness of the samples. Sample analytical results for the silo waste are used as exposure point concentrations in scenarios that assume silo structural failure and subsequent release of waste material into the environment.

Sample analytical techniques produce results that have a degree of uncertainty associated with them. These uncertainties are documented by using laboratory and validation data qualifiers to identify the uncertainty of measurement results. These data qualifiers affect the exposure point concentrations (either measured or modeled) that are based on analytical results. The current method for calculating exposure point concentrations assumes that contaminants are uniformly distributed throughout the medium. It is possible that some pockets of elevated contamination have not been identified, or that elevated pockets of contamination are used to represent a uniform distribution of contamination.

According to the "Risk Assessment Guidance for Superfund" (EPA 1989a), the UCLs are used for all exposure concentrations. This means that 95 percent of the time, the actual mean concentration will be less than the value used in the exposure assessment. Conversely, 5 percent of the time the actual mean concentration will be greater than the value used in the exposure assessment. Also, because UCLs are calculated for the entire waste area, including data from localized contamination not present throughout the entire waste area, UCLs are conservative. This conservatism is in addition to the previously described conservative sample bias.

Many additional uncertainties are associated with the predicted exposure point concentrations for air and groundwater used in exposure scenarios for Operable Unit 4 that are developed using transport models. Due to the complexity of natural environments, simplifying assumptions are used to develop these modeled concentrations. Each assumption carries with it a level of uncertainty that combines with uncertainties associated with other assumptions. In addition, most model parameter values used maximize estimates of transport (and hence risk). Thus the uncertainties associated with modeled concentrations are generally much larger than those associated with measured concentration data. One of the major sources of uncertainty in the groundwater modeling is the process of developing the leachate source term for the vadose zone modeling. One of the major sources of uncertainty in the air modeling is the assumption that there is no vegetative cover to inhibit fugitive dust emissions. This assumption is likely to overestimate the exposure point concentrations. Models were also used to calculate concentrations in plants and animals. Each time concentrations at one level in the food chain are extrapolated from a lower level, uncertainty is introduced into the result.

D.6.2.1.3 Exposure Factors

Each exposure factor value selected for use in this risk assessment has some uncertainty associated with it. These factors are usually based on surveys of physiological and lifestyle profiles across the United States. The attributes and activities studied in these surveys generally have a broad distribution. To account for most of this distribution, this risk assessment follows EPA's recommendation of using the 95th percentile for most of the exposure factors used in this risk assessment. This introduces a conservative bias into the results.

The major source of uncertainty associated with predicting future exposures at the FEMP is the future disposition of the property itself. Because it is not possible to accurately predict what future uses of the land may be, or what the condition of the silos may be in the future, the most conservative (rather than the most likely) future land use is evaluated, as stipulated by the National Oil and Hazardous Substance Pollution Contingency Plan (NCP).

D.6.3 TOXICITY ASSESSMENT

Considerable uncertainty is associated with the qualitative (hazard assessment) and quantitative (dose-response) evaluations of a Superfund risk assessment. The hazard assessment deals with characterizing the nature and strength of the evidence of causation, or the likelihood that a chemical that induces adverse effects in animals will induce adverse effects in humans. Hazard assessment of carcinogenicity is evaluated as a weight-of-evidence determination, using either the IARC (1987) or EPA (1986b) schemes. Positive animal cancer test data suggest that humans contain tissue(s) that may also manifest a carcinogenic response; however, the animal data cannot necessarily be used to predict the target tissue in humans. In the hazard assessment of noncancer effects, however, positive animal data suggest the nature of the effects (i.e., the target tissues and type of effects) anticipated in humans (EPA, 1989g).

Uncertainty in hazard assessment arises from the nature and quality (sensitivity and selectivity) of the animal and human data. Uncertainty is decreased when similar effects are observed across species, strain, sex, and exposure route; when the magnitude of the response is clearly dose-related; when pharmacokinetic data indicate a similar fate in animals and humans; when postulated mechanisms of toxicity are similar for humans and animals; and when the constituent of concern is structurally similar to other chemicals for which the toxicity is more completely characterized. A unique source of uncertainty in cancer hazard assessment involves the relevance of liver tumors in strains of mice with a high background incidence, especially when these tumors provide the only positive response (Scala, 1991). Many chlorinated organic chemicals in EPA cancer weight-of-evidence Group B2 fall into this category.

There are many sources of uncertainty in the dose-response evaluation for cancer (i.e., computation of a slope factor or unit risk) and noncancer effects (i.e., computation of an RfD or RfC). First is the uncertainty regarding interspecies (animal-to-human) extrapolation, which, in the absence of quantitative pharmacokinetic, dosimetric, or mechanistic data, is usually based on consideration of interspecies differences in basal metabolic rate. Second is the uncertainty regarding intraspecies, or individual, variation. Most toxicity experiments are performed with animals that are very similar in age and genotype, so that intragroup biological variation is minimal, but the human population of concern may reflect a great deal of heterogeneity including unusual sensitivity to the constituent of concern. Even toxicity data from human occupational exposure reflect a bias because only those individuals sufficiently healthy to attend work regularly, and those not unusually sensitive to the

COCs, are likely to be occupationally exposed. Third, uncertainty arises from the quality of the key study (from which the quantitative estimate is derived) and the database. For cancer effects, the uncertainty associated with some quality factors (e.g., group size) is expressed within the 95 percent upper bound of the slope factor. For noncancer effects, additional uncertainty factors may be applied in the derivation of the RfD or RfC to reflect poor quality of the key study or gaps in the database.

Another source of uncertainty regarding quantitative risk estimation for carcinogenicity is the method by which data from high doses in animal studies are extrapolated to the dose range expected for environmentally exposed humans. The linearized multistage model, which is used in nearly all quantitative estimations of human risk from animal data, is based on a nonthreshold assumption of carcinogenesis. An impressive body of evidence, however, suggests that epigenetic carcinogens, as well as many genotoxic carcinogens, have a threshold below which they are noncarcinogenic (Williams and Weisburger 1991). Use of the linearized multistage model is unnecessarily conservative for chemicals that exhibit a threshold for carcinogenicity.

A further source of uncertainty for noncancer effects arises from use of an effect level in the estimation of an RfD or RfC, because this estimation is predicated on the assumption of a threshold below which adverse effects are not expected. Therefore, an additional uncertainty factor is usually applied to estimate a no-effect level. Additional uncertainty arises from estimation of an RfD or RfC for chronic exposure from less than chronic data. Unless empirical data indicate that effects do not worsen with increasing duration of exposure, an additional uncertainty factor is applied to the no-effect level in the less-than-chronic study.

The level of uncertainty for different chemicals varies because information concerning some constituents and their associated health effects is comparatively scarce, while for others there is much more information available from health effects studies. For example, uranium has been established as a chemical toxicant based on human and animal studies. The RfD for uranium is based on results of animal studies and is calculated by applying an uncertainty factor of 1000 to an LOAEL for mephrotoxicity in rabbits to provide a margin of safety for extrapolation to humans. The uncertainty factor consists of three factors of 10 each for estimation of an NOAEL from an LOAEL, extrapolation from animals to humans, and for the range of sensitivities among exposed humans.

There is also uncertainty regarding the carcinogenicity of the constituents of concern. For example, uranium as an alpha-particle emitter is also considered to be a carcinogen; however, epidemiological evidence of uranium-induced excess cancer risks are very difficult to obtain. This is largely because the human data available for radiocarcinogenic effects of uranium exposure are for underground miners, who are also simultaneously exposed to radon and radon progeny as a confounding factor. The studies of humans sometimes lack quantitative information concerning uranium exposure, potential uranium exposure through previous employment, concurrent smoking patterns, or concurrent radon

exposure levels, which are needed to more definitively determine the risk attributable to uranium exposure. These facts weaken the power of the human studies to detect any excess risk. The human studies of cancer from exposure to uranium frequently reveal a slight excess risk (if any) above the natural risk. These uncertainties are not well known or easily quantified.

D.6.4 UNCERTAINTY ANALYSIS FOR OPERABLE UNIT 4

Of major importance for risk assessments at the FEMP are the uncertainties associated with each stage of the process. Uncertainties associated with calculations that occur in the early stages of the process are propagated as the calculations are used in the later stages of the process. It is not possible to eliminate all uncertainty from the analysis. Some of the major uncertainties associated with the Operable Unit 4 risk assessment are identified and described below. They are estimated to contribute significant uncertainty to the results of the risk assessment, although the magnitude of the uncertainty cannot be quantified. Table D.6-1 presents uncertainties in the Operable Unit 4 risk assessment. Each is identified, the potential impact on estimated risks is qualitatively estimated, and the direction of bias is specified.

Application of the future land use scenario to the Operable Unit 4 waste area may significantly overestimate future risks. A resident farmer scenario is assumed for future land use for Operable Unit 4. This is highly unlikely, although plausible. The Operable Unit 4 Study Area is too small to support a resident farmer, who is assumed to live, farm, and raise livestock and vegetables on the waste area for 70 years. It is unlikely that the Operable Unit 4 Study Area could fully support these endeavors. Nevertheless, the assumption of the resident farmer for future land use provides the upper bound values for the risk assessment.

The selection of exposure factors for the resident farmer are also conservative. Exposure modeling parameters selected generally represent the habits of a small percentage of the population (usually upper 5 or 10 percent). The effect of the conservative nature of these parameters on the intake and risk modeling is linear. For example, increasing or decreasing drinking water consumption or daily dietary intake by 10 percent would have the effect of increasing or decreasing the estimate of risk by 10 percent. As another example of an overly conservative exposure assumption, receptors are assumed to inhale air at the location of the highest annual average concentration for 8 hours per day for 350 days per year for 70 years. It is unlikely that an actual resident would be exposed at this concentration under this activity pattern.

Uncertainty is inherent in the silo sampling data due to the heterogeneity of the waste forms and the bias introduced in the sampling program. The sampling program implemented does not represent a random sampling. In fact, it intentionally selects samples exhibiting the greatest radiological

TABLE D.6-1

UNCERTAINTIES ASSOCIATED WITH ESTIMATED RISKS
FOR OPERABLE UNIT 4

Source of Uncertainty	Potential Impact on Estimated Risks	Direction of Bias
The applicability of the future resident farmer scenario.	High	Increases conservatism
Bias in silo waste sampling	High for radionuclides	Increases conservatism
Assumptions in geochemical and groundwater and air transport modeling	Moderate to high	Increases conservatism
Impact of sand lens beneath OU4 on groundwater model	Moderate to high	Increases conservatism
Estimated volume of air released from silo head spaces	Moderate to high	Increases conservatism
Environmental transfer factors for contaminants	Moderate to high	Increases conservatism
Contaminant toxicity information	Moderate to high	Increases conservatism
The applicability of the trespassing child scenario under current land use	Moderate	Increases conservatism
Determination of the OU4 RME from all media and exposure routes simultaneously	Moderate	Increases conservatism
Silo headspace radon concentration measurement data	Low	Neutral
High sample quantitation limits (SQLs) for "D"-qualified radiological analytical results in silo waste samples	Low for radionuclides	Decreases conservatism

contamination from each boring zone to ensure detection of any significant concentrations of radionuclides.

Fate and transport modeling contains several major uncertainties. To ensure that concentrations of contaminants in transport media (e.g., air and groundwater) were not underestimated, transport parameters were chosen to calculate the upper bound of possible exposure point concentrations. For air, it was assumed that there was no vegetative cover to inhibit fugitive dust emissions. In addition, silo radon release estimates used in air transport modeling incorporate a conservative bias from application of the Ideal Gas Law, resulting in conservative predictions of airborne risks. Despite this conservative bias, the radon inhalation risk is dominated by the inhalation risk for Th-230 (predominantly from Silo 3) under the scenario that assumes structural failure of the silos. If the radon inhalation risks were actually estimated to be as much as six times greater under the silo structural failure scenario failure scenario, they would equal the inhalation risk for Th-230.

For calculation of future exposure to groundwater, several aspects of the modeling of vertical flow through the glacial overburden to the till introduce major uncertainties. The total mass of each contaminant was calculated by multiplying the UCL by the volume of the entire waste area, thus assuming the UCL concentration is uniformly distributed through the entire source. The uncertainties associated with the UCL also affect soil exposure concentrations.

Another major source of uncertainty in the groundwater modeling process involves development of the leachate source term for the vadose zone modeling. Use of Toxicity Characteristic Leaching Procedure (TCLP) data to characterize leachate concentrations of contaminants in the natural environment adds conservatism to the process because TCLP leaching is performed with an acidic solution. Although this uncertainty could be reduced by using more realistic estimates of potential leachate concentrations, the conservative nature of this uncertainty provides an upper bound on the potential impact of the release scenario and associated potential exposure routes.

An attempt is made to evaluate the impact of the sand lens beneath the FEMP (including the silos) within the context of the groundwater conceptual model for Operable Unit 4. This evaluation utilizes the calculated concentrations of contaminants in leachate predicted to enter the vadose zone from the silo wastes and a dilution factor to derive a conservative estimate of contaminant concentrations in water in the sand lens. In the risk assessment the on-property resident farmer under future land use is assumed to use this water from the sand lens as a sole source of drinking water.

Estimates of the volume of air released each year from the silo headspaces are used to derive radon release rates for Silos 1, 2, and 3 for the current scenario in which the silos remain intact. Estimated volumes of air released are based on application of the Ideal Gas Law assuming that the silos are not capable of sustaining a pressure buildup, a 5°F daily variation in silo headspace air temperature, and

estimates of silo headspace volumes after implementation of the K-65 removal action. The Ideal Gas Law is applicable only at conditions of low pressure and high temperature corresponding to large molar volumes. At conditions resulting in small molal volumes, the attractive forces among the molecules become significant and volume calculations from the Ideal Gas Law tend to be too large. In extreme cases the volume calculated from the Ideal Gas Law can be five times the actual volume. The change in moles of radon gas in Silos 1 and 2 was determined by measurement to be less than 0.2 percent of the average number of moles in each silo in nearly all cases. This indicates that the Ideal Gas Law is conservative when applied to the silos to estimate radon release.

Soil-to-plant transfer factors (B_{iv} values) generally represent the maximum amount of contaminant transfer that may occur. In reality, the contaminant transfer is quite dependent on the metal species, in the same way, soil sorption is dependent on metal solubility. In general, the calculated risk is directly proportional to the transfer factor.

The toxicity information for certain contaminants evaluated in the Operable Unit 4 assessment is a significant source of uncertainty. For example, the cancer weight-of-evidence Group B2 PAHs for which cancer slope factors were not derived were evaluated using the slope factors derived for benzo(a)pyrene. Recent information, however, indicates that the cancer potency of the Group B2 PAHs ranges from 0.0044 to 1.11 times that of benzo(a)pyrene (Thorslund and Charnley, 1988). This indicates that evaluating all the PAHs as equivalent in potency to benzo(a)pyrene leads to an overestimation of the cancer risk of total PAHs.

As another example, the carcinogenicity of all aroclors is assumed to be equivalent to Aroclor-1260, even though the EPA (1992e) acknowledges that there is considerable difference in the carcinogenic potency of the aroclors. A statistically significant cancer response was not seen in animals treated with commercial PCB mixtures containing less than 60 percent chlorine. This observation indicates that the lesser chlorinated aroclors should be classified in Group D rather than Group B2. Because cancer slope factors are not derived for Group D chemicals, it may not be appropriate to evaluate Aroclor-1242, -1248 and -1254 as carcinogens. Application of the slope factor for Aroclor-1260 to the other aroclors may result in a calculated cancer risk being significant when, in fact, there may be no cancer risk.

Version 6.0 of the EPA UBK model was used to estimate the blood lead levels of infants theoretically exposed to contaminated media from Operable Unit 4. In test runs of the model using default exposure parameters, it was learned that errors exist in the source code. For example, altering the plasma-to-urine transition time by several orders of magnitude had no apparent effect on predicted blood lead levels, which indicates that the equations that model renal excretion are not coded into the model. This seriously erodes confidence in the validity of the model. Other sources of uncertainty include the possibility of other undetected errors in the source code, questions regarding the validity of

the equations used in the model, and the applicability of the default parameters to the Operable Unit 4 sites.

The application of the trespassing child receptor under current land use is considered to have moderate impact on the estimated risks. Although it is possible that such an exposure could occur, the likelihood that the combination of exposure parameters used will actually occur is small.

The determination of the RME for Operable Unit 4 considering all media and exposure routes simultaneously incorporates the uncertainties of the exposure assessments for each of the individual exposure routes. However, the magnitude of the uncertainty is not necessarily the sum of the individual uncertainties because consideration of the impacts of multiple exposure routes and media at once can result in an RME receptor at a location that does not correspond to the maximum exposure location for the individual exposure routes and media. Nevertheless, the combination of exposure routes is believed to result in increased conservatism.

Radon release rate calculations for Silos 1, 2, and 3 (silos currently intact) utilize measured radon concentrations to derive results. For example, daily measurements taken during the entire month of December 1992 for Silos 1 and 2 are used to represent the average Silo 1 and 2 headspace radon concentration. These measurements are used to extrapolate an annual radon release rate. It is possible that changes in the season of the year, and associated climatic variations, could result in significant variations in silo headspace radon concentrations. However, examination of Silo 1 and 2 headspace radon concentration data for the balance of the year reveals that the concentration is relatively constant through the seasons of the year.

Available headspace radon concentration data for Silo 3 comprise a small set of only four grab samples collected in September and October of 1990. This is a limited data set; however, the data are used to calculate a conservative UCL radon concentration for the Silo 3 headspace to use in estimating radon release from Silo 3 under the current scenario. The impact of this small data set is actually minor because the Silo 3 radon release estimate for the current air modeling scenario, in which the silos remain intact, is two order of magnitude lower than the Silo 3 radon release estimate for the future air modeling scenario in which silo structural failure is assumed.

Silo contents sample analytical results for radionuclides are qualified with "D" qualifiers in many instances, particularly for Silos 1 and 2. The "D" qualifier indicates a possible false negative result signifying that the indicated contamination could exist at the level reported. Because only one-half of the reported SQL is used in statistical calculations, it is possible that the calculated mean and UCL statistics are underestimated. The Silo 1 and 2 contents sample analytical results for radionuclides have also been statistically evaluated using the reported SQL rather than one-half the SQL. Comparison of the arithmetic means for radionuclides using the SQL with the means using one-half

the SQL (as reported in the October 1992 draft Operable Unit 4 RI Report) reveals that there is little difference for Ac-227, Pb-210, Po-210, Th-230, U-234, U-235, and U-238. The means calculated using one-half the SQL for Pa-231, Ra-226, Th-228, and Th-232 are 40 percent, 150 percent, 44 percent, and 56 percent, respectively, of the corresponding means calculated using the full SQL. Thus, the impact on calculated mean radionuclide concentrations is at most within approximately a factor of two.

This effort to identify potential uncertainties associated with each step of the risk assessment is not intended to discredit the calculation results, but to point out that risks are calculated for hypothetical receptors under a definite, strict method. Refinements of waste area characterization data, exposure assessment models and parameters, and risk characterization information could reduce these uncertainties. There is, however, no added benefit because the risk assessment has succeeded in providing an upper bound that is sufficient for risk managers to make remedial decisions.

D.7.0 SUMMARY

This section contains a summary of risk characterization results from the baseline risk assessment for Operable Unit 4. In addition, a presentation and discussion of the risks associated with exposure to background concentrations of chemicals and radionuclides in soil is included for comparison.

D.7.1 RISK ASSESSMENT RESULTS

The baseline risk assessment is performed in accordance with available EPA guidance for conducting CERCLA risk assessments and the methodology described in the Risk Assessment Work Plan Addendum (DOE 1992a) for performing risk assessments at the FEMP. The process of selecting COCs is summarized in Section D.2.0 in the risk assessment. Tables D.2-3 and D.2-4 list COCs for the waste material inside the K-65 silos and Silo 3 respectively.

The COCs in the K-65 silos include U-238, U-235, U-234, Th-232, Th-230, Th-228, Ra-226, Rn-222, Pb-210, Po-210, Pa-231, and Ac-227; metals including antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, cyanide, lead, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc; and a variety of organic chemicals including aroclors and phthalates. The COCs in Silo 3 include U-238, U-235, U-234, Th-232, Th-230, Th-228, Ra-228, Ra-226, Rn-222, Ra-224, Pb-210, Pa-231, and Ac-227; and metals including arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, zinc, and the following organic materials: 2-nitrophenol and 4-nitrophenol.

Tables D.2-5, D.2-6, and D.2-7 contain a listing of COCs for three data sets including, respectively, surface soil plus berm fill material, berm fill material only, and surface soil only. The summary that represents surface soil plus berm fill material combined is used for the quantitative risk assessment because the data and corresponding data summaries for these three data sets are similar. The COCs for this data set include U-238, U-234, Th-230, Ra-226, Rn-222, Ra-224, Pb-210, Po-210, Sr-90, and Tc-99; metals including antimony, arsenic, beryllium, cadmium, chromium, copper, molybdenum, nickel, silver, thallium, vanadium, and zinc; and a variety of organic chemicals including aroclor, phthalates, and benzo(a)pyrene.

Estimated risks for all receptor exposure pathways quantitatively evaluated under current and future land use scenarios are tabulated in Attachment D.II. Estimated risks summed across pathways within each exposure medium for each receptor under current and future land use conditions are tabulated and discussed in Section D.5.0. Total radiological ILCR, chemical ILCR, and chemical HQ values for each receptor and exposure medium combination are presented in Table D.7-1. Radiological ILCR totals (Table D.7-1) equal to or greater than 10^{-4} are associated with the following exposure media and receptors: soil (for on-property resident receptors), silo contents assuming the future source-term

TABLE D.7-1

TOTAL RADIOLOGICAL AND CHEMICAL RISK

Medium/Source	Type of Risk	Trespassing Child	Grounds Keeper	Off-Property Resident Farmer	Off-Property User Surface Water	CT On-Property Res Farmer	RME On Property Res Farmer	On-Property Resident Child
SOIL Surface Soil and Berm Fill (Current Source-Term Scenario)	Total radiological cancer risk	1.1×10^{-5}	3.1×10^{-5}	NA	NA	1.7×10^{-4}	1.8×10^{-3}	1.6×10^{-4}
	Total chemical cancer risk	6.8×10^{-5}	7.1×10^{-5}	NA	NA	1.1×10^{-4}	4.2×10^{-3}	1.2×10^{-3}
	Total noncancer hazard index	1.2×10^{-1}	6.9×10^{-2}	NA	NA	6.8×10^{0}	1.5×10^{1}	1.1×10^{2}
SILO CONTENTS Silos 1, 2, and 3 (Future Source-Term Scenario)	Total radiological cancer risk	9.4×10^{-3}	2.7×10^{-2}	NA	NA	1.4×10^{-1}	7.8×10^{-1}	1.1×10^{-1}
	Total chemical cancer risk	3.8×10^{-4}	4.7×10^{-4}	NA	NA	7.8×10^{-3}	1.2×10^{-1}	4.3×10^{-2}
	Total noncancer hazard index	1.4×10^{1}	6.3×10^{0}	NA	NA	1.6×10^{2}	4.8×10^{2}	1.7×10^{3}
GROUNDWATER Silos 1, 2, and 3 (Future Source-Term Scenario)	Total radiological cancer risk	NA	NA	1.1×10^{-5}	NA	5.2×10^{-6}	Aquifer 7.3×10^{-5}/ Perched 1.0×10^{0}	2.0×10^{-5}
	Total chemical cancer risk	NA	NA	None	NA	None	Aquifer None/ Perched 1.3×10^{-2}	None
	Total noncancer hazard risk	NA	Na	1.2×10^{-1}	NA	4.6×10^{-1}	Aquifer 8.5×10^{-1} Perched 5.0×10^{1}	3.1×10^{0}
SURFACE WATER Surface Soils, Berm Fill and Silo 3 (Future Source-Term Scenario	Total radiological cancer risk	1.7×10^{-6}	NA	NA	1.2×10^{-6}	NA	NA	5.4×10^{-7}
	Total chemical cancer risk	5.3×10^{-7}	NA	NA	6.7×10^{-7}	NA	NA	3.6×10^{-7}
	Total noncancer hazard index	9.3×10^{-1}	NA	NA	1.3×10^{-2}	NA	NA	5.0×10^{-1}
SEDIMENT Surface Soils, Berm Fill, and Silo 3 (Future Source-Term Scenario)	Total radiological cancer risk	2.3×10^{-1}	NA	NA	NA	NA	NA	1.0×10^{0}
	Total chemical cancer risk	5.3×10^{-6}	NA	NA	NA	NA	NA	2.1×10^{-4}
	Total noncancer hazard index	2.7×10^{-1}	NA	NA	NA	NA	NA	1.2×10^{1}
AIR (Future Source-Term Scenario)	Total radiological cancer risk	8.0×10^{-4}	2.3×10^{-3}	2.2×10^{-3}	NA	3.4×10^{-3}	6.2×10^{-2}	1.5×10^{-3}
	Total chemical cancer risk	2.1×10^{-5}	3.6×10^{-5}	3.5×10^{-5}	NA	5.4×10^{-5}	7.2×10^{-4}	1.0×10^{-4}
	Total noncanacer hazard index	1.7×10^{-1}	1.4×10^{1}	4.8×10^{0}	NA	5.8×10^{1}	1.0×10^{2}	1.6×10^{2}

scenario (for all receptors), perched groundwater assuming the future source-term scenario (for the RME on-property resident), sediment in Paddys Run assuming the future source-term scenario (for the trespassing child and on-property resident child), and air assuming the future source-term scenario (for all receptors). Radiological ILCR totals (Table D.7-1) associated with exposure to the silo contents are much larger than those associated with exposure to any of the other media except sediment and perched groundwater since exposure to the silo contents assumes the future source-term scenario in which silo structural failure occurs, permitting the contents of Silo 3 to spread over the Operable Unit 4 Study Area. Subsequent receptor exposure involves contact with the high contaminant concentrations in this waste. Exposures from groundwater from the Great Miami Aquifer, surface water in Paddys Run, and air are dependent on the impact of environmental transport of the Silo 3 waste to these exposure media. This impact is to dilute the receptor exposure point concentrations and reduce the corresponding receptor risks.

The exception noted for sediment and perched groundwater is attributable to the particularly conservative assumptions inherent in the environmental transport assessment performed for these two exposure media.

The chemical ILCR total (Table D.7-1) for at least one receptor is equal to or greater than 10^{-4} for each exposure medium except surface water. Chemical ILCR values for all receptors exposed directly (ingestion or dermal contact) or indirectly (consuming fruits and vegetables, meat or milk contaminated by exposure of growing plants or food-producing animals) to silo contents equal or exceed 10^{-4}. The chemical ILCR for the RME on-property resident farmer exposed directly or indirectly to groundwater contaminated from silo contents through the perched water is greater than 10^{-4}. No carcinogenic chemicals of concern are predicted to enter the groundwater through the aquifer. The chemical ILCR for the off-property user of surface water contaminated by silo contents, exposed directly (ingestion, dermal contact, and inhalation of volatiles released during household use) and indirectly (consuming foodstuffs contaminated by exposure of growing plants or food-producing animals) is 7×10^{-7}. The chemical ILCR values for the trespassing child and the on-property resident child exposed directly (ingestion and dermal contact) to surface water in Paddys Run during play do not equal or exceed 10^{-6}. Chemical ILCR values from direct contact (ingestion and dermal contact) with sediment in Paddys Run are 5×10^{-6} for the trespassing child and 2×10^{-4} for the on-property resident child. Chemical ILCR values for direct (inhalation) exposure to air contaminated by silo contents are
2×10^{-5} for the trespassing child and 4×10^{-5} for the groundskeeper. Chemical ILCR values for inhalation and indirect exposure (consuming foodstuffs contaminated by airborne distribution of resuspended silo contents) are 4×10^{-5} for the off-property resident farmer and equal to or greater than 10^{-4} for the on-property residents (typical farmer, RME farmer, and child).

Regarding chemical-induced noncancer effects (Table D.7-1), exposure to each contaminated medium except surface water results in a total HI greater than one for at least one receptor. Direct exposure to soil results in an HI less than one for the trespassing child and the groundskeeper. Direct exposure to silo contents results in an HI greater than one for the trespassing child and the groundskeeper. Direct and indirect exposure to soil or silo contents results in HI values markedly greater than one for the on-property residents (typical farmer, RME farmer, and child).

Exposure to groundwater involves direct (ingestion, dermal contact, and inhalation of volatiles released during household use) and indirect (consuming foodstuffs contaminated by exposure of growing plants or food-producing animals) exposure. The source of the groundwater has a marked effect on the HI for the RME farmer. When the groundwater is from the aquifer, the HI is less than one, but when the groundwater is from perched water, the HI is 50. Groundwater from the aquifer results in an HI of 3 for the on-property resident child. Direct exposure to sediment contaminated with silo contents results in an HI less than one for the trespassing child, and an HI of 12 for the on-property resident child. Direct exposure to air contaminated by silo contents results in HI values less than one for the trespassing child, and greater than one for the groundskeeper. Direct and indirect exposure results in HI values markedly greater than one for the on-property residents (typical farmer, RME farmer, and child).

Table D.7-2 summarizes maximum contaminant radiological and chemical risks for each receptor by exposure medium. Each radiological and chemical result presented in this table is associated with the single contaminant that accounts for the largest contribution for that receptor-exposure medium combination. The largest radiological risk values (Table D.7-2) are from the silo pathways and the sediment pathways. Maximum radiological risks from the soil and silo contents are from Ra-226 plus progeny from the external radiation pathway. Maximum radiological risks from groundwater from the Great Miami Aquifer and surface water are from U-234 and U-238. The maximum radiological risk from perched groundwater is from Pb-210. Pb-210 and Th-230 are the radionuclides contributing to the maximum radiological risks from sediment and air, respectively. Maximum chemical risks (Table D.7-2) and maximum hazard quotient values (Table D.7-2) are from the soil, silo contents, and groundwater pathways to the RME on-property resident farmer, and are from soil, silo contents, sediment, and air to the on-property resident child. Arsenic and benzo(a)pyrene are the chemicals contributing the largest chemical ILCR values while uranium, selenium, chromium, arsenic, and cobalt are the chemicals contributing to the largest hazard quotient values.

Figure D.7-1 shows the maximum contaminant risk receptor locations for air, groundwater, silo contents, surface water, and sediment pathways. The maximum exposure location for on-property air, groundwater, and silo contents pathways are either at or immediately adjacent to the Operable Unit 4 Study Area. Thus, the maximum exposure considering all exposure pathways simultaneously, except

TABLE D.7-2

MAXIMUM RADIONUCLIDE AND CHEMICAL RISK SUMMARY

Medium/Source	Type of Risk	Trespassing Child	Grounds-keeper	Off-Property Res Farmer	Off-Property User Surface Water	CT On-Property Res Farmer	RME On-Property Res Farmer	On-Property Res Child	Comments
SOIL Surface soil and berm fill (current source-term scenario)	Radiological maximum risk	9.9×10^{-6}	2.8×10^{-5}	NA	NA	1.4×10^{-4}	1.4×10^{-3}	1.1×10^{-4}	Ra-226
	Chemical maximum risk	1.8×10^{-5}	2.1×10^{-5}	NA	NA	4.3×10^{-5}	1.2×10^{-3}	4.1×10^{-4}	Benzo(a)pyrene
	Chemical maximum hazard quotient	6.6×10^{-2}	3.8×10^{-2}	NA	NA	3.3×10^{0}	1.4×10^{0}	3.5×10^{1}	Chromium
SILO CONTENTS Silos 1, 2, and 3 (future source-term scenario)	Radiological maximum risk	6.6×10^{-3}	1.9×10^{-2}	NA	NA	9.4×10^{-2}	9.8×10^{-1}	7.4×10^{-2}	Ra-226
	Chemical maximum risk	3.2×10^{-4}	4.1×10^{-4}	NA	NA	7.7×10^{-3}	1.5×10^{-1}	4.2×10^{-2}	Arsenic
	Chemical maximum hazard quotient	4.9×10^{0}	2.6×10^{0}	NA	NA	1.1×10^{2}	2.9×10^{2}	9.3×10^{-2}	Uranium/arsenic/ selenium
GROUNDWATER Silos 1, 2, and 3 (future source-term scenario)	Radiological maximum risk	NA	NA	6.3×10^{-6}	NA	3.0×10^{-6}	Aquifer, 4.3×10^{-5}/ Perched, 1.0×10^{0}	1.2×10^{-5}	U-234, U-238, and Pb-210
	Chemical maximum risk	NA	NA	None	NA	None	Aquifer, None/ Perched, 1.3×10^{-2}	None	None/ Arsenic
	Chemical maximum hazard quotient	NA	NA	1.2×10^{-1}	NA	4.6×10^{-1}	Aquifer, 8.5×10^{-1}/ Perched, 3.4×10^{1}	3.1×10^{0}	Uranium/ Arsenic
SURFACE WATER Surface soil, berm fill, and Silo 3 (future source-term scenario)	Radiological maximum risk	9.7×10^{-7}	NA	NA	6.6×10^{-7}	NA	NA	4.8×10^{-7}	U-234/U-238
	Chemical maximum risk	5.1×10^{-7}	NA	NA	6.7×10^{-7}	NA	NA	3.6×10^{-7}	Arsenic
	Chemical maximum hazard quotient	9.2×10^{-1}	NA	NA	1.2×10^{-2}	NA	NA	4.9×10^{-1}	Uranium
SEDIMENT Surface soil, berm fill, and Silo 3 (future condition scenario)	Radiological maximum risk	2.3×10^{-1}	NA	NA	NA	NA	NA	1.0×10^{0}	Pb-210
	Chemical maximum risk	5.3×10^{-6}	NA	NA	NA	NA	NA	2.1×10^{-4}	Arsenic
	Chemical maximum hazard quotient	1.6×10^{-1}	NA	NA	NA	NA	NA	4.6×10^{0}	Vanadium/arsenic/ thallium
AIR (future source-term scenario)	Radiological maximum risk	5.9×10^{-4}	1.7×10^{-3}	1.6×10^{-3}	NA	2.5×10^{-3}	3.3×10^{-2}	9.9×10^{-4}	Th-230
	Chemical maximum risk	1.5×10^{-5}	2.5×10^{-5}	2.4×10^{-5}	NA	3.7×10^{-5}	5.0×10^{-4}	7.0×10^{-5}	Arsenic
	Chemical maximum hazard quotient	1.7×10^{1}	1.4×10^{1}	4.8×10^{0}	NA	5.8×10^{1}	1.0×10^{2}	1.6×10^{2}	Cobalt

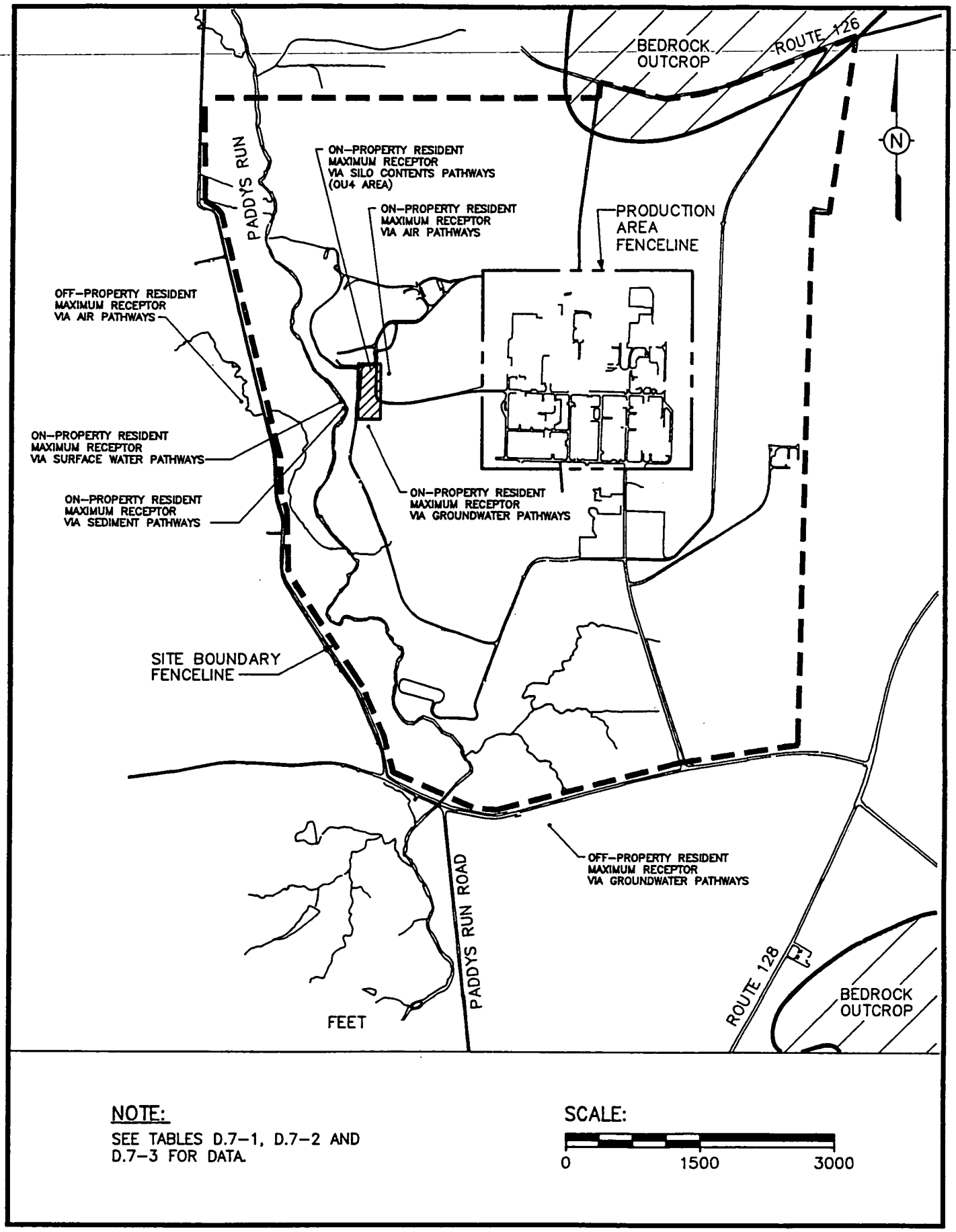

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FIGURE D.7-1. OPERABLE UNIT 4 RECEPTOR LOCATIONS AND MAXIMUM CONTAMINANT RISKS

surface water and sediment, is to the hypothetical resident farm family on the Operable Unit 4 Study Area under future land use.

D.7.2 RISKS FROM NATURAL BACKGROUND

All site-related risks in the risk assessment are calculated without subtracting the contribution from natural background. In some areas in Operable Unit 4 the concentrations of COCs are only slightly above background levels. Therefore, it is important to calculate the risks from background contributions to provide a point of comparison for the site-related risk estimates.

Risks and hazard quotients are calculated for background concentrations of COCs in soil. These results are tabulated in Tables D.7-3 and D.7-4, and include the same exposure pathways quantitatively evaluated for the on-property resident farmer for soil. The risk assessment models and parameter values used for these background calculations are the same as those used for evaluating site-related risks. Soil concentrations used for background risk and hazard quotient calculations are calculated UCL values for the site-specific background soil sample analytical results.

Risks from Th-228, Ra-228, Ra-226, and their short-lived progeny exceed 1×10^{-4}. The exposure pathway that contributes nearly all of this risk is external radiation exposure from these radionuclides (and their short-lived progeny) in surface soil. It is also important to note that the overall lifetime risk from natural background radiation sources (such as cosmic radiation, primordial radionuclides in surface soil and radon) is approximately 1×10^{-2} using this risk assessment methodology.

Hazard quotients have been calculated for natural background concentrations of inorganic chemicals in soil. Results of these calculations for the RME resident adult are given in Table D.7-4. The soil concentrations are calculated UCLs for the site-specific background soil sample analytical results. The HQs estimated using background UCLs and EPA methodology exceed one for five metals: arsenic, manganese, mercury, nickel, and silver. The HQ for natural background levels of barium, boron, cadmium, copper, molybdenum, and thallium exceed 0.1. The results of the calculation of risks and the potential for toxic effects from natural background concentrations of radionuclides and inorganic chemicals suggest that the risk assessment methodology has a conservative bias.

TABLE D.7-3

INCREMENTAL LIFETIME CANCER RISKS (RADIOLOGICAL) FOR SOIL PATHWAYS ASSOCIATED WITH FUTURE LAND USE WITHOUT ACCESS CONTROLS

On-Property Resident - Reasonable Maximum Exposure
Natural Background Concentrations

Radionuclides	Surface Soil Concentration[a] (pCi/g)	Sum of Radionuclide-Specific Risks Across Pathway
Ac-227 + 7 dtrs	2.8×10^{-2}	1.0×10^{-6}
Cs-137 + 1 dtr	4.4×10^{-1}	4.3×10^{-5}
Pb-210 + 2 dtrs	1.0×10^{0}	2.4×10^{-5}
Ra-226 + 5 dtrs	1.2×10^{0}	3.1×10^{-4}
Ra-228 + 1 dtr	1.1×10^{0}	1.3×10^{-4}
Th-228 + 7 dtrs	1.1×10^{0}	2.6×10^{-4}
Th-230	1.5×10^{0}	6.2×10^{-8}
Th-232	1.1×10^{0}	4.0×10^{-8}
U-234	1.0×10^{0}	3.1×10^{-7}
U-235 + 1 dtr	9.1×10^{-2}	9.3×10^{-7}
U-238 + 2 dtrs	1.1×10^{0}	2.2×10^{-6}

[a] Upper 95% confidence limit (UCL) on the mean of the site-specific background soil data.

TABLE D.7-4

TOXIC EFFECTS (CHEMICAL) SOIL PATHWAYS ASSOCIATED WITH FUTURE LAND USE WITHOUT ACTIVE ACCESS CONTROLS

On-Property Resident/Reasonable Maximum Exposure
Natural Background Concentrations

Chemical	Soil Concentration[a] (mg/kg)	Sum of Chemical Toxic Effects Across Pathways
Arsenic	6.38×10^{0}	1.1×10^{0}
Barium	7.86×10^{1}	2.0×10^{-1}
Boron	3.13×10^{1}	7.1×10^{-1}
Cadmium	3.17×10^{-1}	2.3×10^{-1}
Chromium	1.40×10^{1}	5.9×10^{-2}
Cobalt	1.06×10^{1}	1.2×10^{-2}
Copper	1.47×10^{1}	3.1×10^{-1}
Manganese	6.87×10^{2}	2.1×10^{0}
Mercury	1.66×10^{-1}	7.1×10^{0}
Molybdenum	4.19×10^{0}	3.7×10^{-1}
Nickel	2.48×10^{1}	1.1×10^{0}
Silver	3.95×10^{0}	1.7×10^{0}
Thallium	2.59×10^{-1}	1.8×10^{-1}
Vanadium	2.39×10^{1}	3.6×10^{-2}

[a]Upper 95% confidence limit (UCL) on the mean of the background subsurface soil data (36 to 42 inches).

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ATTACHMENT D.I

UNIT RISK AND UNIT TOXICITY FACTORS FOR OPERABLE UNIT 4 BASELINE RISK ASSESSMENT

ATTACHMENT D.I

UNIT RISK AND UNIT TOXICITY FACTORS FOR OPERABLE UNIT 4 BASELINE RISK ASSESSMENT

D.I.1 INTRODUCTION

The unit risk factors (URFs) and unit toxicity factors (UTFs) presented in this attachment are derived using standard EPA exposure models and parameters. These models assume two things :

- The relationship between a constituent's concentration in one environmental medium and the intake attributable to any one exposure pathway associated with that medium is linear. This can be demonstrated by examining the equations and parameters used to estimate intake due to environmental concentrations. In each case, the pathway model equations and parameters are independent of media concentration; and

- The relationship of intake to risk is linear below risks of 1×10^{-2}.

A human exposed to contaminants in one medium may be exposed by a variety of different pathways. This results in a number of intakes from one medium, and these results are cumulative. Since the intake from each exposure pathway from one medium is linear, it can also be demonstrated that the cumulative intake for a given receptor from all exposure pathways associated with a common medium will also be linear with respect to concentration. For example, assume a receptor drinks water and eats food grown with irrigation water from a well producing water containing a measurable concentration of constituent A. As a result of these activities, the receptor ingests a certain amount of constituent A with both the drinking water and the food. If the concentration of constituent A in the well water doubles, so will the magnitude of the intake from drinking water and eating food.

As stated in HEAST, the exposure-to-risk relationship represented by the slope factors cited in HEAST are linear below risk levels of 10^{-2}. The relationship becomes exponential between risk levels of 10^{-2} and 10^{-1}, but remains essentially linear (to within 10 percent) up to a risk value of 2×10^{-1}. This relationship is used to calculate combined Incremental Lifetime Cancer Risks (ILCRs) up to 1×10^{-2}. Risks above this risk range are calculated using the one-hit methodology presented in Section 8.2.1 of EPA 1989a. Figure D.I-1 presents a plot of the exposure-to-risk relationship using these two methodologies.

This section presents the methodology used to quantify the magnitude of exposure expected to result from all reasonable exposure pathways at the FEMP. For convenience, the methodologies used to quantify these exposure pathways are grouped together according to exposure media. These exposure media are water, air, and soil. Exposures from sediment are included in the group detailing the soil

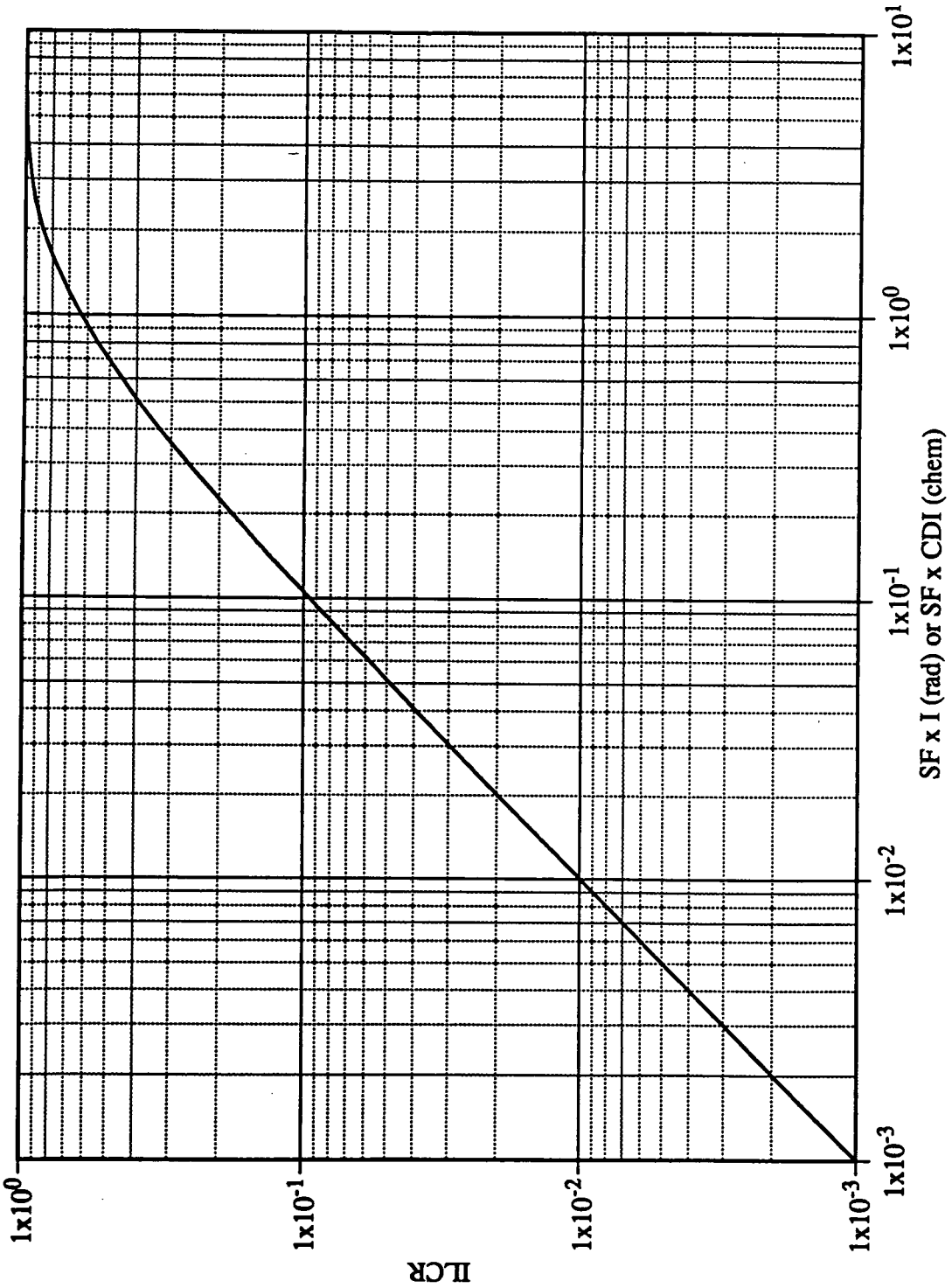

FIGURE DI-1. RELATIONSHIP OF EXPOSURE TO RISK USING CERCLA METHODOLOGY

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exposure pathways. Section D.I.2 presents the methodology followed for exposures to air, Section D.I.3 describes the methodology followed for exposures to water, and Section D.I.4 relates the methodology followed for exposures to soil.

Exposures are quantified using a set of equations and parameters which are unique to each exposure pathway. All parameters and equations are drawn from the FEMP Risk Assessment Work Plan Addendum (DOE 1992a) unless noted otherwise. Table D.3-12 in the baseline risk assessment and Table D.I-1 of this attachment list the parameters used to evaluate the exposures examined in this assessment. These equations and parameters are presented, along with a sample calculation.

The exposure assessment process results in calculated daily intakes (expressed in mg/kg-d) for hazardous chemical contaminants and radioactivity intakes (expressed in pCi) for radionuclide contaminants. These calculated exposure assessment results are multiplied by the appropriate slope factor or HI to yield a URF or UTF. The URFs and UTFs are subsequently used in the risk characterization to quantify human health risks. Intake results are not tabulated separately from the risk characterization results since the calculation of exposure intake is an intermediate result and is not used as the final expression of human health hazard. However, one example calculation is presented for each pathway evaluated. Tables URFs and UTFs are included at the end of this attachment. The tables are organized by receptor for convenient use in the risk assessment calculations.

D.I.2 AIR EXPOSURES

The on-property resident RME is used to illustrate the calculation of air URFs and UTFs.

D.I.2.1 Inhalation

Equations 7-5 and 7-6 from the FEMP Risk Assessment Work Plan Addendum (DOE 1992) are used to quantify intake from the inhalation pathway:

$$\text{(radionuclides)}\quad I_{ai} = (C_{ai})(IR)(ET)(EF)(ED) \qquad \text{(D.I-1)}$$

$$\text{(chemicals)}\quad I_{ai} = (C_{ai})(IR)(ET)(EF)(ED)/(BW)(AT) \qquad \text{(D.I-2)}$$

where

I_{ai} = intake from inhalation (pCi, rad) (mg/kg-d, chem)
C_{ai} = concentration in air (pCi/m^3, rad) (mg/m^3, chem)
IR = inhalation rate (m^3/hr)
ET = exposure time (hr/d)
EF = exposure frequency (d/yr)
ED = exposure duration (yr)
BW = body weight (kg); and
AT = averaging time (d); for noncarcinogens, AT equals (ED) (365 d/yr); for chemical carcinogens, AT equals (70 y/lifetime) (365 d/yr)

Intakes resulting from inhaling air containing 1 pCi/m^3 of U-238 have been selected for the example calculation. The inhalation rate for an adult is 0.83 m^3/h. The exposure duration is 70 years (ED = 70 y/lifetime) and the exposure frequency is 350 days out of every year (EF = 350 d/yr). The exposure time is 5.7 hr/d (ET = 5.7 hr/d). Substituting these values into Equation D.I-1 yields:

$$I_{a\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(0.83\ \text{m}^3/\text{hr})(5.7\ \text{hr/d})(350\ \text{d/y})(70\ \text{y/lifetime}) \qquad \text{(D.I-3)}$$

$$I_{a\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(115910\ \text{m}^3/\text{lifetime})$$

Since the exposure model used in this scenario responds linearly to changes in concentration, each pCi/m^3 of U-238 in air is predicted to result in a lifetime intake of 115,909.5 pCi of U-238 via respiration.

D.I.2.2 Ingestion of Vegetables Contaminated by Aerial Deposition

Eating vegetables contaminated by aerial deposition of contaminated dust can contribute to the total intake of contaminants by humans. Estimating the magnitude of this intake is a two step process. First the concentration in the vegetables is estimated. Then the lifetime intake is calculated. If measured values are not available (e.g. future exposures), this concentration is estimated using Equation 7-10 from the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The intake equation is:

$$C_{avi} = d_d \left[\frac{r_d(1-e^{-\lambda_d t_e})}{Y\lambda_d} + \frac{f_d B_{iv(1)}(1-e^{-\lambda_{ri} t_{bd}})}{\rho\lambda_{ri}} \right] e^{-\lambda_{ri} t_h} \qquad \text{(D.I-4)}$$

where

C_{avi}	=	concentration of the ith contaminant in/on vegetables and fruit (pCi/g, rad) (mg/g, chem)
λ_d	=	effective depletion constant of ith contaminant on the surface plants, also known as the weathering rate (hr^{-1})
λ_{ri}	=	radioactive or chemical decay constant of ith contaminant (hr^{-1})
$B_{iv(1)}$	=	dry soil to wet plant partitioning coefficient of ith contaminant (C_{iv}/C_s)
d_d	=	constituent's deposition rate (pCi/m^2-hr, rad) (mg/m^2-hr, chem)
f_d	=	fraction of year plant is down wind (unitless)
r_d	=	fraction of airborne material retained on plant surface (unitless)
t_e	=	growing season (hrs)
t_{bd}	=	duration soil is exposed to airborne emissions (hrs)
t_h	=	duration of period between harvest and consumption (hrs); and
Y	=	agricultural yield (g/m^2)
ρ	=	effective dry surface soil density (g/m^2)

When measured air concentration data are available, the aerial deposition rate of a constituent per unit area (d_d) is estimated by multiplying the concentration in air by the mean deposition velocity (V m/hr):

$$d_d = (C_{a\ U238}\ pCi/m^3)(V\ m/hr) \qquad (D.I\text{-}5)$$

Vegetables grown in air containing particles of U-238 have been selected for the example calculation. Assuming that the mean deposition velocity for dust in the study area (V) is about 0.0018 m/s (EPA 1991e), the aerial deposition rate of U-238 (d_d) per unit area calculated by Equation D.I-5 is ($C_{a\ U238}$ pCi/m^3) (6.48 m/hr). Assuming the vegetables are centered in the study area, they will always be downwind, so (f_d) is unity (1). The duration of time which the vegetable plot is exposed to aerial deposition in a lifetime (t_{bd}) is 70 years (613,200 hrs). The fraction of airborne material retained on the plant surface (r_d) is 0.25. The weathering removal rate (λ_d) is 0.0021 hr^{-1}. The dry soil to wet plant partitioning coefficient of U-238 in the reproductive portions of vegetables ($B_{iv(1)}$) is 4×10^{-3}. The effective dry surface density of the soil (ρ) is 150,000 g/m^2. The agricultural yield is 1500 g/m^2 (Y), and the growing season (t_e) is 1440 hours. The period between harvest and consumption (t_h) is 24 hours. The radiological decay constant of U-238 (λ_{ri}) is 1.77×10^{-14} hr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches unity (1) (i.e. no significant decay). Substituting these parameter values into Equation D.I-4 and simplifying yields:

$$C_{av\ U238} = (C_{a\ U238}\ pCi/m^3)(6.48\ m/hr)\ \{[(1)(4 \times 10^{-3})(1-\exp(-1.77 \times 10^{-14} \times 613200)]/[(150000\ g/m^2)(1.77 \times 10^{-14}) + [(0.25)(1-e^{-0.0021 \times 1440})]/[(1500\ g/m^2)(0.0021\ hr^{-1})]\} \qquad (D.I\text{-}6)$$

$$C_{av\ U238} = (C_{a\ U238}\ pCi/m^3)(0.595\ m^3/g)$$

Once the constituent's concentration in the vegetables is estimated, the resulting intake by humans can be estimated using Equations 7-15 and 7-16 of the FEMP Risk Assessment Work Plan Addendum (DOE 1992a):

$$\text{(radionuclides)}\quad I_{avi} = (C_{avi})(IR)(FI)(EF)(ED) \qquad (D.I\text{-}7)$$

$$\text{(chemicals)}\quad I_{avi} = (C_{avi})(IR)(FI)(EF)(ED)/(BW)(AT) \qquad (D.I\text{-}8)$$

where

I_{avi}	=	intake from vegetation (pCi, rad) (mg/kg-d, chem)
C_{avi}	=	total concentration of contaminants in vegetable (pCi/g, rad) (mg/g, chem)
IR	=	ingestion rate (g/d)
FI	=	fraction ingested from contaminated source (unitless)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
BW	=	body weight (kg); and
AT	=	averaging time (d); for noncarcinogens, AT equals (ED) (365 d/yr); for chemical carcinogens, AT equals (70 y/lifetime) (365 d/yr).

Continuing the example begun in Equation D.I-6, ingestion of vegetables and fruit containing ($C_{av\ U238}$ pCi/m^3) (0.489 m^3/g) of U-238 for a 70 year lifetime has been selected to illustrate the methodology used to calculate human intake of constituents from plants. The exposure frequency is 350 days per year (EF= 350 d/y). The consumption rate of fruit and vegetables grown in the study area is 122 grams per day (FI x IR = 120 g). The exposure duration (ED) is 70 y/lifetime. The lifetime intake of U-238 from this food supply is given by Equation D.I-7. Using the presented parameter values, this becomes:

$$I_{av\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(0.489\ \text{m}^3/\text{g})(122\ \text{g/d})(350\text{d/y})(70\ \text{y/lifetime}) \qquad \text{(D.I-9)}$$

$$I_{av\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(1461621\ \text{m}^3/\text{lifetime})$$

Since the exposure models used in this scenario respond linearly to changes in concentration, they estimate that each pCi/m^3 of U-238 in air will produce a lifetime intake of 1,461,621 pCi U-238 via this pathway.

D.I.2.3 Ingestion of Meat or Milk Downwind of Source

Forage, feed, and soils downwind of a potential source of contaminated dust can have contamination deposited on them by settling dust. Ingestion of these plants by livestock contributes to the body burden of these contaminants in livestock. Consumption of meat or milk from these animals contributes to the total intake of these contaminants by humans.

The magnitude of the contaminant exposure by humans depends, in part, on the concentration of the constituent in the animal products. If measured values are not available (e.g. future exposures), this concentration can be calculated using the methodology set forth in the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The concentration of a contaminant in animal products, such as beef or milk, is estimated using the following equation:

$$C_{Ai} = F_{Ai}[(C_{afi})(Q_f) + (C_{agi})(Q_g) + (C_{asi})(Q_s)]\, e^{-\lambda_{ri} t_h} \qquad \text{(D.I-10)}$$

where

C_{Ai}	=	concentration of ith contaminant in the animal product (pCi/mL for milk, pCi/g for beef, rad) (mg/L for milk, mg/g for beef, chem)
C_{afi}	=	concentration of ith contaminant in feed (pCi/g)
C_{agi}	=	concentration of ith contaminant in forage (pCi/g)
C_{asi}	=	concentration of ith contaminant in soil (pCi/g)
F_{Ai}	=	elemental transfer coefficient that relates the daily intake by an animal to the concentration of ith contaminant in an edible portion of the animal product (d/L for milk, d/g for meat)
Q_f	=	consumption rate of contaminated feed by livestock (g/d)

Q_g = consumption rate of contaminated forage by livestock (g/d)
Q_s = consumption rate of contaminated soil by livestock (g/d)
λ_{ri} = radioactive or chemical decay constant of ith contaminant (hr^{-1})
t_h = duration of period between harvest and consumption (hrs)

Estimating the magnitude of this intake is a two step process. First, the concentration in the soil, feed, and forage is estimated. If measured values are not available (e.g. future exposures), this concentration is estimated. The amount attributable to dust deposition is calculated using Equations D.I-4 and D.I-5.

Feed and forage grown downwind of air emissions containing $C_{a\ U238}$ pCi/m^3 of U-238 have been selected for the example calculation. Assuming that the mean deposition velocity for dust in the study area (V) is about 0.0018 m/s (EPA 1991), the aerial deposition rate of U-238 (d_d) per unit area calculated by Equation D.I-5 is ($C_{a\ U238}$ pCi/m^3) (6.48 m/hr). Assuming the plants are centered in the study area, they will always be downwind, so (f_d) is unity (1). The duration of time which the plants and surrounding soil are exposed to aerial deposition in a lifetime (t_{bd}) is 70 years. The fraction of airborne material retained on the plant surface (r_d) is 0.25. The weathering removal rate (λ_d) is 0.0021 hr^{-1}. The dry soil to wet plant partitioning coefficient of U-238 in the feed and forage ($B_{iv(2)}$) is 8.5 x 10^{-3}. The effective dry surface density of the soil (ρ) is 150,000 g/m^2. The agricultural yield (Y) is 800 g/m^2, and the growing season (t_e) is 3312 hours for feed and 720 hours for forage. The period between harvest and consumption (t_h) is 6160 hours for feed and 0 hours for forage. The radiological decay constant of U-238 (λ_{ri}) is 1.77 x 10^{-14} hr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches a value of 1 (i.e. no significant decay) for both the forage and the feed calculations. Substituting the parameter values for forage into Equation D.I-4 and simplifying yields:

$$C_{ag\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(6.48\ \text{m/hr})\{[(0.25)(1-e^{-0.0021 \times 720})]/[(800\ \text{g/m}^2)(0.0021\ \text{hr}^{-1})] + [(1)(8.5 \times 10^{-3})((1-e^{-1.77E-14 \times 613200})]/[(150000\ \text{g/m}^2)(1.77 \times 10^{-14}\ \text{hr}^{-1})]\} \quad \text{(D.I-11)}$$

$$C_{ag\ U238} = (C_{ia\ U238}\ \text{pCi/m}^3)(0.977\ \text{m}^3/\text{g})$$

Substituting the parameter values for feed into Equation D.I-4 and simplifying yields:

$$C_{af\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(6.48\ \text{m/hr})\{[(0.25)(1-e^{-0.0021 \times 3312})]/[(800\ \text{g/m}^2)(0.0021\ \text{hr}^{-1})] + [(1)(8.5 \times 10^{-3})((1-e^{-1.77E-14 \times 613200})]/[(150000\ \text{g/m}^2)(1.77 \times 10^{-14}\ \text{hr}^{-1})]\} \quad \text{(D.I-12)}$$

$$C_{af\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(1.19\ \text{m}^3/\text{g})$$

Cows also consume soil while grazing. Concentrations in the soil attributable to aerial deposition can be calculated by multiplying the aerial deposition rate by the second term in parentheses in Equation D.I-4. Since the medium of interest is the soil itself, and not a plant growing in the soil, the $B_{iv(2)}$ term is removed leaving:

$$C_{si} = \frac{f_d(1-e^{-\lambda_{ri} t_{bd}})}{\rho \lambda_{ri}} \; x \; e^{-\lambda_{ri} t_h} \qquad \text{(D.I-13)}$$

Substituting previously described variables in Section D.I.3 into this equation produces an estimated soil concentration of:

$$C_{as\ U238} = (C_{a\ U238}\ pCi/m^3)(6.48\ m/hr)(1)(1-e^{-1.77E-14\ x\ 613200})/[(150000\ g/m^2)(1.77\ x\ 10^{-14})] \qquad \text{(D.I-14)}$$

$$C_{as\ U238} = (C_{a\ U238}\ pCi/m^3)(26.5\ m^3/g)$$

Once the concentrations in feed, forage, and soil have been estimated, concentrations in the animal products can be calculated using Equation D.I-10. Continuing the example begun in Equation D.I-11, the concentrations of U-238 in feed, forage, and soil attributable to dust deposition are about ($C_{a\ U238}$ pCi/m^3) (1.19 m^3/g), ($C_{a\ U238}$ pCi/m^3) (0.977 m^3/g), and ($C_{a\ U238}$ pCi/m^3) (26.5 m^3/g), respectively. In this study, a cow is assumed to consume 25,000 g/d of stored feed (Q_f), 25,000 g/d of forage (Q_g), and 500 g/d of soil. The food to beef biotransfer factor ($F_{m\ U238}$) is 2.0 x 10^{-7} d/g and the food to milk biotransfer factor ($F_{d\ U238}$) is 6.0 x 10^{-7} d/ml. The period between harvest and consumption (t_h) is 480 hours for beef and is 24 hours for milk. The radiological decay constant of U-238 λ_{ri} is 1.55 x 10^{-10} yr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches a value of 1 (i.e. no significant decay) for both the beef and milk calculations. Substituting the presented parameter values for beef into Equation D.I-10 yields a meat concentration ($C_{Ai} = C_{m\ U238}$) of:

$$C_{am\ U238} = (2.0\ x\ 10^{-7}\ d/g)[(C_{a\ U238}\ pCi/m^3)(1.19\ m^3/g)(25000\ g/d)$$
$$+ (C_{a\ U238}\ pCi/m^3)(0.977\ m^3/g)(25000\ g/d)+(C_{a\ U238}\ pCi/m^3)(26.5\ m^3/g)(500\ g/d)] \qquad \text{(D.I-15)}$$
$$C_{am\ U238}=(C_{a\ U238}\ pCi/m^3)(0.0135\ m^3/g)$$

Using the presented parameter values for milk yields a U-238 concentration in milk ($C_{Ai} = C_{d\ U238}$) of:

$$C_{ad\ U238} = (6.0\ x\ 10^{-7}\ d/mL)[(C_{a\ U238}\ pCi/m^3)(1.19\ m^3/g)(25000\ g/d)$$
$$+ (C_{a\ U238}\ pCi/m^3)(0.977\ m^3/g)(25000\ g/d)+(C_{a\ U238}\ pCi/m^3)(26.5\ m^3/g)(500\ g/d)] \qquad \text{(D.I-16)}$$
$$C_{ad\ U238} = (C_{a\ U238}\ pCi/m^3)(0.041\ m^3/mL)$$

Once the constituent's concentration in the animal product is estimated, the resulting intake by humans can be estimated using Equations 7-17 and 7-18 of the FEMP Risk Assessment Work Plan Addendum (DOE 1992a):

$$\text{(radionuclides)}\quad I_{Ai} = (C_{Ai})(IR)(FI)(EF)(ED) \qquad \text{(D.I-17)}$$
$$\text{(chemicals)}\quad I_{Ai} = (C_{Ai})(IR)(FI)(EF)(ED)/(BW)(AT) \qquad \text{(D.I-18)}$$

where

I_{Ai}	=	intake of ith constituent from animal product (pCi, rad) (mg/kg-d, chem)
C_{Ai}	=	concentration of ith contaminant in animal product (pCi/g)
IR	=	ingestion rate (g/d)
FI	=	fraction ingested from contaminated source (unitless)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
BW	=	body weight (kg)
AT	=	averaging time (d); for noncarcinogens, AT equals (ED) (365 d/yr); for chemical carcinogens, AT equals (70 y/lifetime) (365 d/yr)

The calculated concentration of U-238 in beef and milk in the example scenario is about ($C_{a\ U238}$ pCi/m^3) (0.0135 m^3/g) and ($C_{a\ U238}$ pCi/m^3) (0.041 m^3/mL), respectively. The exposure frequency is 350 days per year (EF= 350 d/y). The fraction ingested from the contaminated source (FI x IR) is 75 g/d for beef and 300 mL/d for milk. The exposure duration (ED) is 70 years in days. After substituting the appropriate parameter values for beef ingestion into Equation D.I-17, the lifetime intake of U-238 from eating beef ($I_{Ai} = I_{am\ U238}$) is estimated as:

$$I_{am\ U238} = [(C_{a\ U238}\ \text{pCi/m}^3)(0.0135\ \text{m}^3/\text{g})](75\ \text{g/d})[(350\ \text{d/y})(70\ \text{y/lifetime}) \qquad \text{(D.I-19)}$$

$$I_{am\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(24762\ \text{m}^3/\text{lifetime})$$

After substituting the appropriate parameter values for milk ingestion into Equation D.I-17, the lifetime intake of U-238 from consuming dairy products ($I_{Ai} = I_{ad\ U238}$) is calculated as:

$$I_{ad\ U238} = [(C_{a\ U238}\ \text{pCi/m}^3)(0.041\ \text{m}^3/\text{mL})](300\ \text{mL/d})[(350\ \text{d/y})(70\ \text{y/lifetime}) \qquad \text{(D.I-20)}$$

$$I_{ad\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(297145\ \text{m}^3/\text{lifetime})$$

The total intake from ingesting meat and dairy products raised on feed and forage grown in air containing U-238 ($I_{aA\ U238}$) is:

$$I_{aA\ U238} = I_{am\ U238} + I_{ad\ U238} \qquad \text{(D.I-21)}$$

$$I_{aA\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(24762\ \text{m}^3/\text{lifetime}) + (C_{a\ U238}\ \text{pCi/m}^3)(297147\ \text{m}^3/\text{lifetime})$$

$$I_{aA\ U238} = (C_{a\ U238}\ \text{pCi/m}^3)(321907\ \text{m}^3/\text{lifetime})$$

Since the exposure models used in this scenario respond linearly to changes in concentration, they estimate that each pCi/m^3 of U-238 in air will produce a lifetime intake of 321,907 pCi via these pathways.

D.I.2.4 Calculation of Unit Risk Factor Combining All Airborne Exposure Scenarios

In some situations, a hypothetical resident both inhales air containing suspended material and ingests crops grown in areas of experiencing aerial deposition. The total risks to the same receptor from these two pathways may be calculated as:

$$ILCR_{air\ i} = I_{ai} \times SF_{inh\ i} + (I_{avi} + I_{aAi}) \times SF_{ing\ i} \qquad \text{(D.I-22)}$$

where

$ILCR_{air\ i}$ = incremental Lifetime Cancer Risk (risk of cancer incidence/lifetime)
I_{ai} = intake from inhaling suspended material (pCi/lifetime); and
I_{avi} = intake of material in vegetable/fruit from aerial deposition (pCi/lifetime)
I_{aAi} = intake of material in animal products from aerial deposition (pCi/lifetime)
SF_{ing} = HEAST slope factor for ingestion (r/pCi)
SF_{inh} = HEAST slope factor for inhalation (r/pCi)

A farmer living downwind of a plume of U-238 particles has been selected as the example for this calculation. The total intake by inhalation for this hypothetical receptor for each pCi of U-238 per m^3 of air is calculated in Section D.I.1. Similarly, the intake from each pCi of U-238 per m^3 of air from eating vegetables and animal products grown downwind of air emissions are calculated in Sections D.I.1.2 and D.I.1.3. Substituting these values into Equation D.I-10, along with the appropriate HEAST Slope Factors of inhalation and ingestion of uranium, yields:

$$\begin{aligned} ILCR_{air\ U238} &= (115910\ m^3/\text{lifetime})(5.2 \times 10^{-8}\ r/pCi) \\ &+ [(C_{a\ U238}\ pCi/m^3)(1461621 m^3/\text{lifetime}) \\ &+ (C_{a\ U238}\ pCi/m^3)(321907\ m^3/\text{lifetime})](2.8 \times 10^{-11}\ r/pCi) \qquad \text{(D.I-23)} \\ ILCR_{air\ U238} &= (C_{a\ U238}\ pCi/m^3)(6.1 \times 10^{-3}\ r\text{-}pCi/m^3\text{-lifetime}) \end{aligned}$$

The constant 6.1×10^{-3} r-pCi/m^3-lifetime is the ILCR to the resident adult produced by each pCi/m^3 of U-238 in air from all airborne exposures.

D.I.3 WATER EXPOSURES

The Great Miami River user is used to demonstrate the calculation of the water URFs and UTFs.

D.I.3.1 Drinking Water Ingestion Pathway

Ingestion of contaminated drinking water can be a major contributor to environmental intakes of a constituent of concern. An estimate of intake from drinking water is calculated from Equations 7-3 and 7-4 of the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The intake equations are:

$$\text{(radionuclides)}\quad I_{wi} = (C_{wi})(IR)(ED)(EF) \qquad \text{(D.I-24)}$$

$$\text{(chemicals)}\quad I_{wi} = (C_{wi})(IR)(ED)(EF)/(BW)(AT) \qquad \text{(D.I-25)}$$

where

I_{wi}	=	intake of ith contaminant from drinking water (pCi, rad) (mg/kg-d, chem)
C_{wi}	=	concentration i^{th} in water (pCi/L, rad) (mg/L, chem)
IR	=	ingestion rate (L/d)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
BW	=	body weight (kg); and
AT	=	averaging time (d); for noncarcinogens, AT equals (ED) (365 d/yr [EPA 1991c]); for chemical carcinogens, AT equals (70 y/lifetime) (365 d/yr)

Ingestion of water containing U-238 by a resident adult for a 70 year lifetime has been selected for the example calculation. The ingestion rate (IR) is 2 L/d. The exposure frequency is 350 days per year (EF= 350 d/y). The exposure duration (ED) is 70 years. The lifetime intake is given by Equation D.I-24, above. Using the presented parameter values, this becomes:

$$I_{w\,U238} = (C_{w\,U238}\ \text{pCi/L})(730\ \text{L/d})(70\ \text{y})(350\ \text{d/y});\ \text{and} \qquad \text{(D.I-26)}$$

$$I_{w\,U238} = (C_{w\,U238}\ \text{pCi/L})(49000\ \text{L/lifetime})$$

Since the exposure models used in this scenario respond linearly to changes in concentration, they predict that each pCi/L of U-238 in water will produce a lifetime intake of 49,000 pCi of U-238 via this one pathway.

D.I.3.2 Incidental Ingestion of Surface Water While Swimming

People living near bodies of water receiving contaminated runoff may accidentally ingest contaminated water while swimming. Intake from incidental ingestion of surface water while swimming is quantified using Equations D.I-24 and D.I-25.

Ingestion of surface water containing 1.0 pCi/L of U-238 ($C_{w\,U238}$) while swimming has been selected for the example calculation. The ingestion rate (IR) is 0.05 L/hr. The exposure time (ET) is 2.6 hr/d, the exposure frequency is 7 days per year (EF = 7 d/y), and the exposure duration (ED) is 70 years. The lifetime intake for U-238 is estimated using Equation D.I-24, above. Using the presented parameter values, this becomes:

$$I_{w\,U238} = (C_{w\,U238}\ \text{pCi/L})(0.05\ \text{L/hr})(2.6\ \text{hr/d})(7\ \text{d/y})(70\ \text{y}) \qquad \text{(D.I-27)}$$

$$I_{w\,U238} = (C_{w\,U238}\ \text{pCi/L})(63.7\ \text{L/lifetime})$$

Since the exposure models used in this scenario respond linearly to changes in concentration, each pCi/L of U-238 in water will produce a lifetime intake of 63.7 pCi of U-238 via this one pathway.

D.I.3.3 Volatiles Released by Showering and other Household Water Uses

The amount of a chemical taken into the body via exposure to volatilization of chemicals from showering is calculated as follows:

$$D_s = 10^3 N_s T_s I \frac{FC}{V_a}\left[1 + \frac{1}{aT_s}(e^{-aT_s} - 1)\right] x \left[1 - \exp - \left[0.93 + \frac{1.48 x 10^{-3}}{H}\right]^{-1}\right] \qquad \text{(D.I-28)}$$

where

D_s	=	contaminant dose due to showering (mg/d)
N_s	=	average number of showers per day (shower/d)
T_s	=	time in shower (hr/shower)
I	=	inhalation rate (m^3/hr)
a	=	air exchange rate between shower and rest of house (hr^{-1})
F	=	shower water flow rate (m^3/hr)
V_a	=	volume of showers (m^3)
H	=	Henry's Law Constant (atm-m^3/mol)
C	=	chemical concentration in tap water (mg/L)

Intakes from exposures to volatilization of chemicals in water from other household uses is calculated as follows:

$$D_L = T_h I \frac{Q_w}{Q_a} M C \left[1 - \exp - \left[1.26 + \frac{2.0 x 10^{-3}}{H}\right]^{-1}\right] \qquad \text{(D.I-29)}$$

where

T_h	=	exposure time (hr/d)
Q_w	=	water use in home (L/d)
Q_a	=	volume of air exchange rate for home (m^3/d)
M	=	mixing factor

Total intake of contaminant due to showering and other household uses is the sum of Equations D.I-28 and D.I-29.

For most metals, and hence most radionuclides at the FEMP, volatilization is not a significant pathway because penetration through the skin is minimal. Therefore it is not quantitatively presented for uranium.

D.I.3.4 Dermal Contact While Swimming

The amount of a chemical taken into the body upon exposure via dermal contact is referred to as an absorbed dose and is calculated using the following equation:

$$AB_w = (C_{wi})(SA)(PC)(ET)(ED)(EF)/(BW)(AT) \qquad \text{(D.I-30)}$$

where

AB_w	=	amount of the ith constituent absorbed from contact with water (mg/kg-d)
C_{wi}	=	concentration of the ith constituent in water (mg/L)
SA	=	skin surface area available for contact (cm^2)
PC	=	dermal permeability constant ($L/cm^2/hr$)
ET	=	exposure time (hr/d)
ED	=	exposure duration (yr)
EF	=	exposure frequency (d/yr)
BW	=	body weight (kg)
AT	=	averaging time (d); for noncarcinogens, AT equals (ED) (365 d/yr); for chemical carcinogens, AT equals (70 y\lifetime) (365 d/yr)

For most metals, and hence most radionuclides at the FEMP, dermal absorption is not a significant pathway because penetration through the skin is minimal. Therefore it is not quantitatively presented for uranium.

D.I.3.5 Dermal Contact While Bathing

The amount of a chemical taken into the body upon exposure via dermal contact is referred to as an absorbed dose and is calculated using Equation D.I-30. For most metals, and hence most radionuclides at the FEMP, dermal absorption is not a significant pathway because penetration through the skin is minimal. Therefore it is not quantitatively presented for uranium.

D.I.3.6 Irrigation of Vegetables

Eating vegetables irrigated with contaminated water can contribute to the total intake of contaminants by humans. Estimating the magnitude of this intake is a two step process. First the concentration in the vegetables must be estimated. If measured values are not available (e.g. future exposures) this concentration is estimated using Equation 7-9 from the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The intake equation is:

$$C_{vwi} = d_w \left[\frac{r_w(1-e^{-\lambda_d t_e})}{Y\lambda_d} + \frac{f_w B_{iv(1)}(1-e^{-\lambda_{ri} t_{bw}})}{\rho\lambda_{ri}} \right] e^{-\lambda_{ri} t_h} \qquad \text{(D.I-31)}$$

where

C_{wvi} = concentration of ith contaminant in plants as a result of irrigating plants with contaminated water (pCi/g, rad) (mg/g, chem)
λ_d = effective depletion constant of ith contaminant on the surface plants also known as the weathering removal rate (hr^{-1})
λ_{ri} = radioactive or chemical decay constant of ith contaminant (hr^{-1})
$B_{iv(1)}$ = dry soil to wet plant partitioning coefficient of ith contaminant (C_{iv}/C_s)
d_w = irrigation deposition rate (pCi/m^2-hr, rad) (mg/m^2-hr, chem)
f_d = fraction of year plant is irrigated (unitless)
ρ = effective dry surface density of the soil (g/m^2)
r_w = fraction of water borne material retained on plant surface (unitless)
t_e = growing season (hrs)
t_{bw} = duration of irrigation use (hrs)
t_h = duration of period between harvest and consumption (hrs)
Y = agricultural yield (g/m^2)

Vegetables irrigated with water containing U-238 ($C_{w\ U238}$) have been selected for the example calculation. The mean irrigation rate (d_w) per unit area is 0.081 L/m^2-hr, so the rate of constituent deposition by irrigation is ($C_{w\ U238}$ pCi/L) (0.081 L/m^2-hr), and the fraction of the growing season that the plant is irrigated (f_d) is 1. The duration of irrigation is 70 years (t_{bw} = 613,200 hrs). The fraction of waterborne material retained on the plant surface (r_w) is 0.2. The weathering removal rate (λ_w) is 0.0021 hr^{-1}. The dry soil to wet plant partitioning coefficient of U-238 in the reproductive portions of vegetables ($B_{iv(1)}$) is 4 x 10^{-3}. The effective dry surface density of the soil is 150,000 g/m^2. The agricultural yield is (Y) 1,500 g/m^2. The growing season t_e is 1,440 hours. The period between harvest and consumption (t_h) is 24 hours. The radiological decay constant of U-238 λ_{ri} is 1.77 x 10^{-14} hr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches a value of 1 (i.e. no significant decay).

Substituting these parameter values into Equation D.I-31 and simplifying yields:

$$C_{wv\ U238} = (C_{w\ U238}\ \text{pCi/L})(0.081\ \text{L/m}^2\text{-hr}) + \{[(0.2)(1-e^{-0.0021 \times 1440})]/[(1500\ \text{g/m}^2)(0.0021\ \text{hr}^{-1})] + [(1)(4 \times 10^{-3})((1-e^{-1.77E-14 \times 613200})]/[(150000\ \text{g/m}^2)(1.77 \times 10^{-14}\ \text{hr}^{-1})]\} \quad \text{(D.I-32)}$$

$$C_{wv\ U238} = (C_{w\ U238}\ \text{pCi/L})(6.22 \times 10^{-3}\ \text{L/g})$$

Once the constituent's concentration in the vegetables is estimated, the resulting intake by humans can be estimated using Equations D.I-7 or D.I-8. Continuing the example begun in Equation D.I-32, humans ingest vegetables from the study area for a 70 year lifetime. The calculated concentration of U-238 in vegetables is about ($C_{w\ U238}$ pCi/L) (6.22 x 10^{-3} L/g). The exposure frequency is 350 days out of per year (EF= 350 d/y). The consumption rate of vegetables and fruit grown in the study area is 122 grams per day (FI x IR). The exposure duration (ED) is 70 years per lifetime. The lifetime intake of U-238 from this food supply may be estimated by Equation D.I-7. Using the presented parameter values, this becomes:

$$I_{w\ U238} = (C_{w\ U238}\ pCi/L)(6.22 \times 10^{-3}\ L/g)(122\ g/d)(350\ d/y)(70\ y/lifetime) \quad (D.I\text{-}33)$$

$$I_{w\ U238} = (C_{w\ U\text{-}238}\ pCi/L)(18592\ L/lifetime)$$

Since the exposure models used in this scenario respond linearly to changes in concentration, each pCi/L of U-238 in water will produce a lifetime intake of 18,592 pCi of U-238 via this one pathway.

D.I.3.7 Ingestion of Beef and Dairy Products Produced with River Water

This scenario assumes that river water is used for stock water and irrigation of feed. Animals drinking the water ingest contaminants directly. Plants irrigated with water take up constituents via root uptake, and direct deposition onto exposed surfaces by irrigation water. Ingestion of these plants by livestock also contributes to the body burden of these contaminants in the animals. Humans using animal products from these animals can ingest the contamination contained in them.

The magnitude of the contaminant exposure by humans depends, in part, on the concentration of the constituent in the animal products. If measured values are not available (e.g. future exposures), this concentration can be calculated using the methodology set forth in the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The concentration of a contaminant in animal products, such as beef or milk, is estimated using the following equation:

$$C_{Ai} = F_{Ai}[(C_{fi})(Q_f) + (C_{wi})(Q_w)]\, e^{-\lambda_i t_h} \quad (D.I\text{-}34)$$

where

C_{Ai}	=	concentration of ith contaminant in the animal product (pCi/mL for milk, pCi/g for beef, rad) (mg/L for milk, mg/g for beef, chem)
C_{fi}	=	concentration of ith contaminant in feed (pCi/g, rad) (mg/g, chem)
C_{wi}	=	concentration of contaminant in water (pCi/L, rad) (mg/L, chem)
F_{Ai}	=	element (stable) transfer coefficient that relates the daily intake by an animal to the concentration of ith contaminant in an edible portion of the animal product (d/L for milk, d/g for meat)
Q_f	=	consumption rate of contaminated feed by livestock (g/d)
Q_w	=	consumption rate of contaminated stock water by livestock (L/d)
λ_{ri}	=	radioactive or chemical decay constant of ith contaminant (hr^{-1})
t_h	=	duration of period between harvest and consumption (hrs)

If measured values for the concentrations of constituents in stored feed are not available (e.g. future exposures), this concentration is estimated using Equation 7-9 from the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The equation is:

$$C_{vwi} = d_w \left[\frac{r_w(1-e^{-\lambda_d t_e})}{Y\lambda_d} + \frac{f_w B_{iv(1)}(1-e^{-\lambda_{ri} t_{bw}})}{\rho\lambda_{ri}} \right] e^{-\lambda_{ri} t_h} \qquad \text{(D.I-35)}$$

where

λ_d	=	effective depletion constant of ith contaminant on the surface plants also known as the weathering removal rate (hr^{-1})
λ_{ri}	=	radioactive or chemical decay constant of ith contaminant (hr^{-1})
$B_{iv(1)}$	=	dry soil to wet plant partitioning coefficient of ith contaminant (C_{iv}/C_s)
C_{vwi}	=	concentration of ith contaminant in plants as a result of irrigating plants with contaminated water (pCi/g, rad) (mg/g, chem)
d_w	=	irrigation deposition rate (pCi/m^2-hr, rad) (mg/m^2-hr, chem)
f_d	=	fraction of year plant is irrigated (unitless)
ρ	=	effective dry surface density of the soil (g/m^2)
r_w	=	fraction of water borne material retained on plant surface (unitless)
t_e	=	growing season (hrs)
t_{bw}	=	duration of irrigation use (hrs)
t_h	=	duration of period between harvest and consumption (hrs)
Y	=	agricultural yield (g/m^2)

This example assumes that stored feed is irrigated with river water containing U-238. The mean irrigation rate (d_w)per unit area is 0.081 L/m^2-hr, so the rate of constituent deposition by irrigation is ($C_{w\ U238}$ pCi/L) (0.081 L/m^2-hr) and the fraction of the growing season the plant is irrigated (f_d) is 1. The duration of irrigation (t_{bw}) is 70 years. The fraction of waterborne material retained on the plant surface (r_w) is 0.2. The weathering removal rate (λ_w) is 0.0021 hr^{-1}. The dry soil to wet plant partitioning coefficient of U-238 in the reproductive portions of feed ($B_{iv(2)}$) is 8.5 x 10^{-3}. The effective dry surface density of the soil is 150,000 g/m^2. The agricultural yield is 1,500 g/m^2 (Y). The growing season t_e is 3,312 hours. The period between harvest and consumption (t_h) is 2,160 hours. The radiological decay constant of λ_{ri} for U238 is 1.77 x 10^{-14} hr^{-1} [1]. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches a value of 1 (i.e. no significant decay). Substituting these parameter values into Equation D.I-35 and simplifying yields:

$$C_{if\ U238} = (C_{w\ U238}\ \text{pCi/L})(0.081\ \text{L/m}^2\text{-hr})\{[(0.2)(1-e^{-0.0021 \times 3312})]/[(800\ \text{g/m}^2)(0.0021\ \text{hr}^{-1})]$$
$$+ [(1)(8.5 \times 10^{-3})((1-e^{-1.77E-14 \times 613200})]/[(150000\ \text{g/m}^2)(1.77 \times 10^{-14}\ \text{hr}^{-1})]\} \qquad \text{(D.I-36)}$$
$$C_{if\ U238} = (C_{w\ U238}\ \text{pCi/L})(1.24 \times 10^{-2}\ \text{L/g})$$

Once the concentration in stored feed has been estimated, its contribution to constituent levels in beef and dairy products can be calculated using Equation D.I-34. Continuing the example begun in Equation D.I-36, the calculated concentration of U-238 in stored feed attributable to irrigation is about ($C_{w\ U238}$ pCi/L) (1.24 x 10^{-2} L/g). In this study, a cow is assumed to consume 25,000 g/d of potentially contaminated feed (Q_f). The plant to beef and plant to milk biotransfer factors for U-238

in cows are 8.5 x 10^{-7} d/g ($F_{m\ U238}$) 2 x 10^{-7} d/mL ($F_{d\ U238}$), respectively. The time between harvesting and consumption of stored feed is 2160 hours. The radiological decay constant of U-238 λ_{ri} is 1.77 x 10^{-14} hr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches a value of 1 (i.e. no significant decay) for both meat and milk calculations. Beef cows ingest about 50 L/d of water(Q_{Aw}), while milk cows ingest about 60 L/d.

Substituting parameter values for the beef ingestion scenario in Equation D.I-34 ($C_{Ai} = C_{wm\ U238}$) yields:

$$C_{wm\ U238} = (2.0 \times 10^{-7}\ d/g)[(25000\ g/d)(C_{w\ U238}\ pCi/L)(1.24 \times 10^{-2}\ L/g) + (50\ L/d)(C_{w\ U238}\ pCi/L)] \quad \text{(D.I-37)}$$

$$C_{wm\ U238} = (C_{w\ U238}\ pCi/L)(7.2 \times 10^{-5}\ L/g)$$

Substituting parameter values for the milk ingestion scenario in Equation D.I-34 ($C_{Ai} = C_{wd\ U238}$) yields:

$$C_{wd\ U238} = (6.0 \times 10^{-7}\ d/mL)[(25000\ g/d)(C_{w\ U238}\ pCi/L)(1.24 \times 10^{-2}\ L/g) + (60\ L/d)C_{w\ U238}\ pCi/L)] \quad \text{(D.I-38)}$$

$$C_{wd\ U238} = (C_{w\ U238}\ pCi/L)(2.22 \times 10^{-4}\ L/mL)$$

Once the constituent's concentration in the animal product is estimated, the resulting intake by humans can be estimated using Equations D.I-17 and D.I-18. Continuing the example calculation, the farmer ingests beef containing (7.2 x 10^{-5} L/g)(C_{wU238} pCi/L) of U-238 ($C_{wm\ U238}$ in Equation D.I-37) and dairy products containing 2.22 x 10^{-4} (L/mL)(C_{wU238} pC/L) of U-238 ($C_{wd\ U238}$ in Equation D.I-38) for each pCi/L of U-238 in water during a 70 year lifetime. The exposure frequency is 350 days out of every per year (EF= 350 d/y). The fractions of beef and diary products ingested from the contaminated source (FI x IR) are 75 g/d and 300 mL/d, respectively. The exposure duration (ED) is 70 years. The lifetime intake of U-238 from this supply of animal products is given by Equation D.I-17. Substituting the selected parameter values for the beef ingestion scenario, this becomes:

$$I_{wb\ U238} = (C_{w\ U238}\ pCi/L)(7.2 \times 10^{-5}\ L/g)(75\ g/d)(350\ d/y)(70\ y/lifetime) \quad \text{(D.I-39)}$$

$$I_{wb\ U238} = (C_{w\ U238}\ pCi/L)(132\ L/lifetime)$$

Substituting the selected parameter values for the dairy products ingestion scenario, this becomes:

$$I_{wd\ U238} = (C_{w\ U238}\ pCi/L)(2.22 \times 10^{-4}\ L/mL)(300\ mL/d)(350\ d/y)(70\ y/lifetime) \quad \text{(D.I-40)}$$

$$I_{wd\ U238} = (C_{w\ U238}\ pCi/L)(1632\ L/lifetime)$$

Since the exposure models used in this scenario respond linearly to changes in concentration, each pCi/L of U-238 in water will produce a lifetime intake of 132 pCi of U-238 via the beef ingestion pathway and 1632 pCi of U-238 via the milk ingestion pathway.

D.I.3.8 Ingestion of Fish

If measured concentrations of a constituent in fish are unknown, they are estimated using Equation 7-19 of the FEMP Risk Assessment Work Plan Addendum (DOE 1992a):

$$C_{Fi} = (C_{Wi})(BCF_{Fi})\, e^{-\lambda_{ri} t_h} \qquad \text{(D.I-41)}$$

where

C_{Fi}	=	concentration of the ith constituent in fish (pCi/g, rad) (mg/g, chem)
C_{wi}	=	concentration of the ith constituent in surface water (pCi/L, rad) (mg/L, chem)
BCF_{Fi}	=	fish bioconcentration factor (pCi/g fish per pCi/L, rad) (mg/g fish per mg/L, chem)
λ_{ri}	=	radioactive or chemical decay constant of ith contaminant (hr^{-1})
t_h	=	duration of period between harvest and consumption (hrs)

Fish in water containing U-238 have been selected for the example calculation. The biotransfer factor from water to fish ($BCF_{F\,U238}$) is 0.002 L/g (USNRC 1984 {NUREG/CR-3585}). The period between harvest and consumption (t_h) is 24 hours. The radiological decay constant of U-238 λ_{ri} is 1.77×10^{-14} hr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\, t_h)$ term approaches a value of 1 (i.e. no significant decay). Substituting these parameter values into Equation D.I-41 produces:

$$C_{F\,U238} = (C_{w\,U238}\ \text{pCi/L})(0.002\ \text{L/g})(1) \qquad \text{(D.I-42)}$$

$$C_{F\,U238} = (C_{w\,U238}\ \text{pCi/L})(0.002\ \text{L/g})$$

Once the concentration in fish has been estimated, intake can be calculated as:

$$\text{(radionuclides)}\ I_{Fi} = (C_{Fi})(IR)(FI)(ED)(EF) \qquad \text{(D.I-43)}$$

$$\text{(chemicals)}\ I_{Fi} = (C_{Fi})(IR)(FI)(ED)(EF)/(BW)(AT) \qquad \text{(D.I-44)}$$

where

I_{Fi}	=	intake of ith constituent from fish ingestion (pCi, rad) (mg/kg-d, chem)
C_{Fi}	=	concentration of ith constituent in fish (pCi/kg, rad) (mg/kg, chem)
IR	=	ingestion rate (g/d)
FI	=	fraction ingested from contaminated source (unitless)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)

BW = body weight (kg)
AT = averaging time (d); for noncarcinogens, AT equals (ED) (365 d/yr); for chemical carcinogens, AT equals (70 y/lifetime) (365 d/yr)

Continuing the previous example, it is assumed that a recreational fisherman ingests 54 grams of fish per day (IR x FI) from the study area for 70 years (ED). The exposure frequency (EF) is 350 d/y. The concentration of U-238 in fish from Equation D.I-44 is ($C_{w\ U238}$ pCi/L) (0.002 L/g). Substituting these parameters into Equation D.I-45 yields:

$$I_{F\ U238} = (C_{w\ U238}\ \text{pCi/L})(0.002\ \text{L/g})(54\ \text{g/d})(350\ \text{d/y})\ (70\ \text{y/lifetime}) \qquad \text{(D.I-45)}$$

$$I_{F\ U238} = (C_{w\ U238}\ \text{pCi/L})(2646\ \text{L/lifetime})$$

Since the exposure models used in this scenario respond linearly to changes in concentration, each pCi/L of U-238 present in water will produce a lifetime intake of 2,646 pCi of U-238 via this one pathway.

D.I.3.9 Calculation of Unit Risk Factor For Great Miami River User Scenario

In this scenario, a hypothetical farmer uses river water for drinking, domestic uses, irrigation, stock water, and recreation (fishing and swimming). The total risks to the same receptor from these exposure pathways may be calculated as:

$$ILCR_{water\ i} = (I_{wi} + I_{wvi} + I_{wmi} + I_{wdi} + I_{wsi} + I_{wFi} + I_{wbi} + I_{wsi}) \times SF_{ing\ i} + I_{wgi} \times SF_{inh\ i} \qquad \text{(D.I-46)}$$

where

$ILCR_{water\ i}$ = incremental Lifetime Cancer Risk (risk of cancer incidence/lifetime)
I_{wi} = intake from drinking water (pCi/lifetime)
I_{vi} = intake from ingesting vegetables and fruit (pCi/lifetime)
I_{mi} = intake from ingesting meat (pCi/lifetime)
I_{di} = intake from ingesting diary products (pCi/lifetime)
I_{si} = intake from incidental ingestion while swimming (pCi/lifetime)
I_{Fi} = intake from eating fish (pCi/lifetime)
I_{bi} = intake from absorption while bathing (pCi/lifetime)
I_{si} = intake from absorption while swimming (pCi/lifetime)
I_{wgi} = intake from inhalation while bathing (pCi/lifetime)
$SF_{ing\ i}$ = HEAST slope factor for ingestion of constituent i (r/pCi)
$SF_{inh\ i}$ = HEAST slope factor for inhalation of constituent i (r/pCi)

A farmer living adjacent to the Great Miami River has been selected as the example for this calculation. The total intake for this hypothetical receptor for each pCi/L of U-238 in water from these pathways have been calculated in Sections D.I.3.1 through D.I.3.8. Substituting these values into

Equation D.I-46, along with the appropriate HEAST slope factors for ingestion and inhalation of uranium, yields:

$$ILCR_{water\ U238} = \{[(C_{s\ U238}\ pCi/L)(49000\ L/lifetime) + (C_{s\ U238}\ pCi/L)(63.7\ L/lifetime) + (C_{s\ U238}\ pCi/L)(18592\ L/lifetime) + (C_{s\ U238}\ pCi/L)(132\ L/lifetime) + (C_{s\ U238}\ pCi/L)(1632\ L/lifetime) + (C_{s\ U238}\ pCi/L)(2646\ L/lifetime) + (C_{s\ U238}\ pCi/L)(0\ L/lifetime) + (C_{s\ U238}\ pCi/L)(0\ L/lifetime)] \times 2.8 \times 10^{-11} r\text{-}pCi\} + (C_{s\ U238}\ pCi/L)(0\ L/lifetime) \times (5.2 \times 10^{-8}\ r/pCi) \quad \text{(D.I-47)}$$

$$ILCR_{air\ U238} = 2.0 \times 10^{-6}\ r\text{-}pCi/L\text{-}lifetime$$

The constant 2.0×10^{-6} r-pCi/L-lifetime is the ILCR to the Great Miami River User produced by each pCi/L of U-238 in Great Miami River water from all water pathways investigated.

D.I.4 SOIL AND SEDIMENT EXPOSURES

The on-property resident RME is used to illustrate the calculation of soil URFs and UTFs.

D.I.4.1 Incidental Ingestion of Soil or Sediment

Evaluation of the soil/sediment ingestion pathway is performed using Equations 7-7 and 7-8 from the FEMP Risk Assessment Work Plan Addendum (DOE 1992a):

$$\text{(radionuclides)}\quad I_{si} = (C_{si})(IR)(ED)(EF)(FI) \quad \text{(D.I-48)}$$

$$\text{(chemicals)}\quad I_{si} = (C_{si})(IR)(CF)(FI)(EF)(ED)/(BW)(AT) \quad \text{(D.I-49)}$$

where

I_{si}	=	intake from soil or sediment for isotope i (pCi, rad) (mg/kg-d, chem)
C_{si}	=	concentration of isotope i in soil or sediment (pCi/g, rad) (mg/g, chem)
IR	=	ingestion rate (g/d, rad) (g/d, chem)
CF	=	conversion factor 10^{-6} kg/mg
FI	=	fraction ingested from contaminated source (unitless)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
BW	=	body weight (kg)
AT	=	averaging time (d); for noncarcinogens, AT equals (ED) (365 d/yr); for chemical carcinogens, AT equals (70 y/lifetime) (365 d/yr)

Incidental ingestion of soil by the hypothetical on-property receptor has been selected to illustrate how intakes via the soil ingestion pathway are estimated. The time weighted average annual ingestion rate of soil over a 70 year lifetime from the study area (IR x FI) is about 0.109 g/d. The exposure frequency is 350 days per year (EF= 350 d/y), and the exposure duration (ED) is 70 y/lifetime. Substituting these parameter values into Equation D.I-48 yields:

$$I_{s\ U238} = (C_{s\ U238}\ pCi/g)(0.109\ g/d)(350\ d/y)(70\ y/lifetime) \quad (D.I\text{-}50)$$
$$I_{s\ U238} = (C_{s\ U238}\ pCi/g)(2671\ g/lifetime)$$

Since the exposure models used in this scenario respond linearly to changes in concentration, they estimate that each pCi/g of U-238 in soil will produce a lifetime intake of 2671 pCi of U-238 via this pathway.

D.I.4.2 Dermal Contact with Soil or Sediment

Dermal absorption may also occur upon contact with contaminated soil and sediment and is calculated using Equation 7-23 of the FEMP Risk Assessment Work Plan Addendum (DOE 1992a):

$$AB_{si} = (C_{si})(CF)(SA)(AF)(ABS)(ED)(EF)/(BW)(AT) \quad (D.I\text{-}51)$$

where

AB_{si}	=	amount of ith constituent absorbed during contact with soil or sediment (mg/kg-d)
C_{si}	=	concentration of ith constituent in soil or sediment (mg/kg)
SA	=	skin surface area available for contact (cm^2/event)
AF	=	skin adherence factor (mg/cm^2)
ABS	=	absorption factor (unitless)
CF	=	conversion factor; (10^{-6} kg/mg)
ED	=	exposure duration (yr)
EF	=	exposure frequency (events/yr)
BW	=	body weight (kg)
AT	=	averaging time (d); for noncarcinogens, AT equals (ED) (365 d/yr); for chemical carcinogens, AT equals (70 y/lifetime) (365 d/yr)

For most metals, dermal absorption is not a significant pathway because penetration through the skin is minimal. This example calculation is being performed for U-238, a metal. Hence exposures via this pathway are not quantitatively presented for this example.

D.I.4.3 Ingestion of Vegetables Grown in Contaminated Soil

Plants grown in contaminated soil take up contaminants via root uptake. Ingestion of these plants by humans contributes to the total intake of contaminants by humans. Estimating the magnitude of this intake is a two step process. First, concentrations in the plants are estimated. If measured values are not available (e.g. future exposures), concentrations in the plants are estimated using Equation 7-11 from the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The equation is:

$$C_{svi} = (C_{si})B_{iv(1)}e^{-\lambda_n t_h} \quad (D.I\text{-}52)$$

where

C_{svi} = concentration of ith contaminant in food crops (pCi/g, rad) (mg/g, chem)
C_{si} = concentration of ith contaminant in soil (pCi/g, rad) (mg/g, chem)
$B_{iv(1)}$ = dry soil to wet plant partitioning coefficient of ith contaminant in forage (C_{iv}/C_s)
λ_{ri} = radioactive or chemical decay constant of ith contaminant (hr^{-1})
t_h = duration of period between harvest and consumption (hrs)

Vegetable and fruits grown in soil containing U-238 ($C_{sv\ U238}$) have been selected to illustrate how contaminant concentrations in plants can be estimated from contaminant concentrations in soil. The dry soil to wet plant partitioning coefficient of U-238 in the reproductive portions of vegetables and fruits ($B_{iv(1)}$) is 4 x 10^{-3}. The period between harvest and consumption (t_h) for vegetables is 24 hours, and 720 hours for fruit. The radiological decay constant of U-238 λ_{ri} is 1.77 x 10^{-14} yr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches a value of 1 (i.e. no significant decay). Substituting these parameter values into Equation D.I-52 and simplifying yields:

$$C_{sv\ U238} = (C_{s\ U238}\ pCi/g_{soil})(4 \times 10^{-3}\ g_{soil}/g_{plant})(1) \qquad \text{(D.I-53)}$$

$$C_{sv\ U238} = (C_{s\ U238}\ pCi/g_{soil})(4 \times 10^{-3}\ g_{soil}/g_{plant})$$

Once the concentration in crops has been estimated, the quantity ingested by the on-property resident can be calculated using Equations D.I-7 or D.I-8. Continuing the previous example, the calculated concentration of U-238 in crops ($C_{sv\ U238}$ in Equation D.I-53) is calculated to be 0.004 ($C_{s\ U238}$ pCi/g) for each pCi/g U-238 in soil. The exposure frequency is 350 days per year (EF= 350 d/y). The consumption rate of vegetables and fruit grown in the study area is 122 grams per day (FI x IR). The exposure duration (ED) is 70 years. Substituting these parameter values into Equation D.I-7 and solving produces a lifetime ingestion via vegetables ($I_{sv\ U238}$) of:

$$I_{sv\ U238} = (C_{s\ U238}\ pCi/g_{soil})(4 \times 10^{-3}\ g_{soil}/g_{plant})(122\ g/d)70\ y/lifetime)(350/365) \qquad \text{(D.I-54)}$$

$$I_{sv\ U238} = (C_{s\ U238}\ pCi/g_{soil})(11{,}956\ g_{soil}/lifetime)$$

Since the exposure models used in this scenario respond linearly to changes in concentration, they estimate that each pCi/L of U-238 in water will produce a lifetime intake of 11,956 pCi of U-238via this pathway.

D.I.4.4 Ingestion of Meat or Milk

This scenario assumes that livestock is raised on contaminated soil. Feed and forage grown on contaminated soils take up constituents via root uptake. Ingestion of these plants by livestock contributes to the body burden of these contaminants in the animals. In addition to intake from contaminated feed and forage, cows may receive a significant intake from soil ingestion if the soil is also a source of contamination (Zach and Mayoh 1984). Humans using animal products from these animals can be exposed to the contamination contained in them.

The magnitude of the contaminant exposure by humans depends, in part, on the concentration of the constituent in the animal products. If measured values are not available (e.g. future exposures) this concentration can be calculated using the methodology set forth in the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The concentration of a contaminant in animal products, such as beef or milk, is estimated using the following equation:

$$C_{Ai} = F_{Ai}[(C_{fi})(Q_f) + (C_{gi})(Q_g) + (C_{Si})(Q_S)]\, e^{-\lambda_{ri} t_h} \qquad \text{(D.I-55)}$$

where

C_{Ai}	=	concentration of ith contaminant in the animal product, (pCi/L for milk, pCi/g for beef, rad) (mg/L for milk, mg/g for beef, chem)
C_{si}	=	concentration of contaminant in soil (pCi/g, rad) (mg/g, chem)
C_{gi}	=	concentration of ith contaminant in forage (pCi/g, rad) (mg/g, chem)
C_{fi}	=	concentration of ith contaminant in feed (pCi/g, rad) (mg/g, chem)
F_{Ai}	=	element (stable) transfer coefficient that relates the daily intake by an animal to the concentration of ith contaminant in an edible portion of the animal product (d/L for milk, d/g for meat)
Q_g	=	consumption rate of contaminated forage (pasture grass) (g/d)
Q_s	=	consumption rate of soil by livestock (g/d)
Q_f	=	consumption rate of contaminated feed by an animal (g/d)
λ_{ri}	=	radioactive or chemical decay constant of ith contaminant (hr^{-1})
t_h	=	duration of period between harvest and consumption (hrs)

If measured values for feed and forage are not available (e.g. future exposures), the concentration in these plants that is attributable to direct uptake from soil is estimated using Equation 7-11 from the FEMP Risk Assessment Work Plan Addendum (DOE 1992a). The equation is:

$$C_{s(p)i} = (C_{Si})\, B_{iv(2)}\, e^{-\lambda_{ri} t_h} \qquad \text{(D.I-56)}$$

where

$C_{s(p)i}$	=	concentration of ith contaminant in the plant, where p = g is forage, and p = f is stored feed (pCi/g, rad) (mg/g, chem)
C_{si}	=	concentration of ith contaminant in soil (pCi/g, rad) (mg/g, chem)
$B_{iv(2)}$	=	dry soil to wet plant partitioning coefficient of ith contaminant in forage (C_{sgi}/C_{si})
λ_{ri}	=	radioactive or chemical decay constant of ith contaminant (hr^{-1})
t_h	=	duration of period between harvest and consumption (hrs)

The concentration of U-238 in plants grown in soil U-238 ($C_{s(p)\ U238}$) has been selected to illustrate how contaminant concentrations in feed and forage can be estimated from contaminant concentrations in soil. The dry soil to wet plant partitioning coefficient of U-238 in feed and forage ($B_{iv(2)}$) is 8.5 x 10^{-3} g_{soil}/g_{plant}. The periods between harvest and consumption (t_h) of forage and stored feed are 0

hours and 2160 hours, respectively. The radiological decay constant of U-238 λ_{ri} is 1.77×10^{-14} hr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches a value of 1 (i.e. no significant decay) for both feed and forage calculations. Substituting these parameter values into Equation D.I-56 yields:

$$C_{s(g)\ U238} = C_{s(f)\ U238} = (C_{s\ U238}\ pCi/g_{soil})(8.5 \times 10^{-3}\ g_{soil}/g_{plant}) \qquad \text{(D.I-57)}$$

Once the concentration in vegetation has been estimated, concentrations in the animal product can be calculated using Equation D.I-55. Continuing the example begun in Equation D.I-57, the calculated concentration of U-238 in feed and forage attributable to soil uptake ($C_{sf\ U238}$ and $C_{sg\ U238}$ in Equation D.I-57) is about 0.0085 pCi/g for each pCi/g U-238 in the soil. In this study, cows consume 25,000 g/d of potentially contaminated forage (Q_g), 25,000 g/d of potentially contaminated feed (Q_f), and 500 g/d of potentially contaminated soil (Q_s). The plant to beef and plant to milk biotransfer factors for U-238 in cows are 2.0×10^{-7} d/g (F_{mi}) and 6.0×10^{-7} d/mL (F_{di}), respectively. The times between harvesting and consumption (t_h) of meat and milk are 24 hours and 480 hours, respectively. The radiological decay constant of U-238 λ_r is 1.77×10^{-14} hr^{-1}. This value is so small that the $\exp(-\lambda_{ri}\ t_h)$ term approaches a value of 1 (i.e. no significant decay) for both meat and milk calculations.

Substituting the parameter values presented for the beef cattle scenario in Equation D.I-55 yields a meat concentration ($C_{sm\ U238}$) of:

$$\begin{aligned} C_{sm\ U238} &= [(C_{s\ U238}\ pCi/g_{soil})(8.5 \times 10^{-3}\ g_{soil}/g_{plant})(25000\ g_{plant}/d) \\ &\quad + (C_{s\ U238}\ pCi/g_{soil})(8.5 \times 10^{-3}\ g_{soil}/g_{plant})(25000\ g_{plant}/d) \\ &\quad + (C_{s\ U238}\ pCi/g_{soil})(500\ g_{soil}/d)](2.0 \times 10^{-7}\ d/g_{meat}) \qquad \text{(D.I-58)} \\ C_{sm\ U238} &= (C_s\ pCi/g_{soil})(0.000555\ g_{soil}/g_{meat}) \end{aligned}$$

Substituting the parameter values presented for the dairy scenario in Equation D.I-56 yields a milk concentration ($C_{sd\ U238}$) of:

$$\begin{aligned} C_{sd\ U238} &= [(C_{s\ U238}\ pCi/g_{soil})(8.5 \times 10^{-3}\ g_{soil}/g_{plant})(25000\ g_{plant}/d) \\ &\quad + (C_{s\ U238}\ pCi/g_{soil})(8.5 \times 10^{-3}\ g_{soil}/g_{plant})(25000\ g_{plant}/d) \\ &\quad + (C_{s\ U238}\ pCi/g)(500\ g_{soil}/d)](6.0 \times 10^{-7}\ d/mL_{milk}) \qquad \text{(D.I-59)} \\ C_{sd\ U238} &= (C_{s\ U238}\ pCi/g_{soil})(0.000555\ g_{soil}/mL_{milk}) \end{aligned}$$

Once the concentrations of U-238 in animal products are known, the magnitude of intake by the on-property resident can be estimated. The farmer ingests beef containing 1.85×10^{-4} pCi/g of U-238 ($C_{sm\ U238}$ in Equation D.I-58) and dairy products containing 5.55×10^{-4} pCi/g of U-238 ($C_{sd\ U238}$ in Equation D.I-59) for each pCi/g of U-238 in soil over a 70 year lifetime. The exposure frequency is 350 days per year (EF = 350 d/y). The fraction ingested from the contaminated source (FI x IR) is 75

g/d for beef, and 300 mL/d for dairy products. The exposure duration (ED) is 25,550 days. The lifetime intake of U-238 from this meat supply is given by Equation D.I-17.

Substituting the appropriate parameter values for the beef ingestion scenario produces a lifetime ingestion via meat ($I_{sm\ U238}$) of:

$$I_{sm\ U238} = (C_{s\ U238}\ pCi/g_{soil})(0.000185\ g_{soil}/g_{meat})(75\ g_{meat}/d)(350\ d/y)70\ y/lifetime) \qquad \text{(D.I-60)}$$

$$I_{sm\ U238} = (C_{s\ U238}\ pCi/g_{soil})(340\ g_{soil}/lifetime)$$

Substituting the appropriate parameter values for the dairy product ingestion scenario produces a lifetime ingestion via dairy products ($I_{sd\ U238}$) of:

$$I_{sd\ U238} = (C_{s\ U238}\ pCi/g_{soil})(0.000555\ g_{soil}/mL_{milk})(300\ mL_{milk}/d)(350\ d/y)(70\ y/lifetime) \qquad \text{(D.I-61)}$$

$$I_{sd\ U238} = (C_{s\ U238}\ pCi/g_{soil})(4079\ g_{soil}/lifetime)$$

Since the exposure models used in this scenario respond linearly to changes in concentration, each pCi/g of U-238 in soil will produce a lifetime intake of 340 pCi of U-238 via the beef ingestion pathway and an intake of 4079 pCi of U-238 via the beef ingestion pathway.

D.I.4.5 Direct Radiation Exposure

Since the publication of the Risk Assessment Work Plan Addendum, EPA has published a new set of slope factors. Changes in these slope factors require the use of a different equation to calculate risks resulting from external radiation exposures from soils than the one originally presented in the Risk Assessment Work Plan Addendum. The new equation is:

$$ILCR_e = SF_{ext} \times C_s \times ED \times EF \times CF \times [ET_{in} \times (1-S_i) + ET_{out} \times (1-S_o)] \qquad \text{(D.I-62)}$$

where

$ILCR_e$	=	incremental Lifetime Cancer Risk (ILCR/lifetime)
C_s	=	concentration in surface soil (pCi/g)
SF_{ext}	=	HEAST Slope Factor (ILCR - g/pCi -yr)
ED	=	exposure duration (yr/lifetime)
EF	=	exposure frequency (d/yr)
ET_{in}	=	exposure time indoors on-site (hr/d)
ET_{out}	=	exposure time outdoors on-site (hr/d)
S_i	=	indoor shielding factor (0.5, from Risk Assessment Work Plan Addendum)
S_o	=	outdoor shielding factor outdoors (0, assumes no shielding)
CF	=	1/8760 yr/hr

The risk to an on-property resident RME directly attributable to U-238 in soil is the example calculation. In this calculation, exposure duration (ED) is 70 years, and the exposure frequency is 350 days per year (EF= 350 d/y). The exposure time for outdoor activities assumes the resident is outdoors 2000 hours out of a 350 day year (ET_{out} = 2000 hr/350 d). The exposure time for indoor activities is the remainder of the time available (ET_{in} = 24 hr/d - ET_{out}). The value for the indoor shielding factor (S_i) is 0.5, and the value for the outdoor shielding factor (S_o) is 0. Substituting these parameters into Equation D.I-62 yields:

$$ILCR_e = (SF_e)(C_s)(25550\ d/life)(350/365)(y/8760\ h) \times [(18.3\ hr/d)(1-0.5)+(5.7\ hr/d)(1-0.0)] \quad \text{(D.I-63)}$$

$$ILCR_e = (SF_e\ r\text{-}g/y\text{-}pCi)(C_s\ pCi/g)(41.5\ y/life) \quad \text{(D.I-64)}$$

The risk to an on-property resident RME from soil concentrations of 1 pCi/g U-238 is:

$$ILCR_e = (SF_{ext}\ r\text{-}g/y\text{-}pCi)(C_s\ pCi/g)(41.5\ y/life) \quad \text{(D.I-65)}$$

$$ILCR_e = (SF_{ext}\ r\text{-}g/y\text{-}pCi)(41.5\ C_s\ pCi\text{-}y/g\text{-}life) \quad \text{(D.I-66)}$$

Since the exposure models used in this scenario respond linearly to changes in concentration, each pCi/g of U-238 in soil will produce a source with a strength of 41.5 pCi-y/g-life via the direct exposure pathway.

D.I.4.6 Calculation of Uranium Soil Unit Risk Factor For On-Property Resident

In this scenario, a hypothetical resident ingests contaminated dirt, and crops, beef, and milk grown in or on contaminated soil. The receptor also receives exposures from direct dermal contact and direct irradiation. The total risks to the on-property resident RME exposed to soil containing 1 pCi/g from these pathways may be calculated as:

$$ILCR_{soil\ i} = (I_{s\ i} + I_{sv\ i} + I_{sm\ i} + I_{sd\ i} + I_{sa\ i}) \times SF_{ing\ i} + ILCR_{e\ i} \quad \text{(D.I-67)}$$

where

$ILCR_{soil\ i}$	=	incremental Lifetime Cancer Risk (risk of cancer incidence/lifetime);
$ILCR_{e\ i}$	=	incremental Lifetime Cancer Risk from direct radiation (risk of cancer incidence/lifetime).
$I_{s\ i}$	=	unit intake from soil (pCi/lifetime);
$I_{sv\ i}$	=	unit intake from ingesting vegetables and fruit (pCi/lifetime);
$I_{sm\ i}$	=	unit intake from ingesting meat (pCi/lifetime);
$I_{sd\ i}$	=	unit intake from ingesting diary products (pCi/lifetime);
$I_{sa\ i}$	=	unit intake from absorption during dermal contact (pCi/lifetime); and
$SF_{ing\ i}$	=	HEAST slope factor for ingestion of constituent i (r/pCi).

The intake by this hypothetical receptor for each pCi/L of U-238 in soil from each of these pathways has been calculated in Sections D.I.4.1 through D.I.4.4. The ILCR from external exposure to direct radiation is presented in Section D.I.4.5. Substituting these values into Equation D.I-67, along with the appropriate HEAST Slope Factors for ingestion and inhalation of uranium, yields:

$$
\begin{aligned}
ILCR_{s\ U238} = \{[&(C_{s\ U238}\ pCi/g)(2671\ g/lifetime) + (C_{s\ U238}\ pCi/g)(11956\ g/lifetime) \\
&+ (C_{s\ U238}\ pCi/g)(340\ g/lifetime) + (C_{s\ U238}\ pCi/g)(4076\ g/lifetime) \\
&+ (C_{s\ U238}\ pCi/g)(0\ g/lifetime) + (C_{s\ U238}\ pCi/g)(2759\ g/lifetime) \\
&+ (C_{s\ U238}\ pCi/g)(0\ g/lifetime) + (C_{s\ U238}\ pCi/g)(0\ g/lifetime) \\
&\quad \times 2.8 \times 10^{-11} r/pCi \\
&+ (C_{s\ U238}\ pCi/g)(41.5\ y/lifetime)(3.6 \times 10^{-8}\ r\text{-}g/y\text{-}pCi) \qquad \text{(D.I-68)}
\end{aligned}
$$

$$ILCR_{s\ U238} = (C_{s\ U238}\ pCi/g)(2.0 \times 10^{-6}\ r\text{-}g/pCi\text{-}lifetime)$$

The constant 2.0×10^{-6} r-g/pCi-lifetime is the ILCR to the on-property resident RME produced by each pCi/g of U-238 in soil from all direct exposure pathways investigated.

TABLE D.I-1

UNIT RADIOLOGICAL ILCR: TRESPASSING CHILD
SOIL OR SILO CONTENTS PATHWAYS[a]

Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Soil/Silo Contents	Penetrating External Radiation	Ingestion and External Radiation Risks
Ac-227 + 7 dtrs	1.8E-04	5.5E-09	2.4E-07	2.5E-07
Am-241	6.6E-05	3.7E-09	1.4E-09	5.1E-09
Cs-137 + 1 dtr	3.9E-08	4.4E-10	5.7E-07	5.7E-07
Np-237 + 1 dtr	6.0E-05	3.4E-09	1.2E-07	1.3E-07
Pa-231	7.5E-05	1.4E-09	7.4E-09	8.8E-09
Pb-210 + 2 dtrs	8.3E-06	1.0E-08	4.6E-11	1.0E-08
Pu-238	8.1E-05	3.4E-09	8.0E-12	3.4E-09
Pu-239/240	7.9E-05	3.6E-09	7.7E-12	3.6E-09
Ra-226 + 5 dtrs	6.2E-06	1.9E-09	1.7E-06	1.7E-06
Ra-228 + 1 dtr	1.4E-06	1.6E-09	8.3E-07	8.3E-07
Rn-222 + 4 dtrs	1.6E-08	b	b	c
Ru-106 + Rh-106	9.1E-07	1.5E-10	1.9E-07	1.9E-07
Sr-90 + 1 dtr	1.3E-07	5.6E-10	0.0E+00	5.6E-10
Tc-99	1.7E-08	2.0E-11	1.7E-13	2.0E-11
Th-228 + 7 dtrs	1.6E-04	8.6E-10	1.6E-06	1.6E-06
Th-230	6.0E-05	2.0E-10	1.5E-11	2.2E-10
Th-232	5.8E-05	1.9E-10	7.4E-12	1.9E-10
U-233	5.6E-05	2.5E-10	1.2E-11	2.6E-10
U-234	5.4E-05	2.5E-10	8.5E-12	2.6E-10
U-235 + 1 dtr	5.2E-05	2.5E-10	6.8E-08	6.9E-08
U-238 + 2 dtrs	1.1E-04	4.4E-10	1.0E-08	1.1E-08

[a]All values are in units of risk per pCi/g except inhalation values, which are in units of risk per pCi/m^3.
[b]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[c]Not applicable.

TABLE D.I-2

UNIT CHEMICAL ILCR: TRESPASSING CHILD
SOIL OR SILO CONTENTS PATHWAYS[a]

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Dermal Contact and Ingestion Pathways
Aroclor-1254	0.0E+00	2.2E-06	1.1E-07	2.3E-06
Arsenic	2.8E-02	7.6E-08	2.5E-08	1.0E-07
Benzo(a)anthracene	1.2E-02	3.7E-05	1.0E-07	3.7E-05
Benzo(a)pyrene	1.2E-02	3.7E-05	1.0E-07	3.7E-05
Benzo(b)fluoranthene	1.2E-02	7.3E-06	1.0E-07	7.4E-06
Beryllium	1.6E-02	1.9E-06	6.1E-08	1.9E-06
Bis(2-ethylhexyl) phthalate	0.0E+00	3.4E-08	2.0E-10	3.4E-08
Chrysene	1.2E-02	3.7E-05	1.0E-07	3.7E-05
Dibenzo(a,h)anthracene	1.2E-02	3.7E-05	1.0E-07	3.7E-05
Indeno(1,2,3-cd)pyrene	1.2E-02	3.7E-06	1.0E-07	3.8E-06
Methylene chloride	3.0E-06	6.5E-09	1.1E-10	6.6E-09

[a]All values are in units of risk per mg/kg except inhalation values, which are in units of risk per $\mu g/m^3$.

TABLE D.I-3

UNIT HI: TRESPASSING CHILD
SOIL OR SILO CONTENTS PATHWAYS[a]

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Dermal Contact and Ingestion Pathways
2-Butanone	3.7E-02	2.8E-04	1.7E-06	2.8E-04
4-Methyl-2-pentanone	0.0E+00	2.8E-04	1.7E-06	2.8E-04
Acetone	0.0E+00	1.4E-04	8.3E-07	1.4E-04
Anthracene	0.0E+00	3.9E-05	2.8E-07	3.9E-05
Antimony	0.0E+00	2.1E-03	2.1E-04	2.3E-03
Arsenic	0.0E+00	8.4E-04	2.8E-04	1.1E-03
Barium	7.9E+01	3.6E-05	1.2E-06	3.7E-05
Benzoic acid	0.0E+00	3.5E-06	2.1E-08	3.5E-06
Beryllium	0.0E+00	5.0E-04	1.7E-05	5.2E-04
Bis(2-ethylhexyl) phthalate	0.0E+00	7.0E-04	4.1E-06	7.0E-04
Cadmium (food)	0.0E+00	2.5E-04	8.3E-05	3.4E-04
Cadmium (water)	0.0E+00	5.0E-04	1.7E-04	6.7E-04
Chromium	0.0E+00	5.0E-04	1.7E-05	5.2E-04
Cobalt	3.7E+04	4.2E-05	1.4E-06	4.3E-05
Di-n-butyl phthalate	0.0E+00	1.5E-04	8.3E-07	1.5E-04
Fluoranthene	0.0E+00	7.3E-04	2.1E-06	7.3E-04
Lead	1.1E-02	4.2E-05	1.4E-06	4.3E-05
Manganese	1.0E+02	3.0E-05	5.9E-07	3.1E-05
Mercury	1.3E+02	2.1E-02	2.8E-04	2.1E-02

TABLE D.I-3

UNIT HI: TRESPASSING CHILD
SOIL OR SILO CONTENTS PATHWAYS[a]

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Dermal Contact and Ingestion Pathways
2-Butanone	3.7E-02	2.8E-04	1.7E-06	2.8E-04
4-Methyl-2-pentanone	0.0E+00	2.8E-04	1.7E-06	2.8E-04
Acetone	0.0E+00	1.4E-04	8.3E-07	1.4E-04
Anthracene	0.0E+00	3.9E-05	2.8E-07	3.9E-05
Antimony	0.0E+00	2.1E-03	2.1E-04	2.3E-03
Arsenic	0.0E+00	8.4E-04	2.8E-04	1.1E-03
Barium	7.9E+01	3.6E-05	1.2E-06	3.7E-05
Benzoic acid	0.0E+00	3.5E-06	2.1E-08	3.5E-06
Beryllium	0.0E+00	5.0E-04	1.7E-05	5.2E-04
Bis(2-ethylhexyl) phthalate	0.0E+00	7.0E-04	4.1E-06	7.0E-04
Cadmium (food)	0.0E+00	2.5E-04	8.3E-05	3.4E-04
Cadmium (water)	0.0E+00	5.0E-04	1.7E-04	6.7E-04
Chromium	0.0E+00	5.0E-04	1.7E-05	5.2E-04
Cobalt	3.7E+04	4.2E-05	1.4E-06	4.3E-05
Di-n-butyl phthalate	0.0E+00	1.5E-04	8.3E-07	1.5E-04
Fluoranthene	0.0E+00	7.3E-04	2.1E-06	7.3E-04
Lead	1.1E-02	4.2E-05	1.4E-06	4.3E-05
Manganese	1.0E+02	3.0E-05	5.9E-07	3.1E-05
Mercury	1.3E+02	2.1E-02	2.8E-04	2.1E-02

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TABLE D.I-3
(Continued)

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Dermal Contact and Ingestion Pathways
Methylene chloride	1.3E-02	8.4E-05	1.4E-06	8.5E-05
Molybdenum	0.0E+00	6.6E-05	1.7E-05	8.3E-05
Nickel	0.0E+00	1.3E-04	4.1E-06	1.3E-04
Phenol	0.0E+00	2.3E-05	1.4E-07	2.4E-05
Pyrene	0.0E+00	4.7E-04	2.8E-06	4.7E-04
Selenium	0.0E+00	3.2E-05	1.7E-05	4.8E-05
Silver	0.0E+00	5.0E-04	1.7E-05	5.2E-04
Thallium	0.0E+00	2.1E-03	1.4E-03	3.5E-03
Toluene	1.0E-01	1.9E-06	4.1E-07	2.3E-06
Total Xylenes	0.0E+00	1.9E-07	4.1E-08	2.3E-07
Uranium	0.0E+00	8.4E-04	2.8E-05	8.7E-04
Vanadium	0.0E+00	3.6E-04	1.2E-05	3.7E-04
Zinc	0.0E+00	3.2E-06	4.1E-07	3.6E-06

[a]All values are in units of $(mg/kg)^{-1}$ except inhalation values, which are in units of risk per $(\mu g/m^3)^{-1}$.

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TABLE D.I-4

UNIT RADIOLOGICAL ILCR: TRESPASSING CHILD SURFACE WATER PATHWAYS[a]

Radionuclide	Ingestion of Surface Water	Ingestion of Sediment
Ac-227 + 7 dtrs	5.3E-10	5.5E-09
Am-241	3.6E-10	3.7E-09
Cs-137 + 1 dtr	4.2E-11	4.4E-10
Np-237 + 1 dtr	3.3E-10	3.4E-09
Pa-231	1.4E-10	1.4E-09
Pb-210 + 2 dtrs	9.9E-10	1.0E-08
Pu-238	3.3E-10	3.4E-09
Pu-239/240	3.5E-10	3.6E-09
Ra-226 + 5 dtrs	1.8E-10	1.9E-09
Ra-228 + 1 dtr	1.5E-10	1.6E-09
Ru-106 + Rh-106	1.4E-11	1.5E-10
Sr-90 + 1 dtr	5.4E-11	5.6E-10
Tc-99	2.0E-12	2.0E-11
Th-228 + 7 dtrs	8.3E-11	8.6E-10
Th-230	2.0E-11	2.0E-10
Th-232	1.8E-11	1.9E-10
U-233	2.4E-11	2.5E-10
U-234	2.4E-11	2.5E-10
U-235 + 1 dtr	2.4E-11	2.5E-10
U-238 + 2 dtrs	4.2E-11	4.4E-10

[a]All values are in units of risk per pCi/L.

TABLE D.I-5

UNIT CHEMICAL ILCR: TRESPASSING CHILD
SURFACE WATER PATHWAYS[a]

Chemical	Dermal Contact With Surface Water	Ingestion of Surface Water	Dermal Contact and Ingestion Pathways
Aroclor-1254	1.7E-02	1.1E-05	1.7E-02
Arsenic	1.4E-06	2.4E-06	3.8E-06
Benzo(a)anthracene	3.0E-02	1.0E-05	3.0E-02
Benzo(a)pyrene	4.7E-02	1.0E-05	4.7E-02
Benzo(b)fluoranthene	1.2E-01	1.0E-05	1.2E-01
Beryllium	3.6E-05	5.9E-06	4.2E-05
Bis(2-ethylhexyl) phthalate	5.3E-06	1.9E-08	5.3E-06
Chrysene	3.0E-02	1.0E-05	3.0E-02
Dibenzo(a,h)anthracene	3.7E-02	1.0E-05	3.7E-02
Indeno(1,2,3-cd)pyrene	6.0E-01	1.0E-05	6.0E-01
Methylene chloride	2.9E-08	1.0E-08	3.9E-08

[a]All values are in units of risk per mg/L.

TABLE D.I-6

**UNIT HI: TRESPASSING CHILD
SURFACE WATER PATHWAYS[a]**

Chemical	Dermal Contact with Surface Water	Ingestion of Surface Water	Dermal Contact and Ingestion Pathways
2-Butanone	1.1E-04	1.6E-04	2.7E-04
4-Methyl-2-pentanone	5.9E-05	1.6E-04	2.2E-04
Acetone	2.8E-05	8.0E-05	1.1E-04
Anthracene	1.7E-02	2.7E-05	1.7E-02
Antimony	4.0E-02	2.0E-02	6.0E-02
Arsenic	1.6E-02	2.7E-02	4.3E-02
Barium	7.0E-04	1.1E-04	8.1E-04
Benzoic acid	1.3E-05	2.0E-06	1.5E-05
Beryllium	9.6E-03	1.6E-03	1.1E-02
Bis(2-ethylhexyl) phthalate	1.1E-01	4.0E-04	1.1E-01
Cadmium (food)	4.8E-02	8.0E-03	5.6E-02
Cadmium (water)	9.6E-02	1.6E-02	1.1E-01
Chromium	9.6E-03	1.6E-03	1.1E-02
Cobalt	8.0E-04	1.3E-04	9.3E-04
Di-n-butyl phthalate	4.4E-02	8.0E-05	4.4E-02
Fluoranthene	4.7E-01	2.0E-04	4.7E-01
Manganese	5.7E-04	5.7E-05	6.3E-04

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TABLE D.I-6
(Continued)

Chemical	Dermal Contact with Surface Water	Ingestion of Surface Water	Dermal Contact and Ingestion Pathways
Mercury	4.0E-01	2.7E-02	4.3E-01
Methylene chloride	3.8E-04	1.3E-04	5.1E-04
Molybdenum	1.3E-03	1.6E-03	2.9E-03
Nickel	2.4E-03	4.0E-04	2.8E-03
Phenol	5.6E-05	1.3E-05	6.9E-05
Pyrene	2.2E-01	2.7E-04	2.2E-01
Selenium	6.0E-04	1.6E-03	2.2E-03
Silver	9.6E-03	1.6E-03	1.1E-02
Thallium	4.0E-02	1.3E-01	1.7E-01
Toluene	1.1E-03	4.0E-05	1.2E-03
Total Xylenes	2.6E-04	4.0E-06	2.6E-04
Uranium	1.6E-02	2.7E-03	1.9E-02
Vanadium	7.0E-03	1.1E-03	8.1E-03
Zinc	6.0E-05	4.0E-05	1.0E-04

[a]All values are in units of $[mg/L]^{-1}$.

TABLE D.I-7

UNIT RADIOLOGICAL ILCR: GROUNDSKEEPER
SOIL OR SILO CONTENTS PATHWAYS[a]

Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Soil/Silo Contents	Penetrating External Radiation	Ingestion and External Radiation Risks
Ac-227 + 7 dtrs	5.1E-04	1.5E-08	6.8E-07	6.9E-07
Am-241	1.9E-04	1.1E-08	3.9E-09	1.4E-08
Cs-137 + 1 dtr	1.1E-07	1.2E-09	1.6E-06	1.6E-06
Np-237 + 1 dtr	1.7E-04	9.6E-09	3.4E-07	3.5E-07
Pa-231	2.1E-04	4.0E-09	2.1E-08	2.5E-08
Pb-210 + 2 dtrs	2.3E-05	2.9E-08	1.3E-10	2.9E-08
Pu-238	2.3E-04	9.6E-09	2.2E-11	9.6E-09
Pu-239/240	2.2E-04	1.0E-08	2.2E-11	1.0E-08
Ra-226 + 5 dtrs	1.7E-05	5.3E-09	4.8E-06	4.8E-06
Ra-228 + 1 dtr	4.0E-06	4.4E-09	2.3E-06	2.3E-06
Rn-222 + 4 dtrs	4.5E-08	b	b	c
Ru-106 + Rh-106	2.6E-06	4.2E-10	5.4E-07	5.4E-07
Sr-90 + 1 dtr	3.6E-07	1.6E-09	0.0E+00	1.6E-09
Tc-99	4.8E-08	5.7E-11	4.8E-13	5.7E-11
Th-228 + 7 dtrs	4.5E-04	2.4E-09	4.5E-06	4.5E-06
Th-230	1.7E-04	5.7E-10	4.3E-11	6.1E-10
Th-232	1.6E-04	5.3E-10	2.1E-11	5.5E-10
U-233	1.6E-04	7.0E-10	3.4E-11	7.3E-10
U-234	1.5E-04	7.0E-10	2.4E-11	7.2E-10
U-235 + 1 dtr	1.5E-04	7.0E-10	1.9E-07	1.9E-07
U-238 + 2 dtrs	3.0E-04	1.2E-09	2.9E-08	3.0E-08

[a]All values are in units of risk per pCi/g except inhalation values, which are in units of risk per pCi/m^3.
[b]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[c]Not applicable.

TABLE D.I-8

UNIT CHEMICAL ILCR: GROUNDSKEEPER
SOIL OR SILO CONTENTS PATHWAYS[a]

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil/Silo Contents	Ingestion of Soil//Silo Contents	Dermal Contact and Ingestion Pathways
Aroclor-1254	0.0E+00	2.5E-06	1.9E-07	2.7E-06
Arsenic	4.9E-02	8.6E-08	4.3E-08	1.3E-07
Benzo(a)anthracene	2.0E-02	4.2E-05	1.8E-07	4.2E-05
Benzo(a)pyrene	2.0E-02	4.2E-05	1.8E-07	4.2E-05
Benzo(b)fluoranthene	2.0E-02	8.3E-06	1.8E-07	8.5E-06
Beryllium	2.7E-02	2.1E-06	1.1E-07	2.2E-06
Bis(2-ethylhexyl) phthalate	0.0E+00	3.8E-08	3.4E-10	3.8E-08
Chrysene	2.0E-02	4.2E-05	1.8E-07	4.2E-05
Dibenzo(a,h)anthracene	2.0E-02	4.2E-05	1.8E-07	4.2E-05
Indeno(1,2,3-cd)pyrene	2.0E-02	4.2E-06	1.8E-07	4.3E-06
Methylene chloride	5.2E-06	7.3E-09	1.8E-10	7.5E-09

[a]All values are in units of risk per mg/kg except inhalation values, which are in units of risk per $\mu g/m^3$.

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TABLE D.I-9

UNIT HI: GROUNDSKEEPER SOIL OR SILO CONTENTS PATHWAYS[a]

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Dermal Contact and Ingestion Pathways
2-Butanone	3.0E-02	1.5E-04	1.4E-06	1.5E-04
4-Methyl-2-pentanone	0.0E+00	1.5E-04	1.4E-06	1.5E-04
Acetone	0.0E+00	7.6E-05	6.9E-07	7.7E-05
Anthracene	0.0E+00	2.1E-05	2.3E-07	2.2E-05
Antimony	0.0E+00	1.1E-03	1.7E-04	1.3E-03
Arsenic	0.0E+00	4.6E-04	2.3E-04	6.9E-04
Barium	6.5E+01	2.0E-05	9.8E-07	2.1E-05
Benzoic acid	0.0E+00	1.9E-06	1.7E-08	1.9E-06
Beryllium	0.0E+00	2.7E-04	1.4E-05	2.9E-04
Bis(2-ethylhexyl) phthalate	0.0E+00	3.8E-04	3.4E-06	3.8E-04
Cadmium (food)	0.0E+00	1.4E-04	6.9E-05	2.1E-04
Cadmium (water)	0.0E+00	2.7E-04	1.4E-04	4.1E-04
Chromium	0.0E+00	2.7E-04	1.4E-05	2.9E-04
Cobalt	3.0E+04	2.3E-05	1.1E-06	2.4E-05
Di-n-butyl phthalate	0.0E+00	8.1E-05	6.9E-07	8.1E-05
Fluoranthene	0.0E+00	4.0E-04	1.7E-06	4.0E-04
Manganese	8.3E+01	1.6E-05	4.9E-07	1.7E-05
Mercury	1.1E+02	1.1E-02	2.3E-04	1.2E-02

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TABLE D.I-9
Continued

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Dermal Contact and Ingestion Pathways
Methylene chloride	1.1E-02	4.6E-05	1.1E-06	4.7E-05
Molybdenum	0.0E+00	3.6E-05	1.4E-05	5.0E-05
Nickel	0.0E+00	6.9E-05	3.4E-06	7.2E-05
Phenol	0.0E+00	1.3E-05	1.1E-07	1.3E-05
Pyrene	0.0E+00	2.5E-04	2.3E-06	2.6E-04
Selenium	0.0E+00	1.7E-05	1.4E-05	3.1E-05
Silver	0.0E+00	2.7E-04	1.4E-05	2.9E-04
Thallium	0.0E+00	1.1E-03	1.1E-03	2.3E-03
Toluene	8.3E-02	1.0E-06	3.4E-07	1.4E-06
Total Xylenes	0.0E+00	1.0E-07	3.4E-08	1.4E-07
Uranium	0.0E+00	4.6E-04	2.3E-05	4.8E-04
Vanadium	0.0E+00	2.0E-04	9.8E-06	2.1E-04
Zinc	0.0E+00	1.7E-06	3.4E-07	2.1E-06

[a]All values are in units of $(mg/kg)^{-1}$ except inhalation values, which are in units of $(\mu g/m^3)^{-1}$.

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TABLE D.I-10

UNIT RADIOLOGICAL ILCR: OFF-PROPERTY RESIDENT FARMER SOIL OR SILO CONTENTS AIR PATHWAYS[a]

Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat[b]	Ingestion of Milk[b]	Sum of Radionuclide-Specific Risks Across Pathways
Ac-227 + 7 dtrs	1.0E-02	5.1E-04	8.0E-07	2.6E-06	1.1E-02
Am-241	3.7E-03	3.6E-04	9.6E-08	4.4E-08	4.1E-03
Cs-137 + 1 dtr	2.2E-06	7.4E-05	1.0E-04	1.5E-04	3.3E-04
Np-237 + 1 dtr	3.4E-03	5.0E-04	4.2E-06	1.5E-06	3.9E-03
Pa-231	4.2E-03	1.4E-04	1.0E-07	2.0E-07	4.3E-03
Pb-210 + 2 dtrs	4.6E-04	1.2E-03	2.6E-05	8.7E-05	1.7E-03
Pu-238	4.5E-03	3.2E-04	1.1E-08	8.6E-09	4.8E-03
Pu-239/240	4.4E-03	3.4E-04	1.2E-08	9.6E-09	4.7E-03
Ra-226 + 5 dtrs	3.5E-04	1.9E-04	4.2E-06	3.0E-05	5.7E-04
Ra-228 + 1 dtr	8.0E-05	1.5E-04	2.1E-06	1.5E-05	2.4E-04
Rn-222 + 4 dtrs	8.9E-07	c	c	c	d
Ru-106 + Rh-106	5.1E-05	1.3E-05	1.3E-06	1.7E-09	6.6E-05
Sr-90 + 1 dtr	7.2E-06	4.0E-04	3.2E-05	6.5E-04	1.1E-03
Tc-99	9.6E-07	1.6E-04	2.6E-04	1.2E-03	1.6E-03
Th-228 + 7 dtrs	9.0E-03	7.8E-05	2.4E-08	8.2E-08	9.1E-03
Th-230	3.4E-03	1.9E-05	8.2E-09	2.7E-08	3.4E-03
Th-232	3.2E-03	1.8E-05	7.6E-09	2.5E-08	3.3E-03
U-233	3.1E-03	2.8E-05	4.0E-07	4.8E-06	3.2E-03
U-234	3.0E-03	2.8E-05	4.0E-07	4.8E-06	3.0E-03
U-235 + 1 dtr	2.9E-03	2.8E-05	4.0E-07	4.8E-06	2.9E-03
U-238 + 2 dtrs	6.0E-03	5.0E-05	6.9E-07	8.3E-06	6.1E-03

[a]All values are in units of risk per pCi/m^3.
[b]Contamination of foodstuff or forage due to deposition from air.
[c]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion of food stuffs.
[d]Not applicable.

TABLE D.I-11

UNIT CHEMICAL ILCR: OFF-PROPERTY RESIDENT FARMER SOIL OR SILO CONTENTS PATHWAYS

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
Aroclor-1254	0.0E+00	1.2E-05	1.3E-05	1.5E-05	4.0E-05
Arsenic	9.7E-01	2.2E-06	2.3E-08	1.9E-07	9.7E-01
Benzo(a)anthracene	4.0E-01	1.3E-05	3.8E-06	3.0E-06	4.0E-01
Benzo(a)pyrene	4.0E-01	2.4E-05	1.5E-05	1.1E-05	4.0E-01
Benzo(b)fluoranthene	4.0E-01	8.0E-06	2.5E-05	2.0E-05	4.0E-01
Beryllium	5.4E-01	4.0E-06	5.0E-10	1.4E-07	5.4E-01
Bis(2-ethylhexyl) phthalate	0.0E+00	3.2E-08	4.3E-09	3.4E-09	4.0E-08
Cadmium (food)	4.1E-01	0.0E+00	0.0E+00	0.0E+00	4.1E-01
Cadmium (water)	4.1E-01	0.0E+00	0.0E+00	0.0E+00	4.1E-01
Chromium	2.7E+00	0.0E+00	0.0E+00	0.0E+00	2.7E+00
Chrysene	4.0E-01	1.3E-05	3.8E-06	3.0E-06	4.0E-01
Dibenzo(a,h)anthracene	4.0E-01	1.0E-05	7.5E-06	5.9E-06	4.0E-01
Indeno(1,2,3-cd)pyrene	4.0E-01	6.4E-06	2.7E-04	2.2E-04	4.0E-01
Methylene chloride	1.0E-04	2.4E-06	2.3E-11	1.8E-11	1.1E-04
Nickel	5.4E-02	0.0E+00	0.0E+00	0.0E+00	5.4E-02

[a]Contamination of foodstuff or forage due to deposition from air. All values are in units of risk per $\mu g/m^3$.

TABLE D.I-12

UNIT HI: OFF-PROPERTY RESIDENT FARMER
SILO OR SOIL CONTENTS PATHWAYS

Chemical	Inhalation of Fugitive Dust an VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
2-Butanone	2.2E-01	2.4E-02	2.3E-08	1.8E-08	2.4E-01
4-Methyl-2-pentanone	0.0E+00	8.1E-03	5.1E-08	4.1E-08	8.1E-03
Acetone	0.0E+00	2.4E-02	7.0E-09	5.6E-09	2.4E-02
Anthracene	0.0E+00	1.8E-05	3.0E-07	2.4E-07	1.9E-05
Antimony	0.0E+00	7.6E-03	1.7E-04	4.2E-04	8.2E-03
Arsenic	0.0E+00	4.2E-03	4.3E-05	3.6E-04	4.6E-03
Barium	4.6E+02	3.1E-05	2.7E-06	2.9E-07	4.6E+02
Benzoic acid	0.0E+00	3.6E-05	1.4E-09	1.1E-09	3.6E-05
Beryllium	0.0E+00	1.9E-04	2.3E-08	6.4E-06	1.9E-04
Bis(2-ethylhexyl) phthalate	0.0E+00	1.2E-04	1.6E-05	1.2E-05	1.4E-04
Cadmium (food)	0.0E+00	9.6E-03	1.7E-03	2.3E-04	1.2E-02
Chromium	0.0E+00	2.1E-04	3.6E-05	3.3E-05	2.8E-04
Cobalt	2.2E+05	2.0E-05	5.2E-06	1.3E-05	2.2E+05
Di-n-butyl phthalate	0.0E+00	2.5E-05	2.6E-06	2.1E-06	3.0E-05
Fluoranthene	0.0E+00	5.6E-05	8.2E-06	6.4E-06	7.1E-05
Lead	6.5E-02	0.0E+00	0.0E+00	0.0E+00	6.5E-02
Manganese	5.9E+02	2.9E-05	2.1E-06	5.9E-07	5.9E+02
Mercury	7.5E+02	4.5E-02	4.1E-03	5.6E-01	7.5E+02

TABLE D.I-12
(Continued)

Chemical	Inhalation of Fugitive Dust an VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
Methylene chloride	7.5E-02	5.4E-03	5.0E-08	4.0E-08	8.1E-02
Molybdenum	0.0E+00	9.0E-04	2.5E-04	2.5E-04	1.4E-03
Nickel	0.0E+00	1.7E-04	1.4E-05	2.0E-05	2.1E-04
Phenol	0.0E+00	4.2E-04	6.1E-09	4.8E-09	4.2E-04
Pyrene	0.0E+00	8.5E-05	8.5E-06	6.7E-06	1.0E-04
Selenium	0.0E+00	3.9E-04	1.4E-04	1.3E-04	6.5E-04
Silver	0.0E+00	1.4E-03	5.0E-03	1.9E-04	6.6E-03
Thallium	0.0E+00	1.4E-02	3.7E-03	1.8E-02	3.6E-02
Toluene	5.9E-01	2.4E-04	6.3E-08	5.0E-08	5.9E-01
Total Xylenes	0.0E+00	1.5E-05	0.0E+00	7.1E-09	1.5E-05
Uranium	0.0E+00	3.4E-04	2.5E-05	2.1E-06	3.7E-04
Vanadium	0.0E+00	1.4E-04	0.0E+00	1.0E-05	1.5E-04
Zinc	0.0E+00	2.2E-04	0.0E+00	5.5E-04	7.7E-04

[a]Contamination of foodstuff or forage due to deposition from air. All values are in units of $(\mu g/m^3)^{-1}$.

TABLE D.I-13

UNIT RADIOLOGICAL ILCR: OFF-PROPERTY RESIDENT FARMER GROUNDWATER PATHWAYS[a]

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Sum of Radiation Risks from Water Pathways
Ac-227 + 7 dtrs	1.7E-05	5.2E-06	4.8E-09	1.6E-08	2.2E-05
Am-241	1.2E-05	4.2E-06	5.1E-10	2.4E-10	1.6E-05
Cs-137 + 1 dtr	1.4E-06	8.2E-07	6.3E-07	9.0E-07	3.7E-06
Np-237 + 1 dtr	1.1E-05	5.4E-06	2.5E-08	9.1E-09	1.6E-05
Pa-231	4.5E-06	1.4E-06	5.2E-10	1.1E-09	5.9E-06
Pb-210 + 2 dtrs	3.2E-05	1.2E-05	1.6E-07	5.5E-07	4.5E-05
Pu-238	1.1E-05	3.3E-06	5.9E-11	4.9E-11	1.4E-05
Pu-239/240	1.1E-05	3.5E-06	6.2E-11	5.1E-11	1.5E-05
Ra-226 + 5 dtrs	5.9E-06	1.9E-06	2.3E-08	1.7E-07	8.8E-06
Ra-228 + 1 dtr	4.9E-06	1.5E-06	1.4E-08	1.0E-07	6.5E-06
Ru-106 + Rh-106	4.7E-07	1.8E-07	9.9E-09	1.3E-11	6.5E-07
Sr-90 + 1 dtr	1.8E-06	4.8E-06	2.0E-07	4.1E-06	1.1E-05
Tc-99	6.4E-08	1.9E-06	1.6E-06	7.5E-06	1.1E-05
Th-228 + 7 dtrs	2.7E-06	7.8E-07	1.7E-10	5.9E-10	3.5E-06
Th-230	6.4E-07	1.9E-07	4.2E-11	1.5E-10	8.3E-07
Th-232	5.9E-07	1.8E-07	3.9E-11	1.3E-10	7.6E-07
U-233	7.8E-07	1.0E-06	2.1E-09	2.6E-08	1.8E-06
U-234	7.8E-07	3.0E-07	2.1E-09	2.6E-08	1.1E-06
U-235 + 1 dtr	7.8E-07	3.0E-07	2.1E-09	2.6E-08	1.1E-06
U-238 + 2 dtrs	1.4E-06	5.2E-07	3.7E-09	4.6E-08	1.9E-06

[a]All values are in units of risk per pCi/L. Ingestion of meat and milk is from the contamination of food stuff due to cattle drinking contaminated water and irrigation of the crop consumed by cattle. Ingestion of fruits and vegetables is from contamination of foodstuff from irrigation of the crop consumed by the receptor.

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TABLE D.I-14

UNIT CHEMICAL ILCR: OFF-PROPERTY RESIDENT FARMER GROUNDWATER PATHWAYS[a]

Chemical	Inhalation of VOCs from Home Water Use	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Arsenic	0.0E+00	4.8E-02	2.4E-05	1.6E-02	2.8E-04	2.3E-03	6.7E-02
Beryllium	0.0E+00	1.2E-01	6.0E-04	3.6E-02	6.2E-06	1.7E-03	1.6E-01

[a]All values are in units of risk per mg/L.

[b]Contamination of foodstuff due to cattle drinking contaminated water.

[c]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

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TABLE D.I-15

UNIT HI: OFF-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS[a]

Chemical	Inhalation of VOCs from Home Water Use	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Antimony	0.0E+00	6.9E+01	1.1E-01	3.5E+01	2.1E+00	5.3E+00	1.1E+02
Arsenic	0.0E+00	9.1E+01	4.6E-02	3.1E+01	5.4E-01	4.4E+00	1.3E+02
Barium	0.0E+00	3.9E-01	2.0E-03	1.7E-01	3.3E-02	3.5E-03	6.0E-01
Beryllium	0.0E+00	5.5E+00	2.8E-02	1.7E+00	2.9E-04	7.8E-02	7.3E+00
Boron	0.0E+00	3.0E-01	1.5E-03	3.0E+00	2.4E+00	3.2E-01	6.1E+00
Cadmium (food)	0.0E+00	2.7E+01	1.4E-01	0.0E+00	0.0E+00	0.0E+00	2.7E+01
Cadmium (water)	0.0E+00	5.5E+01	2.8E-01	6.3E+01	4.2E+01	5.8E+00	1.7E+02
Chromium	0.0E+00	5.5E+00	2.8E-02	1.8E+00	4.5E-01	4.0E-01	8.1E+00
Cobalt	0.0E+00	4.6E-01	2.2E-03	1.5E-01	6.5E-02	1.6E-01	8.4E-01
Manganese	0.0E+00	2.0E-01	1.6E-03	1.2E-01	2.6E-02	7.3E-03	3.5E-01
Mercury	0.0E+00	9.1E+01	1.2E+00	1.4E+02	5.1E+01	7.0E+03	7.3E+03
Molybdenum	0.0E+00	5.5E+00	3.7E-03	3.6E+00	3.1E+00	3.1E+00	1.5E+01
Nickel	0.0E+00	1.4E+00	6.8E-03	7.7E-01	1.7E-01	2.5E-01	2.6E+00
Selenium	0.0E+00	5.5E+00	1.8E-03	2.2E+00	1.7E+00	1.6E+00	1.1E+01
Silver	0.0E+00	5.5E+00	2.8E-02	4.9E+00	6.3E+01	2.3E+00	7.5E+01
Thallium	0.0E+00	4.6E+02	1.1E-01	1.4E+02	4.6E+01	2.2E+02	8.6E+02
Uranium	0.0E+00	9.1E+00	4.6E-02	2.9E+00	3.1E-01	2.5E-02	1.2E+01
Vanadium	0.0E+00	3.9E+00	2.0E-02	1.2E+00	4.1E-03	1.2E-01	5.3E+00

TABLE D.I.15
(Continued)

Chemical	Inhalation of VOCs from Home Water Use	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Zinc	0.0E+00	1.4E-01	1.7E-04	6.2E-01	2.8E+00	6.9E+00	1.0E+01

[a]All values are in units of $[mg/L]^{-1}$.
[b]Contamination of foodstuff due to cattle drinking contaminated water.
[c]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

TABLE D.I-16

UNIT RADIOLOGICAL ILCR: OFF-PROPERTY USER OF SURFACE WATER SURFACE WATER PATHWAYS[a]

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Radiation Risks from Water Pathways
Ac-227 + 7 dtrs	1.7E-05	5.2E-06	4.8E-09	1.6E-08	5.0E-06	2.7E-05
Am-241	1.2E-05	4.2E-06	5.1E-10	2.4E-10	3.4E-05	5.0E-05
Cs-137 + 1 dtr	1.4E-06	8.2E-07	6.3E-07	9.0E-07	3.2E-05	3.5E-05
Np-237 + 1 dtr	1.1E-05	5.4E-06	2.5E-08	9.1E-09	1.2E-06	1.7E-05
Pa-231	4.5E-06	1.4E-06	5.2E-10	1.1E-09	5.7E-07	6.5E-06
Pb-210 + 2 dtrs	3.2E-05	1.2E-05	1.6E-07	5.5E-07	3.7E-05	8.3E-05
Pu-238	1.1E-05	3.3E-06	5.9E-11	4.9E-11	3.1E-06	1.7E-05
Pu-239/240	1.1E-05	3.5E-06	6.2E-11	5.1E-11	3.3E-06	1.8E-05
Ra-226 + 5 dtrs	5.9E-06	1.9E-06	2.3E-08	1.7E-07	3.4E-06	1.2E-05
Ra-228 + 1 dtr	4.9E-06	1.5E-06	1.4E-08	1.0E-07	2.8E-06	9.3E-06
Ru-106 + Rh-106	4.7E-07	1.8E-07	9.9E-09	1.3E-11	5.4E-08	7.1E-07
Sr-90 + 1 dtr	1.8E-06	4.8E-06	2.0E-07	4.1E-06	6.1E-07	1.1E-05
Tc-99	6.4E-08	1.9E-06	1.6E-06	7.5E-06	1.1E-08	1.1E-05
Th-228 + 7 dtrs	2.7E-06	7.8E-07	1.7E-10	5.9E-10	9.4E-07	4.4E-06
Th-230	6.4E-07	1.9E-07	4.2E-11	1.5E-10	2.2E-07	1.0E-06
Th-232	5.9E-07	1.8E-07	3.9E-11	1.3E-10	2.0E-07	9.7E-07
U-233	7.8E-07	1.0E-06	2.1E-09	2.6E-08	1.8E-08	1.8E-06
U-234	7.8E-07	3.0E-07	2.1E-09	2.6E-08	1.8E-08	1.1E-06
U-235 + 1 dtr	7.8E-07	3.0E-07	2.1E-09	2.6E-08	1.8E-08	1.1E-06
U-238 + 2 dtrs	1.4E-06	5.2E-07	3.7E-09	4.6E-08	3.2E-08	2.0E-06

[a]All values are in units of risk per pCi/L. Water for all uses is obtained from the Great Miami River. Ingestion of meat and milk is from the contamination of food stuff due to cattle drinking contaminated water and irrigation of the crop consumed by cattle. Ingestion of fruits and vegetables is from contamination of foodstuff from irrigation of the crop consumed by the receptor. Ingestion of fish is from consumption of fish caught from the river.

TABLE D.I-17

UNIT CHEMICAL ILCR: OFF-PROPERTY USER OF SURFACE WATER
SURFACE WATER PATHWAYS

Chemical	Ingestion of Drinking Water	Inhalation of VOCs from Home Water Use	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[a,b]	Ingestion of Meat[a,b]	Ingestion of Fish	Dermal Contact and Ingestion Pathways
Aroclor-1254	2.1E-01	0.0E+00	4.1E-01	7.9E-02	1.6E-01	1.8E-01	5.7E+02	5.7E+02
Arsenic	4.8E-02	0.0E+00	2.4E-05	1.6E-02	2.8E-04	2.3E-03	5.7E-02	1.2E-01
Benzo(a)anthracene	2.0E-01	0.0E+00	7.0E-01	7.9E-02	4.7E-02	3.7E-02	5.5E+01	5.5E+01
Benzo(a)pyrene	2.0E-01	0.0E+00	1.1E+00	1.1E-01	1.8E-01	1.4E-01	1.1E+02	1.1E+02
Benzo(b)fluoranthene	2.0E-01	0.0E+00	2.8E+00	6.5E-02	3.1E-01	2.4E-01	3.1E+02	3.2E+02
Beryllium	1.2E-01	0.0E+00	6.0E-04	3.6E-02	6.2E-06	1.7E-03	6.0E-02	2.2E-01
Bis(2-ethylhexyl) phthalate	3.8E-04	0.0E+00	1.2E-04	1.7E-04	5.4E-05	4.2E-05	8.8E-03	9.6E-03
Chrysene	2.0E-01	0.0E+00	7.0E-01	7.9E-02	4.7E-02	3.7E-02	5.7E+01	5.8E+01
Dibenzo(a,h)anthracene	2.0E-01	0.0E+00	8.8E-01	7.2E-02	9.4E-02	7.2E-02	1.1E+02	1.1E+02
Indeno(1,2,3-cd)pyrene	2.0E-01	0.0E+00	1.4E+01	6.1E-02	3.4E+00	2.6E+00	2.1E+03	2.1E+03
Methylene chloride	2.1E-04	1.6E-04	6.8E-07	6.6E-03	2.8E-07	2.2E-07	2.8E-05	6.8E-03

[a]Contamination of foodstuff due to cattle drinking contaminated water. All values are in units of risk per mg/L.
[b]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

TABLE D.I-18

UNIT HI: OFF-PROPERTY USER OF SURFACE WATER
SURFACE WATER PATHWAYS

Chemical	Ingestion of Drinking Water	Inhalation of VOCs from Home Water Use	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[a,b]	Ingestion of Meat[a,b]	Ingestion of Fish	Dermal Contact and Ingestion Pathways
2-Butanone	5.5E-01	3.4E-01	4.3E-04	6.5E+01	2.9E-04	2.3E-04	0.0E+00	6.6E+01
4-Methyl-2-pentanone	5.5E-01	0.0E+00	2.3E-04	2.2E+01	6.4E-04	5.1E-04	5.9E-02	2.2E+01
Acetone	2.7E-01	0.0E+00	1.1E-04	6.3E+01	8.8E-05	7.0E-05	2.9E-03	6.4E+01
Anthracene	9.1E-02	0.0E+00	6.7E-02	6.8E-02	3.7E-03	2.9E-03	2.3E+00	2.5E+00
Antimony	6.9E+01	0.0E+00	1.1E-01	3.5E+01	2.1E+00	5.3E+00	1.9E+00	1.1E+02
Arsenic	9.1E+01	0.0E+00	4.6E-02	3.1E+01	5.4E-01	4.4E+00	1.1E+02	2.4E+02
Barium	3.9E-01	0.0E+00	2.0E-03	1.7E-01	3.3E-02	3.5E-03	0.0E+00	6.0E-01
Benzoic acid	6.9E-03	0.0E+00	5.3E-05	9.7E-02	1.7E-05	1.4E-05	2.9E-03	1.1E-01
Beryllium	5.5E+00	0.0E+00	2.8E-02	1.7E+00	2.9E-04	7.8E-02	2.8E+00	1.0E+01
Bis(2-ethylhexyl) phthalate	1.4E+00	0.0E+00	4.4E-01	6.1E-01	1.9E-01	1.5E-01	3.1E+01	3.4E+01
Cadmium (water)	5.5E+01	0.0E+00	2.8E-01	6.3E+01	4.2E+01	5.8E+00	1.2E+02	2.9E+02
Chromium	5.5E+00	0.0E+00	2.8E-02	1.8E+00	4.5E-01	4.0E-01	2.4E+00	1.1E+01
Cobalt	4.6E-01	0.0E+00	2.2E-03	1.5E-01	6.5E-02	1.6E-01	0.0E+00	8.4E-01
Di-n-butyl phthalate	2.7E-01	0.0E+00	1.8E-01	1.3E-01	3.3E-02	2.6E-02	3.9E+01	4.0E+01
Fluoranthene	6.9E-01	0.0E+00	1.8E+00	3.0E-01	1.0E-01	7.9E-02	2.1E+01	2.4E+01
Manganese	2.0E-01	0.0E+00	1.6E-03	1.2E-01	2.6E-02	7.3E-03	0.0E+00	3.5E-01
Mercury	9.1E+01	0.0E+00	1.2E+00	1.4E+02	5.1E+01	7.0E+03	1.4E+04	2.1E+04

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TABLE D.I-18
(Continued)

Chemical	Ingestion of Drinking Water	Inhalation of VOCs from Home Water Use	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[a,b]	Ingestion of Meat[a,b]	Ingestion of Fish	Dermal Contact and Ingestion Pathways
Methylene chloride	4.6E-01	1.2E-01	1.5E-03	1.5E+01	6.3E-04	5.0E-04	6.2E-02	1.5E+01
Molybdenum	5.5E+00	0.0E+00	3.7E-03	3.6E+00	3.1E+00	3.1E+00	0.0E+00	1.5E+01
Nickel	1.4E+00	0.0E+00	6.8E-03	7.7E-01	1.7E-01	2.5E-01	1.7E+00	4.3E+00
Phenol	4.6E-02	0.0E+00	2.2E-04	1.1E+00	7.6E-05	6.0E-05	1.7E-03	1.2E+00
Pyrene	9.1E-01	0.0E+00	9.1E-01	4.3E-01	1.1E-01	8.3E-02	6.7E+01	6.9E+01
Selenium	5.5E+00	0.0E+00	1.8E-03	2.2E+00	1.7E+00	1.6E+00	2.4E+00	1.3E+01
Silver	5.5E+00	0.0E+00	2.8E-02	4.9E+00	6.3E+01	2.3E+00	4.6E+02	5.3E+02
Thallium	4.6E+02	0.0E+00	1.1E-01	1.4E+02	4.6E+01	2.2E+02	0.0E+00	8.6E+02
Toluene	1.4E-01	9.3E-01	4.5E-03	6.8E-01	7.8E-04	6.2E-04	4.0E-02	9.8E-01
Total Xylenes	1.4E-02	0.0E+00	1.0E-03	4.4E-02	1.1E-06	8.8E-05	4.4E-02	1.0E-01
Uranium	9.1E+00	0.0E+00	4.6E-02	2.9E+00	3.1E-01	2.5E-02	0.0E+00	1.2E+01
Vanadium	3.9E+00	0.0E+00	2.0E-02	1.2E+00	7.1E-04	1.2E-01	0.0E+00	5.3E+00
Zinc	1.4E-01	0.0E+00	1.7E-04	6.2E-01	1.2E-02	6.9E+00	1.7E-01	7.9E+00

[a]Contamination of foodstuff due to cattle drinking contaminated water. All values are in units of $(mg/L)^{-1}$.
[b]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

TABLE D.I-19

UNIT RADIOLOGICAL ILCR: CT ON-PROPERTY RESIDENT FARMER
SOIL OR SILO CONTENTS PATHWAYS[a]

	Inhalation and Air Dispersion[b]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruit	Ingestion of Meat	Ingestion of Milk	Radionuclide-Specific Risks Across Pathways
Ac-227 + 7 dtrs	7.6E-04	3.3E-05	5.4E-08	1.7E-07	7.9E-04
Am-241	2.8E-04	2.3E-05	6.5E-09	3.0E-09	3.0E-04
Cs-137 + 1 dtr	1.6E-07	4.8E-06	7.0E-06	9.9E-06	2.2E-05
Np-237 + 1 dtr	2.5E-04	3.2E-05	2.8E-07	1.0E-07	2.8E-04
Pa-231	3.1E-04	8.8E-06	6.8E-09	1.4E-08	3.2E-04
Pb-210 + 2 dtrs	3.5E-05	7.5E-05	1.8E-06	5.9E-06	1.2E-04
Pu-238	3.4E-04	2.1E-05	7.3E-10	5.8E-10	3.6E-04
Pu-239/240	3.3E-04	2.2E-05	8.1E-10	6.5E-10	3.5E-04
Ra-226 + 5 dtrs	2.6E-05	1.2E-05	2.8E-07	2.0E-06	4.0E-05
Ra-228 + 1 dtr	6.0E-06	9.4E-06	1.4E-07	1.0E-06	1.7E-05
Rn-222 + 4 dtrs	6.6E-08	c	c	c	6.6E-08
Ru-106 + Rh-106	3.8E-06	8.6E-07	9.0E-08	1.1E-10	4.7E-06
Sr-90 + 1 dtr	5.3E-07	2.6E-05	2.2E-06	4.4E-05	7.2E-05
Tc-99	7.2E-08	1.0E-05	1.7E-05	8.1E-05	1.1E-04
Th-228 + 7 dtrs	6.7E-04	5.0E-06	1.6E-09	5.5E-09	6.8E-04
Th-230	2.5E-04	1.2E-06	5.5E-10	1.8E-09	2.5E-04
Th-232	2.4E-04	1.1E-06	5.1E-10	1.7E-09	2.4E-04

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TABLE D.I-19
(Continued)

	Inhalation and Air Dispersion[b]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruit	Ingestion of Meat	Ingestion of Milk	Radionuclide-Specific Risks Across Pathways
U-233	2.3E-04	1.8E-06	2.7E-08	3.2E-07	2.4E-04
U-234	2.2E-04	1.8E-06	2.7E-08	3.2E-07	2.3E-04
U-235 + 1 dtr	2.2E-04	1.8E-06	2.7E-08	3.2E-07	2.2E-04
U-238 + 2 dtrs	4.5E-04	3.2E-06	4.7E-08	5.6E-07	4.5E-04

TABLE D.I-19
(Continued)

	Ingestion, External Radiation, Root Uptake[d,e]					
Radionuclides	Soil Ingestion	Ingestion of Vegetables/ Fruit	Ingestion of Meat	Ingestion of Milk	External Exposure	Radionuclide-Specific Risks Across Pathways
Ac-227 + 7 dtrs	8.7E-08	2.4E-08	7.3E-10	2.3E-09	3.4E-06	3.5E-06
Am-241	5.9E-08	1.1E-08	8.1E-11	3.7E-11	2.0E-08	9.0E-08
Cs-137 + 1 dtr	6.9E-09	1.6E-07	3.1E-07	4.3E-07	8.0E-06	8.9E-06
Np-237 + 1 dtr	5.4E-08	4.2E-07	8.2E-09	3.0E-09	1.7E-06	2.2E-06
Pa-231	2.3E-08	4.4E-09	7.1E-11	1.4E-10	1.0E-07	1.3E-07
Pb-210 + 2 dtrs	1.6E-07	1.1E-06	6.6E-08	2.2E-07	6.4E-10	1.6E-06
Pu-238	5.4E-08	1.9E-09	7.1E-12	5.7E-12	1.1E-10	5.6E-08
Pu-239/240	5.7E-08	2.0E-09	7.4E-12	5.9E-12	1.1E-10	5.9E-08
Ra-226 + 5 dtrs	3.0E-08	3.5E-08	4.6E-09	3.3E-08	2.4E-05	2.4E-05
Ra-228 + 1 dtr	2.5E-08	2.8E-08	3.7E-09	2.7E-08	1.2E-05	1.2E-05
Ru-106 + Rh-106	2.4E-09	3.2E-08	7.2E-09	8.9E-12	2.7E-06	2.7E-06
Sr-90 + 1 dtr	8.9E-09	1.7E-06	1.7E-07	3.3E-06	[f]	5.2E-06
Tc-99	3.2E-10	3.8E-07	6.5E-07	3.1E-06	2.4E-12	4.1E-06
Th-228 + 7 dtrs	1.4E-08	8.4E-10	2.1E-11	7.3E-11	2.2E-05	2.2E-05
Th-230	3.2E-09	2.1E-10	5.2E-12	1.7E-11	2.2E-10	3.7E-09
Th-232	3.0E-09	2.0E-10	4.8E-12	1.6E-11	1.0E-10	3.3E-09
U-233	4.0E-09	1.2E-08	3.7E-10	4.4E-09	1.7E-10	2.1E-08
U-234	4.0E-09	1.2E-08	3.7E-10	4.4E-09	1.2E-10	2.1E-08

TABLE D.I-19
(Continued)

Ingestion, External Radiation, Root Uptake[d,e]						
Radionuclides	Soil Ingestion	Ingestion of Vegetables/ Fruit	Ingestion of Meat	Ingestion of Milk	External Exposure	Radionuclide-Specific Risks Across Pathways
U-235 + 1 dtr	4.0E-09	1.2E-08	3.7E-10	4.4E-09	9.6E-07	9.8E-07
U-238 + 2 dtrs	6.9E-09	2.2E-08	6.4E-10	7.7E-09	1.4E-07	1.8E-07

[a]All values are in units of risk per pCi/m^3.
[b]Contamination of foodstuff and forage due to deposition from air.
[c]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[d]All values are in units of risk per pCi/g.
[e]Contamination of foodstuff and forage due to root uptake.
[f]Radionuclide is a beta-particle emitter and does not emit penetrating radiation.

TABLE D.I-20

UNIT CHEMICAL ILCR: CT ON-PROPERTY RESIDENT FARMER
SOIL OR SILO CONTENTS PATHWAYS

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
Aroclor-1254	0.0E+00	7.8E-07	8.6E-07	1.0E-06	2.7E-06
Arsenic	7.2E-02	1.4E-07	1.5E-09	1.3E-08	7.2E-02
Benzo(a)anthracene	2.9E-02	8.5E-07	2.5E-07	2.0E-07	2.9E-02
Benzo(a)pyrene	2.9E-02	1.6E-06	9.8E-07	7.7E-07	2.9E-02
Benzo(b)fluoranthene	2.9E-02	5.1E-07	1.7E-06	1.3E-06	2.9E-02
Beryllium	4.1E-02	2.6E-07	3.3E-11	9.3E-09	4.1E-02
Bis(2-ethylhexyl) phthalate	0.0E+00	2.1E-09	2.9E-10	2.3E-10	2.6E-09
Cadmium (food)	3.0E-02	0.0E+00	0.0E+00	0.0E+00	3.0E-02
Cadmium (water)	3.0E-02	0.0E+00	0.0E+00	0.0E+00	3.0E-02
Chromium	2.0E-01	0.0E+00	0.0E+00	0.0E+00	2.0E-01
Chrysene	2.9E-02	8.5E-07	2.5E-07	2.0E-07	2.9E-02
Dibenzo(a,h)anthracene	2.9E-02	6.7E-07	5.1E-07	4.0E-07	2.94E-02
Indeno(1,2,3-cd)pyrene	2.9E-02	4.2E-07	1.8E-05	1.5E-05	3.0E-02
Methylene chloride	7.7E-06	1.6E-07	1.5E-12	1.2E-12	7.9E-06
Nickel	4.1E-03	0.0E+00	0.0E+00	0.0E+00	4.1E-03

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TABLE D.I-20
(Continued)

	Ingestion, Dermal Contact, and Root Uptake					
Chemical	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[b]	Ingestion of Meat[b]	Dermal Contact and Ingestion Pathways
Aroclor-1254	2.1E-07	1.4E-05	1.4E-05	1.0E-05	1.2E-05	3.7E-05
Arsenic	7.1E-09	1.9E-06	1.9E-06	2.9E-08	2.4E-07	2.4E-06
Benzo(a)anthracene	3.4E-06	1.8E-05	1.8E-05	3.6E-06	2.8E-06	2.9E-05
Benzo(a)pyrene	3.4E-06	4.4E-05	4.4E-05	2.2E-05	1.7E-05	8.7E-05
Benzo(b)fluoranthene	6.8E-07	4.9E-06	4.9E-06	9.2E-06	7.3E-06	2.3E-05
Beryllium	1.7E-07	1.2E-06	1.2E-06	2.7E-10	7.4E-08	2.0E-06
Bis(2-ethylhexyl) phthalate	3.1E-09	5.1E-08	5.1E-08	5.1E-09	4.1E-09	6.5E-08
Chrysene	3.4E-06	1.8E-05	1.8E-05	3.6E-06	2.8E-06	2.9E-05
Dibenzo(a,h)anthracene	3.4E-06	1.1E-05	1.1E-05	5.1E-06	4.1E-06	2.4E-05
Indeno(1,2,3-cd)pyrene	3.4E-07	1.1E-06	1.1E-06	2.7E-05	2.1E-05	5.0E-05
Methylene chloride	6.0E-10	5.9E-06	5.9E-06	5.4E-11	4.3E-11	5.9E-06

[a]Contamination of foodstuff or forage due to deposition from air. All values are in units of risk per $\mu g/m^3$.
[b]Contamination of foodstuff or forage due to root uptake from soil or silo contents. All values are in units of risk per mg/kg.

TABLE D.I-21

UNIT HI: CT ON-PROPERTY RESIDENT FARMER
SOIL OR SILO CONTENTS PATHWAYS

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
2-Butanone	1.3E-01	1.2E-02	1.2E-08	9.5E-09	1.4E-01
4-Methyl-2-pentanone	0.0E+00	4.1E-03	2.7E-08	2.1E-08	4.1E-03
Acetone	0.0E+00	1.2E-02	3.7E-09	2.9E-09	1.2E-02
Anthracene	0.0E+00	9.1E-06	1.6E-07	1.2E-07	9.4E-06
Antimony	0.0E+00	3.8E-03	8.9E-05	2.2E-04	4.1E-03
Arsenic	0.0E+00	2.1E-03	2.3E-05	1.9E-04	2.3E-03
Barium	2.7E+02	1.6E-05	1.4E-06	1.5E-07	2.7E+02
Benzoic acid	0.0E+00	1.8E-05	7.2E-10	5.7E-10	1.8E-05
Beryllium	0.0E+00	9.3E-05	1.2E-08	3.4E-06	9.7E-05
Bis(2-ethylhexyl) phthalate	0.0E+00	5.8E-05	8.1E-06	6.4E-06	7.2E-05
Cadmium (food)	0.0E+00	4.8E-03	8.8E-04	1.2E-04	5.8E-03
Cadmium (water)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.00E+00
Chromium	0.0E+00	1.0E-04	1.9E-05	1.7E-05	1.4E-04
Cobalt	1.3E+05	1.0E-05	2.7E-06	6.8E-06	1.3E+05
Di-n-butyl phthalate	0.0E+00	1.3E-05	1.4E-06	1.1E-06	1.5E-05
Fluoranthene	0.0E+00	2.8E-05	4.3E-06	3.4E-06	3.6E-05
Lead	3.8E-02	0.0E+00	0.0E+00	0.0E+00	3.8E-02
Manganese	3.4E+02	1.5E-05	1.1E-06	3.1E-07	3.4E+02

TABLE D.I-21
(Continued)

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
Mercury	4.4E+02	2.2E-02	2.1E-03	2.9E-01	4.4E+02
Methylene chloride	4.4E-02	2.7E-03	2.6E-08	2.1E-08	4.6E-02
Molybdenum	0.0E+00	4.5E-04	1.3E-04	1.3E-04	7.1E-04
Nickel	0.0E+00	8.7E-05	7.1E-06	1.1E-05	1.1E-04
Phenol	0.0E+00	2.1E-04	3.2E-09	2.5E-09	2.1E-04
Pyrene	0.0E+00	4.3E-05	4.5E-06	3.5E-06	5.1E-05
Selenium	0.0E+00	1.9E-04	7.2E-05	6.7E-05	3.3E-04
Silver	0.0E+00	6.9E-04	2.6E-03	9.9E-05	3.4E-03
Thallium	0.0E+00	7.2E-03	1.9E-03	9.7E-03	1.9E-02
Toluene	3.4E-01	1.2E-04	3.3E-08	2.6E-08	3.4E-01
Total Xylenes	0.0E+00	7.7E-06	0.0E+00	3.7E-09	7.7E-06
Uranium	0.0E+00	1.7E-04	1.3E-05	1.1E-06	1.9E-04
Vanadium	0.0E+00	6.9E-05	0.0E+00	5.4E-06	7.5E-05
Zinc	0.0E+00	1.1E-04	0.0E+00	2.9E-04	4.0E-04

TABLE D.I-21
(Continued)

Chemical	Ingestion, Dermal Contact, and Root Uptake					
	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk/Dairy Products[b]	Ingestion of Meat[b]	Dermal Contact and Ingestion Pathways
2-Butanone	3.5E-05	2.2E-05	4.6E-01	4.3E-07	3.4E-07	4.6E-01
4-Methyl-2-pentanone	3.5E-05	2.2E-05	1.5E-01	9.6E-07	7.6E-07	1.5E-01
Acetone	1.7E-05	1.1E-05	4.5E-01	1.3E-07	1.0E-07	4.5E-01
Anthracene	4.9E-06	3.6E-06	2.9E-04	4.2E-06	3.3E-06	3.1E-04
Antimony	2.6E-04	2.7E-03	1.1E-01	2.7E-03	6.7E-03	1.2E-01
Arsenic	1.0E-04	3.6E-03	2.8E-02	4.3E-04	3.6E-03	3.6E-02
Barium	4.5E-06	1.5E-05	3.7E-04	4.0E-05	4.3E-06	4.4E-04
Benzoic acid	4.4E-07	2.7E-07	6.7E-04	2.5E-08	2.0E-08	6.7E-04
Beryllium	6.3E-05	2.2E-04	4.2E-04	9.7E-08	2.7E-05	7.3E-04
Bis(2-ethylhexyl) phthalate	8.7E-05	5.4E-05	1.4E-03	1.4E-04	1.1E-04	1.8E-03
Cadmium (food)	3.1E-05	1.1E-03	1.7E-01	3.0E-02	4.1E-03	2.0E-01
Chromium	6.3E-05	2.2E-04	8.2E-04	1.2E-04	1.1E-04	1.3E-03
Cobalt	5.2E-06	1.8E-05	1.2E-04	3.6E-05	9.0E-05	2.7E-04
Di-n-butyl phthalate	1.8E-05	1.1E-05	3.2E-04	2.6E-05	2.1E-05	4.0E-04
Fluoranthene	9.1E-05	2.7E-05	6.8E-04	7.4E-05	5.8E-05	9.3E-04
Manganese	3.7E-06	7.7E-06	4.4E-04	3.4E-05	9.6E-06	5.0E-04
Mercury	2.6E-03	3.6E-03	8.0E-01	7.3E-02	1.0E+01	1.1E+01
Methylene chloride	1.0E-05	1.8E-05	1.0E-01	9.3E-07	7.4E-07	1.0E-01

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TABLE D.I-21
(Continued)

Chemical	Ingestion, Dermal Contact, and Root Uptake					
	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk/Dairy Products[b]	Ingestion of Meat[b]	Dermal Contact and Ingestion Pathways
Molybdenum	8.2E-06	2.2E-04	1.4E-02	4.0E-03	4.0E-03	2.2E-02
Nickel	1.6E-05	5.4E-05	2.5E-03	1.6E-04	2.4E-04	3.0E-03
Phenol	2.9E-06	1.8E-06	7.9E-03	1.1E-07	8.9E-08	7.9E-03
Pyrene	5.8E-05	3.6E-05	1.1E-03	8.5E-05	6.7E-05	1.4E-03
Selenium	3.9E-06	2.2E-04	4.2E-03	1.1E-03	1.0E-03	6.5E-03
Silver	6.3E-05	2.2E-04	2.3E-02	8.6E-02	3.2E-03	1.1E-01
Thallium	2.6E-04	1.8E-02	1.2E-02	7.2E-03	3.6E-02	7.3E-02
Toluene	2.4E-07	5.4E-06	4.5E-03	1.1E-06	8.9E-07	4.5E-03
Total Xylenes	2.4E-08	5.4E-07	2.8E-04	1.6E-07	1.3E-07	2.9E-04
Uranium	1.0E-04	3.6E-04	1.3E-03	9.2E-05	7.6E-06	1.8E-03
Vanadium	4.5E-05	1.5E-04	4.0E-04	8.5E-07	2.6E-05	6.2E-04
Zinc	3.9E-07	5.4E-06	4.1E-03	4.0E-03	1.0E-02	1.8E-02

[a]Contamination of foodstuff or forage due to deposition from air. All values are in units of $(\mu g/m^3)^{-1}$.
[b]Contamination of foodstuff or forage due to root uptake from soil or silo contents. All values are in units of $(mg/kg)^{-1}$.

TABLE D.I-22

UNIT RADIOLOGICAL ILCR: CT ON-PROPERTY RESIDENT FARMER GROUNDWATER PATHWAYS[a]

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Radiation Risks from Water Pathways
Ac-227 + 7 dtrs	1.2E-06	3.3E-07	3.2E-10	1.1E-09	1.5E-06
Am-241	8.3E-07	2.7E-07	3.4E-11	1.6E-11	1.1E-06
Cs-137 + 1 dtr	9.7E-08	5.3E-08	4.3E-08	6.1E-08	2.5E-07
Np-237 + 1 dtr	7.6E-07	3.5E-07	1.7E-09	6.1E-10	1.1E-06
Pa-231	3.2E-07	8.8E-08	3.5E-11	7.3E-11	4.1E-07
Pb-210 + 2 dtrs	2.3E-06	7.8E-07	1.1E-08	3.7E-08	3.1E-06
Pu-238	7.6E-07	2.1E-07	4.0E-12	3.3E-12	9.8E-07
Pu-239/240	8.0E-07	2.3E-07	4.2E-12	3.4E-12	1.0E-06
Ra-226 + 5 dtrs	4.2E-07	1.2E-07	1.5E-09	1.1E-08	6.4E-07
Ra-228 + 1 dtr	3.5E-07	9.5E-08	9.3E-10	6.9E-09	4.5E-07
Ru-106 + Rh-106	3.3E-08	1.2E-08	6.6E-10	8.5E-13	4.5E-08
Sr-90 + 1 dtr	1.2E-07	3.1E-07	1.4E-08	2.7E-07	7.2E-07
Tc-99	4.5E-09	1.3E-07	1.1E-07	5.1E-07	7.5E-07
Th-228 + 7 dtrs	1.9E-07	5.1E-08	1.1E-11	4.0E-11	2.4E-07
Th-230	4.5E-08	1.2E-08	2.9E-12	9.8E-12	5.7E-08
Th-232	4.2E-08	1.1E-08	2.6E-12	9.1E-12	5.3E-08
U-233	5.5E-08	6.6E-08	1.4E-10	1.8E-09	1.2E-07
U-234	5.5E-08	1.9E-08	1.4E-10	1.8E-09	7.7E-08
U-235 + 1 dtr	5.5E-08	1.9E-08	1.4E-10	1.8E-09	7.7E-08
U-238 + 2 dtrs	9.7E-08	3.4E-08	2.5E-10	3.1E-09	1.3E-07

[a]All values are in units of risk per pCi/L. Ingestion of meat and milk is from the contamination of food stuff due to cattle drinking contaminated water and irrigation of the crop consumed by cattle. Ingestion of fruits and vegetables is from contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

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TABLE D.I-23

UNIT CHEMICAL ILCR: CT ON-PROPERTY RESIDENT FARMER GROUNDWATER PATHWAYS[a]

Chemical	Inhalation of VOCs from Home Water Use	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Arsenic	0.0E+00	3.4E-03	1.6E-06	1.1E-03	1.9E-05	1.6E-04	4.6E-03
Beryllium	0.0E+00	8.3E-03	4.0E-05	2.4E-03	4.2E-07	1.1E-04	1.1E-02

[a]All values are in units of risk per mg/L.

[b]Contamination of foodstuff due to cattle drinking contaminated water.

[c]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

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TABLE D.I-24

UNIT HI: CT ON-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS[a]

Chemical	Inhalation of VOCs from Home Water Use	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Antimony	0.0E+00	3.8E+01	6.1E-02	1.8E+01	1.1E+00	2.8E+00	5.9E+01
Arsenic	0.0E+00	5.0E+01	2.4E-02	1.6E+01	2.8E-01	2.3E+00	6.9E+01
Barium	0.0E+00	2.2E-01	1.0E-03	8.5E-02	1.7E-02	1.9E-03	3.2E-01
Beryllium	0.0E+00	3.0E+00	1.5E-02	8.5E-01	1.5E-04	4.1E-02	3.9E+00
Boron	0.0E+00	1.7E-01	8.2E-04	1.5E+00	1.3E+00	1.7E-01	3.1E+00
Cadmium (food)	0.0E+00	1.5E+01	7.4E-02	0.0E+00	0.0E+00	0.0E+00	1.5E+01
Cadmium (water)	0.0E+00	3.0E+01	1.5E-01	3.2E+01	2.2E+01	3.0E+00	8.7E+01
Chromium	0.0E+00	3.0E+00	1.5E-02	8.8E-01	2.4E-01	2.1E-01	4.3E+00
Cobalt	0.0E+00	2.5E-01	1.2E-03	7.7E-02	3.4E-02	8.4E-02	4.5E-01
Manganese	0.0E+00	1.1E-01	8.7E-04	6.1E-02	1.3E-02	3.8E-03	1.9E-01
Mercury	0.0E+00	5.0E+01	6.0E-01	7.0E+01	2.7E+01	3.7E+03	3.8E+03
Molybdenum	0.0E+00	3.0E+00	1.9E-03	1.8E+00	1.6E+00	1.6E+00	8.0E+00
Nickel	0.0E+00	7.5E-01	3.6E-03	3.8E-01	8.9E-02	1.3E-01	1.4E+00
Selenium	0.0E+00	3.0E+00	9.1E-04	1.1E+00	9.0E-01	8.2E-01	5.9E+00
Silver	0.0E+00	3.0E+00	1.5E-02	2.4E+00	3.3E+01	1.2E+00	4.0E+01
Thallium	0.0E+00	2.5E+02	6.1E-02	6.9E+01	2.4E+01	1.2E+02	4.6E+02
Uranium	0.0E+00	5.0E+00	2.4E-02	1.5E+00	1.6E-01	1.3E-02	6.7E+00
Vanadium	0.0E+00	2.2E+00	1.0E-02	6.2E-01	2.2E-03	6.5E-02	2.8E+00

TABLE D.I-24
(Continued)

Chemical	Inhalation of VOCs from Home Water Use	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Zinc	0.0E+00	7.5E-02	9.0E-05	3.1E-01	1.5E+00	3.6E+00	5.5E+00

[a]All values are in units per $[mg/L]^{-1}$.
[b]Contamination of foodstuff due to cattle drinking contaminated water.
[c]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

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TABLE D.I-25

UNIT RADIOLOGICAL ILCR: RME ON-PROPERTY RESIDENT FARMER
SOIL OR SILO CONTENTS PATHWAYS[a]

	Inhalation and Air Dispersion[b]				
Radionuclide	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Radionuclide-Specific Risks Across Pathways
Ac-227 + 7 dtrs	1.0E-02	5.1E-04	8.0E-07	2.6E-06	1.1E-02
Am-241	3.7E-03	3.6E-04	9.6E-08	4.4E-08	4.1E-03
Cs-137 + 1 dtr	2.2E-06	7.4E-05	1.0E-04	1.5E-04	3.3E-04
Np-237 + 1 dtr	3.4E-03	5.0E-04	4.2E-06	1.5E-06	3.9E-03
Pa-231	4.2E-03	1.4E-04	1.0E-07	2.0E-07	4.3E-03
Pb-210 + 2 dtrs	4.6E-04	1.2E-03	2.6E-05	8.7E-05	1.7E-03
Pu-238	4.5E-03	3.2E-04	1.1E-08	8.6E-09	4.8E-03
Pu-239/240	4.4E-03	3.4E-04	1.2E-08	9.6E-09	4.7E-03
Ra-226 + 5 dtrs	3.5E-04	1.9E-04	4.2E-06	3.0E-05	5.7E-04
Ra-228 + 1 dtr	8.0E-05	1.5E-04	2.1E-06	1.5E-05	2.4E-04
Rn-222 + 4 dtrs	8.9E-07	c	c	c	8.9E-07
Ru-106 + Rh-106	5.1E-05	1.3E-05	1.3E-06	1.7E-09	6.6E-05
Sr-90 + 1 dtr	7.2E-06	4.0E-04	3.2E-05	6.5E-04	1.1E-03
Tc-99	9.6E-07	1.6E-04	2.6E-04	1.2E-03	1.6E-03
Th-228 + 7 dtrs	9.0E-03	7.8E-05	2.4E-08	8.2E-08	9.1E-03
Th-230	3.4E-03	1.9E-05	8.2E-09	2.7E-08	3.4E-03
Th-232	3.2E-03	1.8E-05	7.6E-09	2.5E-08	3.3E-03

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TABLE D.I-25
(Continued)

	Inhalation and Air Dispersion[b]				
Radionuclide	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Radionuclide-Specific Risks Across Pathways
U-233	3.1E-03	2.8E-05	4.0E-07	4.8E-06	3.2E-03
U-234	3.0E-03	2.8E-05	4.0E-07	4.8E-06	3.0E-03
U-235 + 1 dtr	2.9E-03	2.8E-05	4.0E-07	4.8E-06	2.9E-03
U-238 + 2 dtrs	6.0E-03	5.0E-05	6.9E-07	8.3E-06	6.1E-03

TABLE D.I-25
(Continued)

	Ingestion, External Radiation, Root Uptake[d,e]					
Radionuclide	Soil Ingestion	Ingestion of Vegetables/Fruit	Ingestion of Meat	Ingestion of Milk	External Exposure	Radionuclide-Specific Risks Across Pathways
Ac-227 + 7 dtrs	4.1E-06	3.6E-07	1.1E-08	3.5E-08	3.5E-05	4.0E-05
Am-241	2.8E-06	1.7E-07	1.2E-09	5.5E-10	2.0E-07	3.2E-06
Cs-137 + 1 dtr	3.3E-07	2.5E-06	4.6E-06	6.4E-06	8.3E-05	9.7E-05
Np-237 + 1 dtr	2.6E-06	6.6E-06	1.2E-07	4.4E-08	1.8E-05	2.7E-05
Pa-231	1.1E-06	6.9E-08	1.1E-09	2.1E-09	1.1E-06	2.3E-06
Pb-210 + 2 dtrs	7.9E-06	1.8E-05	9.9E-07	3.3E-06	6.6E-09	3.0E-05
Pu-238	2.6E-06	3.0E-08	1.1E-10	8.4E-11	1.2E-09	2.6E-06
Pu-239/240	2.7E-06	3.1E-08	1.1E-10	8.8E-11	1.1E-09	2.7E-06
Ra-226 + 5 dtrs	1.4E-06	5.4E-07	6.9E-08	5.0E-07	2.5E-04	2.5E-04
Ra-228 + 1 dtr	1.2E-06	4.4E-07	5.5E-08	4.0E-07	1.2E-04	1.2E-04
Ru-106 + Rh-106	1.1E-07	5.0E-07	1.1E-07	1.3E-10	2.8E-05	2.8E-05
Sr-90 + 1 dtr	4.2E-07	2.7E-05	2.5E-06	4.9E-05	[f]	7.9E-05
Tc-99	1.5E-08	5.8E-06	9.7E-06	4.5E-05	2.5E-11	6.1E-05
Th-228 + 7 dtrs	6.6E-07	1.3E-08	3.2E-10	1.1E-09	2.3E-04	2.3E-04
Th-230	1.5E-07	3.3E-09	7.8E-11	2.6E-10	2.2E-09	1.6E-07
Th-232	1.4E-07	3.0E-09	7.2E-11	2.4E-10	1.1E-09	1.4E-07
U-233	1.9E-07	1.9E-07	5.4E-09	6.5E-08	1.7E-09	4.6E-07
U-234	1.9E-07	1.9E-07	5.4E-09	6.5E-08	1.2E-09	4.6E-07
U-235 + 1 dtr	1.9E-07	1.9E-07	5.4E-09	6.5E-08	1.0E-05	1.0E-05

TABLE D.I-25
(Continued)

	Ingestion, External Radiation, Root Uptake[d,e]					
Radionuclide	Soil Ingestion	Ingestion of Vegetables/Fruit	Ingestion of Meat	Ingestion of Milk	External Exposure	Radionuclide-Specific Risks Across Pathways
U-238 + 2 dtrs	3.3E-07	3.3E-07	9.5E-09	1.1E-07	1.5E-06	2.3E-06

[a]All values are in units of risk per pCi/m^3.
[b]Contamination of foodstuff and forage due to deposition from air.
[c]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[d]All values are in units of risk per pCi/g.
[e]Contamination of foodstuff and forage due to root uptake.
[f]Radionuclide is a beta-particle emitter and does not emit penetrating radiation.

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TABLE D.I-26

UNIT CHEMICAL ILCR: RME ON-PROPERTY RESIDENT FARMER SOIL OR SILO CONTENTS PATHWAYS

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
Aroclor-1254	0.0E+00	1.2E-05	1.3E-05	1.5E-05	4.0E-05
Arsenic	9.7E-01	2.2E-06	2.3E-08	1.9E-07	9.7E-01
Benzo(a)anthracene	4.0E-01	1.3E-05	3.8E-06	3.0E-06	4.0E-01
Benzo(a)pyrene	4.0E-01	2.4E-05	1.5E-05	1.1E-05	4.0E-01
Benzo(b)fluoranthene	4.0E-01	8.0E-06	2.5E-05	2.0E-05	4.0E-01
Beryllium	5.4E-01	4.0E-06	5.0E-10	1.4E-07	5.4E-01
Bis(2-ethylhexyl) phthalate	0.0E+00	3.2E-08	4.3E-09	3.4E-09	4.0E-08
Cadmium (food)	4.1E-01	0.0E+00	0.0E+00	0.0E+00	4.1E-01
Cadmium (water)	4.1E-01	0.0E+00	0.0E+00	0.0E+00	4.1E-01
Chromium	2.7E+00	0.0E+00	0.0E+00	0.0E+00	2.7E+00
Chrysene	4.0E-01	1.3E-05	3.8E-06	3.0E-06	4.0E-01
Dibenzo(a,h)anthracene	4.0E-01	1.0E-05	7.5E-06	5.9E-06	4.0E-01
Indeno(1,2,3-cd)pyrene	4.0E-01	6.4E-06	2.7E-04	2.2E-04	4.0E-01
Methylene chloride	1.0E-04	2.4E-06	2.3E-11	1.8E-11	1.1E-04

TABLE D.I-26
(Continued)

Chemical	Ingestion, Dermal Contact, and Root Uptake					
	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[b]	Ingestion of Meat[b]	Dermal Contact and Ingestion Pathways
Aroclor-1254	7.0E-05	1.2E-05	2.2E-04	1.5E-04	1.8E-04	6.3E-04
Arsenic	2.4E-06	2.6E-06	3.0E-05	4.3E-07	3.6E-06	3.9E-05
Benzo(a)anthracene	1.2E-03	1.1E-05	2.7E-04	5.3E-05	4.2E-05	1.5E-03
Benzo(a)pyrene	1.2E-03	1.1E-05	6.9E-04	3.2E-04	2.5E-04	2.4E-03
Benzo(b)fluoranthene	2.3E-04	1.1E-05	7.5E-05	1.4E-04	1.1E-04	5.6E-04
Beryllium	5.9E-05	6.4E-06	1.8E-05	4.0E-09	1.1E-06	8.5E-05
Bis(2-ethylhexyl) phthalate	1.1E-06	2.1E-08	7.8E-07	7.6E-08	6.0E-08	2.0E-06
Chrysene	1.2E-03	1.1E-05	2.7E-04	5.3E-05	4.2E-05	1.5E-03
Dibenzo(a,h)anthracene	1.2E-03	1.1E-05	1.7E-04	7.6E-05	6.0E-05	1.5E-03
Indeno(1,2,3-cd)pyrene	1.2E-04	1.1E-05	1.8E-05	4.0E-04	3.1E-04	8.5E-04
Methylene chloride	2.1E-07	1.1E-08	9.2E-05	8.0E-10	6.3E-10	9.2E-05

[a]Contamination of foodstuff or forage due to deposition from air. All values are in units of risk per $\mu g/m^3$.
[b]Contamination of foodstuff or forage due to root uptake from soil or silo contents. All values are in units of risk per mg/kg.

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TABLE D.I-27

UNIT HI: RME ON-PROPERTY RESIDENT FARMER
SOIL OR SILO CONTENTS PATHWAYS

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
2-Butanone	2.2E-01	2.4E-02	2.3E-08	1.8E-08	2.4E-01
4-Methyl-2-pentanone	0.0E+00	8.1E-03	5.1E-08	4.1E-08	8.1E-03
Acetone	0.0E+00	2.4E-02	7.0E-09	5.6E-09	2.4E-02
Anthracene	0.0E+00	1.8E-05	3.0E-07	2.4E-07	1.9E-05
Antimony	0.0E+00	7.6E-03	1.7E-04	4.2E-04	8.2E-03
Arsenic	0.0E+00	4.2E-03	4.3E-05	3.6E-04	4.6E-03
Barium	4.6E+02	3.1E-05	2.7E-06	2.9E-07	4.6E+02
Benzoic acid	0.0E+00	3.6E-05	1.4E-09	1.1E-09	3.6E-05
Beryllium	0.0E+00	1.9E-04	2.3E-08	6.4E-06	1.9E-04
Bis(2-ethylhexyl) phthalate	0.0E+00	1.2E-04	1.6E-05	1.2E-05	1.4E-04
Cadmium (food)	0.0E+00	9.6E-03	1.7E-03	2.3E-04	1.2E-02
Chromium	0.0E+00	2.1E-04	3.6E-05	3.3E-05	2.8E-04
Cobalt	2.2E+05	2.0E-05	5.2E-06	1.3E-05	2.2E+05
Di-n-butyl phthalate	0.0E+00	2.5E-05	2.6E-06	2.1E-06	3.0E-05
Fluoranthene	0.0E+00	5.6E-05	8.2E-06	6.4E-06	7.1E-05
Lead	6.5E-02	0.0E+00	0.0E+00	0.0E+00	6.5E-02
Manganese	5.9E+02	2.9E-05	2.1E-06	5.9E-07	6.9E+02

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TABLE D.I-27
(Continued)

Chemical	Inhalation and Air Dispersion				
	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
Mercury	7.5E+02	4.5E-02	4.1E-03	5.6E-01	7.5E+02
Methylene chloride	7.5E-02	5.4E-03	5.0E-08	4.0E-08	8.1E-02
Molybdenum	0.0E+00	9.0E-04	2.5E-04	2.5E-04	1.4E-03
Nickel	0.0E+00	1.7E-04	1.4E-05	2.0E-05	2.1E-04
Phenol	0.0E+00	4.2E-04	6.1E-09	4.8E-09	4.2E-04
Pyrene	0.0E+00	8.5E-05	8.5E-06	6.7E-06	1.0E-04
Selenium	0.0E+00	3.9E-04	1.4E-04	1.3E-04	6.5E-04
Silver	0.0E+00	1.4E-03	5.0E-03	1.9E-04	6.6E-03
Thallium	0.0E+00	1.4E-02	3.7E-03	1.8E-02	3.6E-02
Toluene	5.9E-01	2.4E-04	6.3E-08	5.0E-08	5.9E-01
Total Xylenes	0.0E+00	1.5E-05	0.0E+00	7.1E-09	1.5E-05
Uranium	0.0E+00	3.4E-04	2.5E-05	2.1E-06	3.7E-04
Vanadium	0.0E+00	1.4E-04	0.0E+00	1.0E-05	1.5E-04
Zinc	0.0E+00	2.2E-04	0.0E+00	5.5E-04	7.7E-04

TABLE D.I-27
(Continued)

Chemical	Ingestion, Dermal Contact, and Root Uptake					
	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[b]	Ingestion of Meat[b]	Dermal Contact and Ingestion Pathways
2-Butanone	1.5E-03	3.0E-05	9.2E-01	8.1E-07	6.4E-07	9.2E-01
4-Methyl-2-pentanone	1.5E-03	3.0E-05	3.0E-01	1.8E-06	1.4E-06	3.1E-01
Acetone	7.6E-04	1.5E-05	8.9E-01	2.5E-07	2.0E-07	8.9E-01
Anthracene	2.1E-04	5.0E-06	5.8E-04	8.0E-06	6.3E-06	8.1E-04
Antimony	1.1E-02	3.7E-03	2.1E-01	5.1E-03	1.3E-02	2.4E-01
Arsenic	4.6E-03	5.0E-03	5.6E-02	8.2E-04	6.9E-03	7.3E-02
Barium	2.0E-04	2.1E-05	7.5E-04	7.7E-05	8.3E-06	1.1E-03
Benzoic acid	1.9E-05	3.7E-07	1.3E-03	4.9E-08	3.8E-08	1.4E-03
Beryllium	2.7E-03	3.0E-04	8.4E-04	1.9E-07	5.1E-05	3.9E-03
Bis(2-ethylhexyl) phthalate	3.8E-03	7.5E-05	2.8E-03	2.7E-04	2.2E-04	7.2E-03
Cadmium (water)	2.7E-03	3.0E-03	0.0E+00	0.0E+00	0.0E+00	5.7E-03
Cadmium (food)	1.4E-03	1.5E-03	3.3E-01	5.7E-02	7.8E-03	4.0E-01
Chromium	2.7E-03	3.0E-04	1.6E-03	2.3E-04	2.1E-04	5.1E-03
Cobalt	2.3E-04	2.5E-05	2.4E-04	6.9E-05	1.7E-04	7.3E-04
Di-n-butyl phthalate	8.1E-04	1.5E-05	6.4E-04	5.0E-05	3.9E-05	1.6E-03
Fluoranthene	4.0E-03	3.7E-05	1.4E-03	1.4E-04	1.1E-04	5.6E-03
Manganese	1.6E-04	1.1E-05	8.8E-04	6.4E-05	1.8E-05	1.1E-03
Mercury	1.1E-01	5.0E-03	1.6E+00	1.4E-01	1.9E+01	2.1E+01

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TABLE D.I-27
(Continued)

	Ingestion, Dermal Contact, and Root Uptake					
Chemical	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[b]	Ingestion of Meat[b]	Dermal Contact and Ingestion Pathways
Methylene chloride	4.6E-04	2.5E-05	2.0E-01	1.8E-06	1.4E-06	2.1E-01
Molybdenum	3.6E-04	3.0E-04	2.8E-02	7.7E-03	7.7E-03	4.4E-02
Nickel	6.9E-04	7.5E-05	5.0E-03	3.1E-04	4.6E-04	6.5E-03
Phenol	1.3E-04	2.5E-06	1.6E-02	2.2E-07	1.7E-07	1.6E-02
Pyrene	2.5E-03	5.0E-05	2.2E-03	1.6E-04	1.3E-04	5.1E-03
Selenium	1.7E-04	3.0E-04	8.4E-03	2.1E-03	1.9E-03	1.3E-02
Silver	2.7E-03	3.0E-04	4.6E-02	1.6E-01	6.2E-03	2.2E-01
Thallium	1.1E-02	2.5E-02	2.3E-02	1.4E-02	6.9E-02	1.4E-01
Toluene	1.0E-05	7.5E-06	9.0E-03	2.2E-06	1.7E-06	9.1E-03
Total Xylenes	1.0E-06	7.5E-07	0.0E+00	0.0E+00	2.4E-07	2.0E-06
Uranium	4.6E-03	5.0E-04	2.5E-03	1.8E-04	1.5E-05	7.8E-03
Vanadium	2.0E-03	2.1E-04	7.9E-04	1.6E-06	5.1E-05	3.0E-03
Zinc	1.7E-05	7.5E-06	8.1E-03	7.7E-03	1.9E-02	3.5E-02

[a]Contamination of foodstuff or forage due to deposition from air. All values are in units of $(\mu g/m^3)^{-1}$.
[b]Contamination of foodstuff or forage due to root uptake from soil or silo contents. All values are in units of $(mg/kg)^{-1}$.

TABLE D.I-28

UNIT RADIOLOGICAL ILCR: RME ON-PROPERTY RESIDENT FARMER GROUNDWATER PATHWAYS[a]

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/Fruits	Ingestion of Meat	Ingestion of Milk	Radiation Risks from Water Pathways
Ac-227 + 7 dtrs	1.7E-05	5.2E-06	4.8E-09	1.6E-08	2.2E-05
Am-241	1.2E-05	4.2E-06	5.1E-10	2.4E-10	1.6E-05
Cs-137 + 1 dtr	1.4E-06	8.2E-07	6.3E-07	9.0E-07	3.7E-06
Np-237 + 1 dtr	1.1E-05	5.4E-06	2.5E-08	9.1E-09	1.6E-05
Pa-231	4.5E-06	1.4E-06	5.2E-10	1.1E-09	5.9E-06
Pb-210 + 2 dtrs	3.2E-05	1.2E-05	1.6E-07	5.5E-07	4.5E-05
Pu-238	1.1E-05	3.3E-06	5.9E-11	4.9E-11	1.4E-05
Pu-239/240	1.1E-05	3.5E-06	6.2E-11	5.1E-11	1.5E-05
Ra-226 + 5 dtrs	5.9E-06	1.9E-06	2.3E-08	1.7E-07	8.8E-06
Ra-228 + 1 dtr	4.9E-06	1.5E-06	1.4E-08	1.0E-07	6.5E-06
Ru-106 + Rh-106	4.7E-07	1.8E-07	9.9E-09	1.3E-11	6.5E-07
Sr-90 + 1 dtr	1.8E-06	4.8E-06	2.0E-07	4.1E-06	1.1E-05
Tc-99	6.4E-08	1.9E-06	1.6E-06	7.5E-06	1.1E-05
Th-228 + 7 dtrs	2.7E-06	7.8E-07	1.7E-10	5.9E-10	3.5E-06
Th-230	6.4E-07	1.9E-07	4.2E-11	1.5E-10	8.3E-07
Th-232	5.9E-07	1.8E-07	3.9E-11	1.3E-10	7.6E-07
U-233	7.8E-07	1.0E-06	2.1E-09	2.6E-08	1.8E-06
U-234	7.8E-07	3.0E-07	2.1E-09	2.6E-08	1.1E-06
U-235 + 1 dtr	7.8E-07	3.0E-07	2.1E-09	2.6E-08	1.1E-06
U-238 + 2 dtrs	1.4E-06	5.2E-07	3.7E-09	4.6E-08	1.9E-06

[a]All values are in units of risk per pCi/L. Ingestion of meat and milk is from the contamination of food stuff due to cattle drinking contaminated water and irrigation of the crop consumed by cattle. Ingestion of fruits and vegetables is from contamination of foodstuff from irrigation of the crop consumed by the receptor.

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TABLE D.I-29

UNIT CHEMICAL ILCR: RME ON-PROPERTY RESIDENT FARMER GROUNDWATER PATHWAYS[a]

Chemical	Inhalation of VOCs from Home Water Use	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruit[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Arsenic	0.0E+00	4.8E-02	2.4E-05	1.6E-02	2.8E-04	2.3E-03	6.7E-02
Beryllium	0.0E+00	1.2E-01	6.0E-04	3.6E-02	6.2E-06	1.7E-03	1.6E-01

[a]All values are in units of risk per mg/L.

[b]Contamination of foodstuff due to cattle drinking contaminated water.

[c]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

TABLE D.I-30

UNIT HI: RME ON-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS[a]

Chemical	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Antimony	6.9E+01	1.1E-01	3.5E+01	2.1E+00	5.3E+00	1.1E+02
Arsenic	9.1E+01	4.6E-02	3.1E+01	5.4E-01	4.4E+00	1.3E+02
Barium	3.9E-01	2.0E-03	1.7E-01	3.3E-02	3.5E-03	6.0E-01
Beryllium	5.5E+00	2.8E-03	1.7E+00	2.9E-04	7.8E-02	7.3E+00
Boron	3.0E-01	1.5E-03	3.0E+00	2.4E+00	3.2E-01	6.1E+00
Cadmium (food)	2.7E+01	1.4E-01	0.0E+00	0.0E+00	0.0E+00	2.7E+01
Cadmium (water)	5.5E+01	2.8E-01	6.3E+01	4.2E+01	5.8E+00	1.7E+02
Chromium	5.5E+00	2.8E-02	1.8E+00	4.5E-01	4.0E-01	8.1E+00
Cobalt	4.6E-01	2.2E-03	1.5E-01	6.5E-02	1.6E-01	8.4E-01
Manganese	2.0E-01	1.6E-03	1.2E-01	2.6E-02	7.3E-03	3.5E-01
Mercury	9.1E+01	1.2E+00	1.4E+02	5.1E+01	7.0E+03	7.3E+03
Molybdenum	5.5E+00	3.7E-03	3.6E+00	3.1E+00	3.1E+00	1.5E+01
Nickel	1.4E+00	6.8E-03	7.7E-01	1.7E-01	2.5E-01	2.6E+00
Selenium	5.5E+00	1.8E-03	2.2E+00	1.7E+00	1.6E+00	1.1E+01
Silver	5.5E+00	2.8E-02	4.9E+00	6.3E+01	2.3E+00	7.5E+01
Thallium	4.6E+02	1.1E-01	1.4E+02	4.6E+01	2.2E+02	8.6E+02
Uranium	9.1E+00	4.6E-02	2.9E+00	3.1E-01	2.5E-02	1.2E+01
Vanadium	3.9E+00	2.0E-02	1.2E+00	4.1E-03	1.2E-01	5.3E+00

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TABLE D.I-30
(Continued)

Chemical	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Zinc	1.4E-01	1.7E-04	6.2E-01	2.8E+00	6.9E+00	1.0E+01

[a]All values are in units of $[mg/L]^{-1}$.

[b]Contamination of foodstuff due to cattle drinking contaminated water.

[c]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

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TABLE D.I-31

UNIT RADIOLOGICAL ILCR: ON-PROPERTY RESIDENT CHILD
SOIL OR SILO CONTENTS PATHWAYS[a]

	Inhalation and Air Dispersion[b]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Radionuclide-Specific Risks Across Pathways
Ac-227 + 7 dtrs	3.1E-04	3.7E-05	2.6E-08	6.6E-07	3.4E-04
Am-241	1.1E-04	2.5E-05	3.2E-09	1.1E-08	1.4E-04
Cs-137 + 1 dtr	6.6E-08	5.3E-06	3.5E-06	3.8E-05	4.7E-05
Np-237 + 1 dtr	1.0E-04	3.5E-05	1.4E-07	3.9E-07	1.4E-04
Pa-231	1.3E-04	9.7E-06	3.3E-09	5.2E-08	1.4E-04
Pb-210 + 2 dtrs	1.4E-05	8.2E-05	8.7E-07	2.2E-05	1.2E-04
Pu-238	1.4E-04	2.3E-05	3.6E-10	2.2E-09	1.6E-04
Pu-239/240	1.3E-04	2.4E-05	4.0E-10	2.5E-09	1.6E-04
Ra-226 + 5 dtrs	1.0E-05	1.4E-05	1.4E-07	7.7E-06	3.2E-05
Ra-228 + 1 dtr	2.4E-06	1.0E-05	6.9E-08	3.9E-06	1.7E-05
Rn-222 + 4 dtrs	2.7E-08	c	c	c	2.7E-08
Ru-106 + Rh-106	1.5E-06	9.4E-07	4.4E-08	4.3E-10	2.5E-06
Sr-90 + 1 dtr	2.2E-07	2.8E-05	1.1E-06	1.7E-04	2.0E-04
Tc-99	2.9E-08	1.1E-05	8.5E-06	3.1E-04	3.3E-04
Th-228 + 7 dtrs	2.7E-04	5.5E-06	8.0E-10	2.1E-08	2.8E-04
Th-230	1.0E-04	1.4E-06	2.7E-10	7.0E-09	1.0E-04
Th-232	9.8E-05	1.3E-06	2.5E-10	6.5E-09	9.9E-05

TABLE DI-31
(Continued)

	Inhalation and Air Dispersion[b]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Radionuclide-Specific Risks Across Pathways
U-233	9.4E-05	2.0E-06	1.3E-08	1.2E-06	9.7E-05
U-234	9.1E-05	2.0E-06	1.3E-08	1.2E-06	9.4E-05
U-235 + 1 dtr	8.7E-05	2.0E-06	1.3E-08	1.2E-06	9.0E-05
U-238 + 2 dtrs	1.8E-04	3.6E-06	2.3E-08	2.1E-06	1.9E-04

TABLE D.I-31
(Continued)

Ingestion, External Radiation, Root Uptake[d,e]						
Radionuclides	Soil Ingestion	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	External Exposure	Radionuclide-Specific Risks Across Pathways
Ac-227 + 7 dtrs	1.5E-07	2.6E-08	3.6E-10	8.9E-09	2.6E-06	2.8E-06
Am-241	1.0E-07	1.2E-08	4.0E-11	1.4E-10	1.5E-08	1.3E-07
Cs-137 + 1 dtr	1.2E-08	1.8E-07	1.5E-07	1.6E-06	6.2E-06	8.2E-06
Np-237 + 1 dtr	9.2E-08	4.7E-07	4.1E-09	1.1E-08	1.3E-06	1.9E-06
Pa-231	3.9E-08	4.9E-09	3.5E-11	5.4E-10	8.1E-08	1.3E-07
Pb-210 + 2 dtrs	2.8E-07	1.3E-06	3.3E-08	8.5E-07	5.0E-10	2.4E-06
Pu-238	9.2E-08	2.1E-09	3.5E-12	2.2E-11	8.7E-11	9.5E-08
Pu-239/240	9.7E-08	2.2E-09	3.7E-12	2.3E-11	8.4E-11	9.9E-08
Ra-226 + 5 dtrs	5.0E-08	3.8E-08	2.3E-09	1.3E-07	1.9E-05	1.9E-05
Ra-228 + 1 dtr	4.2E-08	3.1E-08	1.8E-09	1.0E-07	9.0E-06	9.2E-06
Ru-106 + Rh-106	4.0E-09	3.5E-08	3.5E-09	3.4E-11	2.1E-06	2.1E-06
Sr-90 + 1 dtr	1.5E-08	1.9E-06	8.1E-08	1.3E-05	f	1.5E-05
Tc-99	5.5E-10	4.2E-07	3.2E-07	1.2E-05	1.9E-12	1.2E-05
Th-228 + 7 dtrs	2.3E-08	9.2E-10	1.1E-11	2.8E-10	1.7E-05	1.7E-05
Th-230	5.5E-09	2.4E-10	2.6E-12	6.7E-11	1.7E-10	5.9E-09
Th-232	5.0E-09	2.2E-10	2.4E-12	6.2E-11	8.1E-11	5.4E-09
U-233	6.7E-09	1.4E-08	1.8E-10	1.7E-08	1.3E-10	3.7E-08
U-234	6.7E-09	1.4E-08	1.8E-10	1.7E-08	9.3E-11	3.7E-08

TABLE D.I-31
(Continued)

Radionuclides	Ingestion, External Radiation, Root Uptake[d,e]					
	Soil Ingestion	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	External Exposure	Radionuclide-Specific Risks Across Pathways
U-235 + 1 dtr	6.7E-09	1.4E-08	1.8E-10	1.7E-08	7.5E-07	7.9E-07
U-238 + 2 dtrs	1.2E-08	2.4E-08	3.2E-10	2.9E-08	1.1E-07	1.8E-07

[a]All values are in units of risk per pCi/m^3.

[b]Contamination of foodstuff and forage due to deposition from air.

[c]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.

[d]All values are in units of risk per pCi/g.

[e]Contamination of foodstuff and forage due to root uptake.

[f]Radionuclide is a beta-particle emitter and does not emit penetrating radiation.

TABLE D.I-32

UNIT CHEMICAL ILCR: ON-PROPERTY RESIDENT CHILD
SOIL OR SILO CONTENTS PATHWAYS

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
Aroclor-1254	0.0E+00	4.0E-06	1.5E-05	2.3E-06	2.2E-05
Arsenic	1.4E-01	7.4E-07	2.7E-08	2.9E-08	1.4E-01
Benzo(a)anthracene	5.6E-02	4.4E-06	4.5E-06	4.6E-07	5.6E-02
Benzo(a)pyrene	5.6E-02	8.0E-06	1.7E-05	1.8E-06	5.6E-02
Benzo(b)fluoranthene	5.6E-02	2.7E-06	3.0E-05	3.1E-06	5.6E-02
Beryllium	7.6E-02	1.3E-06	5.9E-10	2.1E-08	7.6E-02
Bis(2-ethylhexyl) phthalate	0.0E+00	1.1E-08	5.2E-09	5.3E-10	1.6E-08
Cadmium (food)	5.7E-02	0.0E+00	0.0E+00	0.0E+00	5.7E-02
Cadmium (water)	5.7E-02	0.0E+00	0.0E+00	0.0E+00	5.7E-02
Chromium	3.8E-01	0.0E+00	0.0E+00	0.0E+00	3.8E-01
Chrysene	5.6E-02	4.4E-06	4.5E-06	4.6E-07	5.6E-02
Dibenzo(a,h)anthracene	5.6E-02	3.5E-06	9.0E-06	9.2E-07	5.6E-02
Indeno(1,2,3-cd)pyrene	5.6E-02	2.1E-06	3.3E-04	3.4E-05	5.6E-02
Methylene chloride	1.5E-05	8.1E-07	2.7E-11	2.8E-12	1.5E-05
Nickel	7.6E-03	0.0E+00	0.0E+00	0.0E+00	7.6E-03

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TABLE D.I-32
(Continued)

Chemical	Ingestion, Dermal Contact, and Root Uptake					
	Dermal Contact with Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Investion of Milk[b]	Ingestion of Meat[b]	Inhalation and Ingestion Pathways
Aroclor-1254	1.0E-05	8.4E-06	7.3E-05	1.8E-04	2.7E-05	3.0E-04
Arsenic	3.5E-07	1.9E-06	9.8E-06	5.2E-07	5.6E-07	1.3E-05
Benzo(a)anthracene	1.7E-04	8.0E-06	9.1E-05	6.4E-05	6.5E-06	3.4E-04
Benzo(a)pyrene	1.7E-04	8.0E-06	2.3E-04	3.8E-04	3.9E-05	8.3E-04
Benzo(b)fluoranthene	3.4E-05	8.0E-06	2.5E-05	1.6E-04	1.7E-05	2.5E-04
Beryllium	8.5E-06	4.7E-06	6.0E-06	4.8E-09	1.7E-07	1.9E-05
Bis(2-ethylhexyl) phthalate	1.5E-07	1.5E-08	2.6E-07	9.1E-08	9.3E-09	5.3E-07
Chrysene	1.7E-04	8.0E-06	9.1E-05	6.4E-05	6.5E-06	3.4E-04
Dibenzo(a,h)anthracene	1.7E-04	8.0E-06	5.6E-05	9.1E-05	9.3E-06	3.3E-04
Indeno(1,2,3-cd)pyrene	1.7E-05	8.0E-06	5.9E-06	4.7E-04	4.8E-05	5.5E-04
Methylene chloride	3.0E-08	8.2E-09	3.1E-05	9.6E-10	9.8E-11	3.1E-05

[a]Contamination of foodstuff or forage due to deposition from air. All values are in units of risk per $\mu g/m^3$.
[b]Contamination of foodstuff or forage due to root uptake from soil or silo contents. All values are in units of risk per mg/kg.

TABLE D.I-33

UNIT HI: ON-PROPERTY RESIDENT CHILD
SOIL OR SILO CONTENTS PATHWAYS

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
2-Butanone	3.5E-01	9.4E-02	3.2E-07	3.3E-08	4.5E-01
4-Methyl-2-pentanone	0.0E+00	3.1E-02	7.2E-07	7.3E-08	3.1E-02
Acetone	0.0E+00	9.2E-02	9.9E-08	1.0E-08	9.2E-02
Anthracene	0.0E+00	7.0E-05	4.2E-06	4.3E-07	7.5E-05
Antimony	0.0E+00	3.0E-02	2.4E-03	7.6E-04	3.3E-02
Arsenic	0.0E+00	1.6E-02	6.0E-04	6.5E-04	1.8E-02
Barium	7.6E+02	1.2E-04	3.7E-05	5.1E-07	7.6E+02
Benzoic acid	0.0E+00	1.4E-04	1.9E-08	2.0E-09	1.4E-04
Beryllium	0.0E+00	7.2E-04	3.2E-07	1.2E-05	7.3E-04
Bis(2-ethylhexyl) phthalate	0.0E+00	4.5E-04	2.2E-04	2.2E-05	6.9E-04
Cadmium (food)	0.0E+00	3.7E-02	2.4E-02	4.2E-04	6.1E-02
Chromium	0.0E+00	8.0E-04	5.1E-04	6.0E-05	1.4E-03
Cobalt	3.5E+05	7.7E-05	7.3E-05	2.4E-05	3.5E+05
Di-n-butyl phthalate	0.0E+00	9.7E-05	3.7E-05	3.8E-06	1.4E-04
Fluoranthene	0.0E+00	2.2E-04	1.1E-04	1.2E-05	3.4E-04
Lead	1.1E-01	0.0E+00	0.0E+00	0.0E+00	1.1E-01
Manganese	9.7E+02	1.1E-04	2.9E-05	1.1E-06	9.7E+02

TABLE D.I-33
(Continued)

Chemical	Inhalation and Air Dispersion				
	Inhalation of Fugitive Dust and VOCs	Ingestion of Vegetables/ Fruits[a]	Ingestion of Milk[a]	Ingestion of Meat[a]	Inhalation and Ingestion Pathways
Mercury	1.2E+03	1.7E-01	5.7E-02	1.0E+00	1.2E+03
Methylene chloride	1.2E-01	2.1E-02	7.0E-07	7.2E-08	1.4E-01
Molybdenum	0.0E+00	3.5E-03	3.5E-03	4.4E-04	7.4E-03
Nickel	0.0E+00	6.7E-04	1.9E-04	3.7E-05	9.0E-04
Phenol	0.0E+00	1.6E-03	8.5E-08	8.7E-09	1.6E-03
Pyrene	0.0E+00	3.3E-04	1.2E-04	1.2E-05	4.6E-04
Selenium	0.0E+00	1.5E-03	1.9E-03	2.3E-04	3.6E-03
Silver	0.0E+00	5.3E-03	7.0E-02	3.4E-04	7.6E-02
Thallium	0.0E+00	5.5E-02	5.2E-02	3.3E-02	1.4E-01
Toluene	9.7E-01	9.4E-04	8.8E-07	8.9E-08	9.7E-01
Total Xylenes	0.0E+00	6.0E-05	0.0E+00	1.3E-08	6.0E-05
Uranium	0.0E+00	1.3E-03	3.5E-04	3.7E-06	1.7E-03
Vanadium	0.0E+00	5.4E-04	0.0E+00	1.9E-05	5.5E-04
Zinc	0.0E+00	8.5E-04	0.0E+00	1.0E-03	1.9E-03

TABLE D.I-33
(Continued)

Chemical	Ingestion, Dermal Contact, and Root Uptake					
	Dermal Contact With Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[b]	Ingestion of Meat[b]	Dermal Contact and Ingestion Pathways
2-Butanone	2.6E-03	2.6E-04	3.6E+00	1.1E-05	1.2E-06	3.6E+00
4-Methyl-2-pentanone	2.6E-03	2.6E-04	1.2E+00	2.6E-05	2.6E-06	1.2E+00
Acetone	1.3E-03	1.3E-04	3.5E+00	3.5E-06	3.6E-07	3.5E+00
Anthracene	3.6E-04	4.3E-05	2.3E-03	1.1E-04	1.1E-05	2.8E-03
Antimony	1.9E-02	3.2E-02	8.2E-01	7.2E-02	2.3E-02	9.6E-01
Arsenic	7.7E-03	4.3E-02	2.2E-01	1.2E-02	1.2E-02	2.9E-01
Barium	3.3E-04	1.8E-04	2.9E-03	1.1E-03	1.5E-05	4.5E-03
Benzoic acid	3.2E-05	3.2E-06	5.2E-03	6.8E-07	6.9E-08	5.2E-03
Beryllium	4.6E-03	2.6E-03	3.3E-03	2.6E-06	9.3E-05	1.1E-02
Bis(2-ethylhexyl) phthalate	6.4E-03	6.4E-04	1.1E-02	3.8E-03	3.9E-04	2.2E-02
Cadmium (food)	2.3E-03	1.3E-02	1.3E+00	7.9E-01	1.4E-02	2.1E+00
Cadmium (water)	4.6E-03	2.6E-02	0.0E+00	0.0E+00	0.0E+00	3.0E-02
Chromium	4.6E-03	2.6E-03	6.3E-03	3.2E-03	3.8E-04	1.7E-02
Cobalt	3.8E-04	2.1E-04	9.3E-04	9.6E-04	3.1E-04	2.8E-03
Di-n-butyl phthalate	1.4E-03	1.3E-04	2.5E-03	6.9E-04	7.1E-05	4.7E-03
Fluoranthene	6.7E-03	3.2E-04	5.2E-03	2.0E-03	2.0E-04	1.4E-02
Manganese	2.7E-04	9.1E-05	3.4E-03	9.0E-04	3.3E-05	4.7E-03
Mercury	1.9E-01	4.3E-02	6.1E+00	1.9E+00	3.5E+01	4.3E+01
Methylene chloride	7.7E-04	2.1E-04	7.9E-01	2.5E-05	2.5E-06	8.0E-01
Molybdenum	6.1E-04	2.6E-03	1.1E-01	1.1E-01	1.4E-02	2.3E-01

TABLE D.I-33
(Continued)

Chemical	Ingestion, Dermal Contact, and Root Uptake					
	Dermal Contact With Soil/Silo Contents	Ingestion of Soil/Silo Contents	Ingestion of Vegetables/ Fruits[b]	Ingestion of Milk[b]	Ingestion of Meat[b]	Dermal Contact and Ingestion Pathways
Nickel	1.2E-03	6.4E-04	2.0E-02	4.3E-03	8.3E-04	2.6E-02
Phenol	2.1E-04	2.1E-05	6.1E-02	3.0E-06	3.1E-07	6.1E-02
Pyrene	4.3E-03	4.3E-04	8.5E-03	2.3E-03	2.3E-04	1.6E-02
Selenium	2.9E-04	2.6E-03	3.2E-02	2.9E-02	3.5E-03	6.8E-02
Silver	4.6E-03	2.6E-03	1.8E-01	2.3E+00	1.1E-02	2.5E+00
Thallium	1.9E-02	2.1E-01	9.0E-02	1.9E-01	1.2E-01	6.4E-01
Toluene	1.7E-05	6.4E-05	3.5E-02	3.0E-05	3.1E-06	3.5E-02
Total Xylenes	1.7E-06	6.4E-06	2.2E-03	0.0E+00	4.3E-07	2.2E-03
Uranium	7.7E-03	4.3E-03	9.8E-03	2.5E-03	2.6E-05	2.4E-02
Vanadium	3.3E-03	1.8E-03	3.1E-03	2.3E-05	9.1E-05	8.3E-03
Zinc	2.9E-05	6.4E-05	3.2E-02	1.1E-01	3.5E-02	1.7E-01

[a]Contamination of foodstuff or forage due to deposition from air. All values are in units of $(\mu g/m^3)^{-1}$.
[b]Contamination of foodstuff or forage due to root uptake from soil or silo contents. All values are in units of $(mg/kg)^{-1}$.

TABLE D.I-34

UNIT RADIOLOGICAL ILCR: ON-PROPERTY RESIDENT CHILD GROUNDWATER PATHWAYS[a]

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Radiation Risks from Water Pathways
Ac-227 + 7 dtrs	1.0E-06	4.3E-06	1.9E-09	4.1E-09	5.3E-06
Am-241	7.1E-07	3.5E-06	2.0E-10	6.2E-11	4.2E-06
Cs-137 + 1 dtr	8.2E-08	6.8E-07	2.5E-07	2.3E-07	1.2E-06
Np-237 + 1 dtr	6.5E-07	4.5E-06	9.6E-09	2.3E-09	5.1E-06
Pa-231	2.7E-07	1.1E-06	2.0E-10	2.8E-10	1.4E-06
Pb-210 + 2 dtrs	1.9E-06	1.0E-05	6.2E-08	1.4E-07	1.2E-05
Pu-238	6.5E-07	2.8E-06	2.3E-11	1.3E-11	3.4E-06
Pu-239/240	6.8E-07	2.9E-06	2.4E-11	1.3E-11	3.6E-06
Ra-226 + 5 dtrs	3.5E-07	1.6E-06	8.8E-09	4.3E-08	2.1E-06
Ra-228 + 1 dtr	2.9E-07	1.2E-06	5.3E-09	2.6E-08	1.5E-06
Ru-106 + Rh-106	2.8E-08	1.5E-07	3.8E-09	3.3E-12	1.8E-07
Sr-90 + 1 dtr	1.1E-07	4.0E-06	7.9E-08	1.0E-06	5.2E-06
Tc-99	3.8E-09	1.6E-06	6.2E-07	1.9E-06	4.2E-06
Th-228 + 7 dtrs	1.6E-07	6.5E-07	6.5E-11	1.5E-10	8.1E-07
Th-230	3.8E-08	1.6E-07	1.6E-11	3.8E-11	2.0E-07
Th-232	3.5E-08	1.5E-07	1.5E-11	3.5E-11	1.8E-07
U-233	4.7E-08	8.5E-07	8.2E-10	6.7E-09	9.0E-07
U-234	4.7E-08	2.5E-07	8.2E-10	6.7E-09	3.0E-07
U-235 + 1 dtr	4.7E-08	2.5E-07	8.2E-10	6.7E-09	3.0E-07
U-238 + 2 dtrs	8.2E-08	4.3E-07	1.4E-09	1.2E-08	5.3E-07

[a]All values are in units at risk per pCi/L. Ingestion of meat and milk is from the contamination of food stuff due to cattle drinking contaminated water and irrigation of the crop consumed by cattle. Ingestion of fruits and vegetables is from contamination of foodstuff from irrigation of the crop consumed by the receptor.

TABLE D.I-35

UNIT CHEMICAL ILCR: ON-PROPERTY RESIDENT CHILD
GROUNDWATER PATHWAYS[a]

Chemical	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Arsenic	1.3E-02	1.3E-05	5.5E-03	3.4E-04	3.6E-04	2.0E-02
Beryllium	3.3E-02	3.2E-04	1.2E-02	7.4E-06	2.6E-04	4.5E-02

[a]All values are in units of risk per mg/L.

[b]Contamination of foodstuff due to cattle drinking contaminated water.

[c]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

TABLE D.I-36

UNIT HI: ON-PROPERTY RESIDENT CHILD
GROUNDWATER PATHWAYS[a]

Chemical	Ingestion of Drinking Water	Dermal Contact While Bathing	Ingestion of Vegetables/ Fruits[c]	Ingestion of Milk[b,c]	Ingestion of Meat[b,c]	Dermal Contact and Ingestion Pathways
Antimony	2.2E+02	7.3E-01	1.4E+02	3.0E+01	9.5E+00	4.0E+02
Arsenic	3.0E+02	2.8E-01	1.2E+02	7.5E+00	7.9E+00	4.4E+02
Barium	1.4E+00	1.2E-02	6.6E-01	4.7E-01	6.4E-03	2.4E+00
Beryllium	1.8E+01	1.7E-01	6.6E+00	4.0E-03	1.4E-01	2.5E+01
Boron	9.9E-01	9.4E-03	1.2E+01	3.4E+01	5.8E-01	4.7E+01
Cadmium (food)	9.0E+01	8.4E-01	0.0E+00	0.0E+00	0.0E+00	9.0E+01
Cadmium (water)	1.8E+02	1.7E+00	2.5E+02	5.9E+02	1.0E+01	1.0E+03
Chromium	1.8E+01	1.7E-01	6.8E+00	6.3E+00	7.3E-01	3.2E+01
Cobalt	1.5E+00	1.4E-02	6.0E-01	9.1E-01	2.9E-01	3.3E+00
Manganese	6.4E-01	1.0E-02	4.7E-01	3.6E-01	1.3E-02	1.5E+00
Mercury	3.0E+02	7.0E+00	5.4E+02	7.1E+02	1.3E+04	1.4E+04
Molybdenum	1.8E+01	2.2E-02	1.4E+01	4.3E+01	5.5E+00	8.1E+01
Nickel	4.5E+00	4.2E-02	3.0E+00	2.4E+00	4.6E-01	1.0E+01
Selenium	1.8E+01	1.1E-02	8.7E+00	2.4E+01	2.8E+00	5.3E+01
Silver	1.8E+01	1.7E-01	1.9E+01	8.8E+02	4.2E+00	9.2E+02
Thallium	1.5E+03	7.0E-01	5.4E+02	6.4E+02	4.0E+02	3.1E+03
Uranium	3.0E+01	2.8E-01	1.1E+01	4.3E+00	4.5E-02	4.6E+01
Vanadium	1.3E+01	1.2E-01	4.8E+00	5.7E-02	2.3E-01	1.8E+01
Zinc	4.5E-01	1.1E-03	2.4E+00	3.9E+01	1.3E+01	5.4E+01

TABLE D.I-36
(Continued)

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[a]All values are in units of $[mg/L]^{-1}$.

[b]Contamination of foodstuff due to cattle drinking contaminated water.

[c]Contamination of foodstuff from irrigation of the crop consumed by the receptor or by cattle.

TABLE D.I-37

UNIT RADIOLOGICAL ILCR: ON-PROPERTY RESIDENT CHILD
SURFACE WATER PATHWAYS

Radionuclide	Ingestion of Surface Water[a]	Ingestion of Sediment[b]
Ac-227 + 7 dtrs	2.6E-10	1.5E-07
Am-241	1.8E-10	1.0E-07
Cs-137 + 1 dtr	2.1E-11	1.2E-08
Np-237 + 1 dtr	1.7E-10	9.2E-08
Pa-231	6.9E-11	3.9E-08
Pb-210 + 2 dtrs	5.0E-10	2.8E-07
Pu-238	1.7E-10	9.2E-08
Pu-239/240	1.7E-10	9.7E-08
Ra-226 + 5 dtrs	9.0E-11	5.0E-08
Ra-228 + 1 dtr	7.5E-11	4.2E-08
Ru-106 + Rh-106	7.1E-12	4.0E-09
Sr-90 + 1 dtr	2.7E-11	1.5E-08
Tc-99	9.8E-13	5.5E-10
Th-228 + 7 dtrs	4.1E-11	2.3E-08
Th-230	9.8E-12	5.5E-09
Th-232	9.0E-12	5.0E-09
U-233	1.2E-11	6.7E-09
U-234	1.2E-11	6.7E-09
U-235 + 1 dtr	1.2E-11	6.7E-09
U-238 + 2 dtrs	2.1E-11	1.2E-08

[a]All values are in units of risk per pCi/L.
[b]All values are in units of risk per pCi/g.

TABLE D.I-38

UNIT CHEMICAL ILCR: ON-PROPERTY RESIDENT CHILD
SURFACE WATER PATHWAYS[a]

Chemical	Dermal Contact With Surface Water	Ingestion of Surface Water	Dermal Contact and Ingestion Pathways
Aroclor-1254	1.2E-02	1.5E-05	1.2E-02
Arsenic	9.6E-07	3.4E-06	4.4E-06
Benzo(a)anthracene	2.0E-02	1.4E-05	2.0E-02
Benzo(a)pyrene	3.0E-02	1.4E-05	3.0E-02
Benzo(b)fluoranthene	8.1E-02	1.4E-05	8.1E-02
Beryllium	2.4E-05	8.4E-06	3.2E-05
Bis(2-ethylhexyl) phthalate	3.6E-06	2.7E-08	3.6E-06
Chrysene	2.0E-03	1.4E-05	2.0E-03
Dibenzo(a,h)anthracene	2.6E-02	1.4E-05	2.6E-02
Indeno(1,2,3-cd)pyrene	4.0E-01	1.4E-05	4.0E-01
Methylene chloride	1.9E-08	1.5E-08	3.4E-08

[a]All values are in units of risk per mg/L.

TABLE D.I-39

UNIT HI: ON-PROPERTY RESIDENT CHILD
SURFACE WATER PATHWAYS[a]

Chemical	Dermal Contact With Surface Water	Ingestion of Surface Water	Dermal Contact and Ingestion Pathways
2-Butanone	1.4E-04	4.6E-04	6.0E-04
4-Methyl-2-pentanone	7.8E-05	4.6E-04	5.3E-04
Acetone	3.7E-05	2.3E-04	2.6E-04
Anthracene	2.3E-02	7.6E-05	2.3E-02
Antimony	5.3E-03	5.7E-02	1.1E-01
Arsenic	2.2E-02	7.6E-02	9.8E-02
Barium	9.2E-04	3.3E-04	1.3E-04
Benzoic acid	1.8E-05	5.7E-06	2.4E-05
Beryllium	1.3E-02	4.6E-03	1.8E-02
Bis(2-ethylhexyl) phthalate	1.4E-01	1.1E-03	1.4E-01
Cadmium (food)	6.4E-02	2.3E-02	8.7E-02
Cadmium (water)	1.3E-01	4.6E-02	1.5E-01
Chromium	1.3E-02	4.6E-03	1.8E-02
Cobalt	1.1E-03	3.8E-04	1.5E-03
Di-n-butyl phthalate	5.8E-02	2.3E-04	5.8E-02
Fluoranthene	6.0E-01	5.7E-04	6.0E-01
Manganese	7.7E-04	1.6E-04	9.3E-04
Mercury	5.5E-01	7.6E-02	6.3E-01
Methylene chloride	5.0E-04	3.8E-04	8.8E-04
Molybdenum	1.7E-03	4.6E-03	6.3E-03
Nickel	3.2E-03	1.1E-03	4.3E-03
Phenol	7.3E-05	3.8E-05	1.1E-04
Pyrene	3.0E-01	7.6E-04	3.0E-01
Selenium	8.0E-04	4.6E-03	5.4E-03
Silver	1.3E-02	4.6E-03	1.8E-02
Thallium	5.3E-02	3.8E-01	4.3E-01

TABLE D.I-39
(Continued)

Chemical	Dermal Contact With Surface Water	Ingestion of Surface Water	Dermal Contact and Ingestion Pathways
Toluene	1.5E-03	1.1E-04	1.6E-03
Total Xylenes	3.5E-04	1.1E-05	3.6E-04
Uranium	2.2E-02	7.6E-03	3.0E-02
Vanadium	9.2E-03	3.3E-03	1.3E-02
Zinc	8.0E-05	1.1E-04	1.9E-04

[a]All values are in units of $(mg/L)^{-1}$.

ATTACHMENT D.II

RISK CALCULATION RESULTS

TABLE D.II-1

RADIOLOGICAL ILCR: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SOIL/AIR PATHWAYS, CURRENT LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Soil Ingestion	Penetrating External Radiation	Risks from Ingestion and External Radiation
SILOS INTACT				
Pb-210 + 2 dtrs	1.1E-09	4.0E-08	1.8E-10	4.0E-08
Ra-226 + 5 dtrs	3.8E-09	1.1E-08	9.9E-06	9.9E-06
Ra-228 + 1 dtr	3.4E-10	1.8E-09	9.1E-07	9.1E-07
Rn-222 + 4 dtrs	2.6E-06	[a]	[a]	NA[b]
Sr-90 + 1 dtr	4.5E-11	7.3E-10	[c]	7.3E-10
Tc-99	3.1E-12	1.6E-11	1.4E-13	1.6E-11
Th-228 + 7 dtrs	5.3E-09[d]	[e]	[e]	NA
Th-230	6.6E-08	8.0E-10	6.0E-11	8.6E-10
Th-232	2.5E-09	2.7E-10	1.0E-11	2.8E-10
U-234	4.0E-08	8.0E-10	2.7E-11	8.3E-10
U-238 + 2 dtrs	2.8E-07	5.3E-09	1.2E-07	1.3E-07

[a] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[b] NA = Not applicable.
[c] Radionuclide is a beta-particle emitter and does not emit penetrating radiation.
[d] Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[e] Radionuclide is not a constituent of concern for this source term.

TABLE D.II-2

CHEMICAL ILCR: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SOIL/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil	Soil Ingestion	Risks from Ingestion and Dermal Contact Pathways
SILOS INTACT				
Aroclor-1254	0.00E+00	6.65E-08	3.28E-09	6.98E-08
Benzo(a)anthracene	1.27E-09	1.52E-05	4.30E-08	1.53E-05
Benzo(a)pyrene	1.09E-09	1.81E-05	5.10E-08	1.81E-05
Benzo(b)fluoranthene	1.71E-09	3.79E-06	5.37E-08	3.85E-06
Beryllium	2.99E-09	1.57E-06	5.17E-08	1.62E-06
Bis(2-ethylhexyl) phthalate	0.00E+00	1.27E-08	7.50E-11	1.27E-08
Chromium	3.45E-07	0.00E+00	0.00E+00	0.00E+00
Chrysene	1.15E-09	1.41E-05	4.00E-08	1.42E-05
Dibenzo(a,h)anthracene	7.36E-10	1.05E-05	2.97E-08	1.05E-05
Indeno(1,2,3-cd)pyrene	1.29E-09	1.56E-06	4.40E-08	1.60E-06
Methylene chloride	1.21E-14	1.29E-10	2.13E-12	1.31E-10
Nickel	1.11E-08	0.00E+00	0.00E+00	0.00E+00
Cadmium	1.43E-08	0.00E+00	0.00E+00	0.00E+00

TABLE D.II-3

NONCANCER HI: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SOIL/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil	Soil Ingestion	Risks from Ingestion and Dermal Contact Pathways
SILO INTACT				
2-Butanone	3.67E-11	1.83E-06	1.09E-08	1.84E-06
4-Methyl-2-pentanone	0.00E+00	8.39E-07	4.97E-09	8.44E-07
Acetone	0.00E+00	8.31E-06	4.92E-08	8.36E-06
Anthracene	0.00E+00	1.08E-05	7.63E-08	1.09E-05
Antimony	0.00E+00	6.01E-02	5.93E-03	6.61E-02
Benzoic acid	0.00E+00	2.06E-07	1.22E-09	2.08E-07
Beryllium	0.00E+00	4.26E-04	1.40E-05	4.40E-04
Bis(2-ethylhexyl) phthalate	0.00E+00	2.64E-04	1.56E-06	2.65E-04
Cadmium (food)	0.00E+00	1.35E-03	4.44E-04	1.79E-03
Chromium	0.00E+00	1.03E-02	3.38E-04	1.06E-02
Di-n-butyl phthalate	0.00E+00	2.81E-05	1.57E-07	2.83E-05
Fluoranthene	0.00E+00	3.10E-04	8.77E-07	3.11E-04
Methylene chloride	5.12E-11	1.68E-06	2.76E-08	1.70E-06
Molybdenum	0.00E+00	3.89E-04	9.74E-05	4.87E-04
Nickel	0.00E+00	3.88E-03	1.28E-04	4.01E-03
Phenol	0.00E+00	5.36E-06	3.18E-08	5.39E-06
Pyrene	0.00E+00	2.10E-04	1.24E-06	2.11E-04
Silver	0.00E+00	4.94E-03	1.63E-04	5.10E-03
Thallium	0.00E+00	6.73E-04	4.43E-04	1.12E-03
Toluene	5.00E-10	1.55E-08	3.39E-09	1.89E-08
Zinc	0.00E+00	1.63E-04	2.15E-05	1.85E-04
Total Xylenes	0.00E+00	1.13E-09	2.49E-10	1.38E-09
Uranium	0.00E+00	3.00E-02	9.86E-04	3.09E-02

TABLE D.II-4

RADIOLOGICAL ILCR: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Penetrating External Radiation	Ingestion of Silo Contents	Risks from External Radiation and Ingestion
SILO STRUCTURAL FAILURE				
Ac-227 + 7 dtrs	1.8E-05	1.9E-04	4.3E-06	1.9E-04
Pa-231	1.1E-05	6.9E-06	1.3E-06	8.2E-05
Pb-210 + 2 dtrs	6.4E-06	2.2E-07	4.7E-05	4.7E-05
Ra-226 + 5 dtrs	3.9E-06	6.6E-03	7.4E-06	6.6E-03
Ra-228 + 1 dtr	9.2E-08	3.4E-04	6.6E-07	3.4E-04
Rn-222 + 4 dtrs	8.6E-05	[a]	[a]	NA[b]
Sr-90 + 1 dtr	4.2E-11	[c]	[d]	NA
Tc-99	2.7E-12	[c]	[d]	NA
Th-228 + 7 dtrs	2.2E-05	2.1E-03	1.1E-06	2.1E-03
Th-230	5.9E-04	8.5E-07	1.1E-05	1.2E-05
Th-232	8.1E-06	7.3E-09	1.9E-07	2.0E-07
U-234	1.7E-05	1.6E-08	4.8E-07	5.0E-07
U-235 + 1 dtr	9.9E-07	8.2E-06	3.0E-08	8.2E-06
U-238 + 2 dtrs	3.2E-05	1.8E-05	7.9E-07	1.9E-05

[a] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[b] NA = Not applicable.
[c] Radionuclide is a beta-particle emitter and does not emit penetrating radiation.
[d] Radionuclide is not a constituent of concern for this source term.

TABLE D.II-5

CHEMICAL ILCR: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil	Soil Ingestion	Chemical-Specific Risk Across Pathways
SILO STRUCTURAL FAILURE				
Arsenic	1.45E-05	2.39E-04	7.87E-05	3.18E-04
Benzo(a)anthracene	1.16E-09	0.00E+00	0.00E+00	0.00E+00
Benzo(a)pyrene	9.93E-10	0.00E+00	0.00E+00	0.00E+00
Benzo(b)fluoranthene	1.58E-09	0.00E+00	0.00E+00	0.00E+00
Beryllium	7.71E-08	5.41E-05	1.78E-06	5.59E-05
Chromium	5.05E-06	0.00E+00	0.00E+00	0.00E+00
Chrysene	1.05E-09	0.00E+00	0.00E+00	0.00E+00
Dibenzo(a,h)anthracene	6.79E-10	0.00E+00	0.00E+00	0.00E+00
Methylene chloride	1.21E-14	0.00E+00	0.00E+00	0.00E+00
Nickel	1.11E-06	0.00E+00	0.00E+00	0.00E+00

TABLE D.II-6

NONCANCER HI: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Silo Content	Ingestion of Silo Content	Risks from Ingestion and Dermal Contact Pathways
SILO STRUCTURAL FAILURE				
2-Butanone	3.67E-11	0.00E+00	0.00E+00	0.00E+00
Antimony	0.00E+00	1.15E-02	1.14E-03	1.27E-02
Arsenic	0.00E+00	2.66E+00	8.74E-01	3.53E+00
Barium	3.29E-03	4.88E-05	1.07E-05	5.95E-05
Beryllium	0.00E+00	1.47E-02	4.83E-04	1.52E-02
Cadmium (food)	0.00E+00	2.37E-02	7.79E-03	3.15E-02
Chromium	0.00E+00	1.99E-01	6.54E-03	2.05E-01
Cobalt	1.70E+01	1.03E-01	3.40E-03	1.07E-01
Lead	4.23E-06	0.00E+00	0.00E+00	0.00E+00
Manganese	8.37E-02	1.55E-01	3.05E-03	1.58E-01
Mercury	1.43E-05	2.07E-05	4.08E-07	2.11E-05
Methylene chloride	5.12E-11	0.00E+00	0.00E+00	0.00E+00
Nickel	0.00E+00	5.40E-01	1.78E-02	5.57E-01
Silver	0.00E+00	9.28E-03	3.05E-04	9.58E-03
Thallium	0.00E+00	1.18E-01	7.75E-02	1.95E-01
Toluene	5.00E-10	0.00E+00	0.00E+00	0.00E+00
Selenium	0.00E+00	4.81E+00	6.33E-02	4.88E+00
Uranium	0.00E+00	4.48E+00	1.47E-01	4.63E+00
Vanadium	0.00E+00	1.10E-01	5.78E-02	1.68E-01
Zinc	0.00E+00	1.68E-03	2.21E-04	1.90E-03

TABLE D.II-7

RADIOLOGICAL ILCR: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SURFACE WATER PATHWAYS, CURRENT LAND USE

Radionuclide	Ingestion of Surface Water	Risks Across Pathways
SILOS INTACT		
Pb-210 + 2 dtrs	3.1E-11	3.1E-11
Ra-226 + 5 dtrs	3.6E-11	3.6E-11
Ra-228 + 1 dtr	5.7E-12	5.7E-12
Sr-90 + dtr	1.7E-10	1.7E-10
Tc-99	1.8E-10	1.8E-10
Th-230	3.2E-13	3.2E-13
Th-232	1.0E-13	1.0E-13
U-234	9.4E-10	9.4E-10
U-238 + 2 dtrs	6.3E-09	6.3E-09
SILO STRUCTURAL FAILURE		
Ac-227 + 7 dtrs	4.1E-09	4.1E-09
Pa-231	1.1E-09	1.1E-09
Pb-210 + 2 dtrs	3.7E-08	3.7E-08
Ra-226 + 5 dtrs	2.3E-08	2.3E-08
Ra-228 + 1 dtr	2.1E-09	2.1E-09
Th-228 + 7 dtrs	4.6E-10	4.6E-10
Th-230	4.6E-09	4.6E-09
Th-232	7.2E-11	7.2E-11
U-234	6.0E-07	6.0E-07
U-235 + 1 dtr	3.6E-08	3.6E-08
U-238 + 2 dtrs	9.7E-07	9.7E-07

TABLE D.II-8

CHEMICAL ILCR: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SURFACE WATER PATHWAYS, CURRENT LAND USE

Chemical	Ingestion of Surface Water	Dermal Exposure While Swimming	Risks Across Pathways
SILOS INTACT			
Aroclor-1254	1.79E-13	3.03E-10	3.03E-10
Benzo(a)anthracene	6.68E-12	2.01E-08	2.01E-08
Benzo(a)pyrene	3.39E-11	1.57E-07	1.57E-07
Benzo(b)fluoranthene	8.67E-13	1.06E-08	1.06E-08
Beryllium	4.52E-11	2.74E-10	3.19E-10
Bis(2-ethylhexyl) phthalate	2.29E-14	6.34E-12	6.36E-12
Chrysene	5.98E-12	1.80E-08	1.80E-08
Dibenzo(a,h)anthracene	1.89E-12	7.21E-09	8.21E-09
Indeno(1,2,3-cd)pyrene	5.78E-14	3.53E-09	3.53E-09
Methylene chloride	5.53E-12	1.57E-11	2.12E-11
SILO STRUCTURAL FAILURE			
Arsenic	2.22E-07	1.35E-07	3.57E-07
Beryllium	7.63E-10	4.62E-09	5.38E-09

TABLE D.II-9

NONCANCER HI: TRESPASSING CHILD WITHOUT ACCESS CONTROLS
SURFACE WATER PATHWAYS, CURRENT LAND USE

Chemical	Ingestion of Surface Water	Dermal Exposure While Swimming	Risks Across Pathways
SILOS INTACT			
2-Butanone	9.08E-08	6.21E-08	1.53E-07
4-Methyl-2-pentanone	1.75E-08	6.43E-09	2.39E-08
Acetone	5.02E-07	1.72E-07	6.74E-07
Anthracene	1.62E-10	1.04E-07	1.04E-07
Antimony	2.79E-05	5.63E-05	8.42E-05
Benzoic acid	9.16E-10	6.12E-09	7.04E-09
Beryllium	1.23E-08	7.44E-08	8.67E-08
Bis(2-ethylhexyl) phthalate	4.78E-10	1.32E-07	1.32E-07
Cadmium (food)	1.04E-06	6.28E-06	7.32E-06
Cadmium (water)	2.07E-06	1.25E-05	1.46E-06
Chromium	2.55E-07	1.54E-06	1.80E-06
Di-n-butyl phthalate	5.97E-11	3.27E-08	3.27E-08
Fluoranthene	2.39E-10	5.44E-07	5.44E-07
Methylene chloride	7.17E-08	2.03E-07	2.75E-07
Nickel	2.23E-07	1.35E-06	1.58E-06
Phenol	5.58E-08	2.32E-07	2.88E-07
Pyrene	4.78E-10	4.08E-07	4.08E-07
Silver	1.04E-06	6.28E-06	7.32E-06
Thallium	3.32E-07	1.01E-07	4.32E-07
Toluene	3.98E-10	1.13E-08	1.17E-08
Uranium	5.84E-04	3.54E-01	3.55E-01
Total Xylenes	1.35E-11	8.85E-10	8.98E-10
SILO STRUCTURAL FAILURE			
Antimony	7.84E-07	1.73E-05	1.81E-05
Arsenic	7.48E-04	4.94E-03	5.69E-03
Barium	4.48E-08	2.96E-06	3.00E-06
Beryllium	6.27E-08	4.14E-06	4.20E-06

TABLE D.II-9
(Continued)

Chemical	Ingestion of Surface Water	Dermal Exposure While Swimming	Risks Across Pathways
Cadmium (food)	2.65E-06	1.75E-04	1.78E-04
Cadmium (water)	5.31E-06	3.50E-04	3.55E-04
Chromium	7.24E-07	4.78E-05	4.85E-05
Cobalt	1.25E-06	8.22E-05	8.35E-05
Manganese	2.93E-06	3.22E-04	3.25E-04
Mercury	3.22E-06	5.30E-04	5.33E-04
Nickel	4.71E-06	3.10E-04	3.15E-04
Selenium	8.69E-07	3.59E-06	4.46E-06
Silver	2.90E-07	1.91E-05	1.94E-05
Thallium	8.85E-06	2.92E-05	3.81E-05
Uranium	1.37E-02	9.02E-01	9.16E-01
Vanadium	6.89E-06	4.56E-04	4.63E-04
Zinc	1.57E-08	2.59E-07	2.75E-07

TABLE D.II-10

RADIOLOGICAL ILCR: GROUNDSKEEPER SOIL/AIR PATHWAYS, CURRENT LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Soil Ingestion	Penetrating External Radiation	Risks from Ingestion and External Radiation
SILOS INTACT				
Pb-210 + 2 dtrs	3.0E-09	1.2E-07	5.2E-10	1.2E-07
Ra-226 + 5 dtrs	1.0E-08	3.1E-08	2.8E-05	2.8E-05
Ra-228 + 1 dtr	9.6E-10	4.8E-09	2.5E-06	2.5E-06
Rn-222 + 4 dtrs	7.2E-06	[a]	[a]	NA[b]
Sr-90 + dtr	1.3E-10	2.1E-09	[c]	2.1E-09
Tc-99	8.6E-12	4.7E-11	3.9E-13	4.7E-11
Th-228 + 7 dtrs	1.5E-08[d]	[e]	[e]	NA
Th-230	1.9E-07	2.3E-09	1.7E-10	2.5E-09
Th-232	6.9E-09	7.4E-10	2.9E-11	7.7E-10
U-234	1.1E-07	2.2E-09	7.7E-11	2.3E-09
U-238 + 2 dtrs	7.5E-07	1.4E-08	3.5E-07	3.6E-07

[a]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[b]NA = Not applicable.
[c]Radionuclide is a beta-particle emitter and does not emit penetrating radiation.
[d]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[e]Radionuclide is not a constituent of concern for this source term.

TABLE D.II-11

CHEMICAL ILCR: GROUNDSKEEPER
SOIL/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil	Soil Ingestion	Risk from Ingestion and Dermal Contact Pathways
SILO INTACT				
Aroclor-1254	0.00E+00	7.53E-08	5.65E-09	8.10E-08
Benzo(a)anthracene	2.18E-09	1.72E-05	7.41E-08	1.73E-05
Benzo(a)pyrene	1.87E-09	2.04E-05	8.79E-08	2.05E-05
Benzo(b)fluoranthene	2.95E-09	4.30E-06	9.25E-08	4.39E-06
Beryllium	5.16E-09	1.78E-06	8.90E-08	1.87E-06
Bis(2-ethylhexyl) phthalate	0.00E+00	1.44E-08	1.29E-10	1.45E-08
Chromium	5.94E-07	0.00E+00	0.00E+00	0.00E+00
Chrysene	1.98E-09	1.60E-05	6.89E-08	1.61E-05
Dibenzo(a,h)anthracene	1.27E-09	1.19E-05	5.12E-08	1.20E-05
Indeno(1,2,3-cd)pyrene	2.22E-09	1.76E-06	7.59E-08	1.84E-06
Methylene chloride	2.08E-14	1.47E-10	3.66E-12	1.50E-10
Nickel	1.92E-08	0.00E+00	0.00E+00	0.00E+00
Cadmium	2.46E-08	0.00E+00	0.00E+00	0.00E+00

TABLE D.II-12

NONCANCER HI: GROUNDSKEEPER
SOIL/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil	Soil Ingestion	Hazard Indices From Ingestion and Dermal Contact Pathways
SILO INTACT				
2-Butanone	3.03E-11	9.97E-07	8.98E-09	1.01E-06
4-Methyl-2-pentanone	0.00E+00	4.57E-07	4.11E-09	4.61E-07
Acetone	0.00E+00	4.52E-06	4.07E-08	4.56E-06
Anthracene	0.00E+00	5.87E-06	6.31E-08	5.94E-06
Antimony	0.00E+00	3.27E-02	4.91E-03	3.76E-02
Benzoic acid	0.00E+00	1.12E-07	1.01E-09	1.13E-07
Beryllium	0.00E+00	2.32E-04	1.16E-05	2.43E-04
Bis(2-ethylhexyl) phthalate	0.00E+00	1.44E-04	1.29E-06	1.45E-04
Cadmium (food)	0.00E+00	7.34E-04	3.67E-04	1.10E-03
Chromium	0.00E+00	5.60E-03	2.80E-04	5.88E-03
Di-n-butyl phthalate	0.00E+00	1.53E-05	1.30E-07	1.54E-05
Fluoranthene	0.00E+00	1.69E-04	7.25E-07	1.69E-04
Methylene chloride	4.23E-11	9.12E-07	2.28E-08	9.35E-07
Molybdenum	0.00E+00	2.12E-04	8.05E-05	2.92E-04
Nickel	0.00E+00	2.11E-03	1.06E-04	2.22E-03
Phenol	0.00E+00	2.92E-06	2.63E-08	2.94E-06
Pyrene	0.00E+00	1.14E-04	1.03E-06	1.15E-04
Silver	0.00E+00	2.69E-03	1.34E-04	2.82E-03
Thallium	0.00E+00	3.66E-04	3.66E-04	7.32E-04
Toluene	4.13E-10	8.42E-09	2.81E-09	1.12E-08
Zinc	0.00E+00	8.87E-05	1.77E-05	1.06E-04
Total Xylenes	0.00E+00	6.17E-10	2.06E-10	8.23E-10
Uranium	0.00E+00	1.63E-02	8.15E-04	1.71E-02

TABLE D.II-13

RADIOLOGICAL ILCR: GROUNDSKEEPER SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Penetrating External Radiation	Ingestion of Silo Contents	Risks from External Radiation and Ingestion
SILO STRUCTURAL FAILURE				
Ac-227 + 7 dtrs	5.1E-05	5.4E-04	1.2E-05	5.5E-04
Pa-231	3.1E-05	2.0E-05	3.7E-06	2.4E-05
Pb-210 + 2 dtrs	1.8E-05	6.1E-07	1.4E-04	1.4E-04
Ra-226 + 5 dtrs	1.1E-05	1.9E-02	2.1E-05	1.9E-02
Ra-228 + 1 dtr	2.6E-07	9.4E-04	1.8E-06	9.4E-04
Rn-222 + 4 dtrs	2.4E-04	[a]	[a]	NA[b]
Sr-90 + 1 dtr	1.2E-10	[c]	[d]	NA
Tc-99	7.7E-12	[c]	[d]	NA
Th-228 + 7 dtrs	6.3E-05	5.9E-03	3.1E-06	5.9E-03
Th-230	1.7E-03	2.5E-06	3.2E-05	3.5E-05
Th-232	2.2E-05	2.1E-08	5.2E-07	5.4E-07
U-234	4.8E-05	4.6E-08	1.3E-06	1.3E-06
U-235 + 1 dtr	2.8E-06	2.3E-05	8.4E-08	2.3E-05
U-238 + 2 dtrs	8.7E-05	5.2E-05	2.2E-06	5.4E-05

[a]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[b]NA = Not applicable.
[c]Radionuclide is a beta-particle emitter and does not emit penetrating radiation.
[d]Radionuclide is not a constituent of concern for this source term.

TABLE D.II-14

CHEMICAL ILCR: GROUNDSKEEPER
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Silo Contents	Ingestion of Silo Contents	Risks From Ingestion and Dermal Contact Pathways
SILO STRUCTURAL FAILURE				
Arsenic	2.50E-05	2.71E-04	1.36E-04	4.07E-04
Benzo(a)anthracene	2.00E-09	0.00E+00	0.00E+00	0.00E+00
Benzo(a)pyrene	1.71E-09	0.00E+00	0.00E+00	0.00E+00
Benzo(b)fluoranthene	2.71E-09	0.00E+00	0.00E+00	0.00E+00
Beryllium	1.33E-07	6.13E-05	3.06E-06	6.44E-05
Chromium	8.70E-06	0.00E+00	0.00E+00	0.00E+00
Chrysene	1.80E-09	0.00E+00	0.00E+00	0.00E+00
Dibenzo(a,h)anthracene	1.17E-09	0.00E+00	0.00E+00	0.00E+00
Methylene chloride	2.08E-14	0.00E+00	0.00E+00	0.00E+00
Nickel	1.91E-04	0.00E+00	0.00E+00	0.00E+00

TABLE D.II-15

NONCANCER HI: GROUNDSKEEPER
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Silo Contents	Ingestion of Silo Contents	Hazard Indices from Ingestion and Dermal Contact Pathways
SILO STRUCTURAL FAILURE				
2-Butanone	3.03E-11	0.00E+00	0.00E+00	0.00E+00
Antimony	0.00E+00	6.28E-03	9.42E-04	7.22E-03
Arsenic	0.00E+00	1.45E+00	7.23E-01	2.17E+00
Barium	2.72E-03	5.06E-03	2.53E-04	5.31E-03
Beryllium	0.00E+00	7.98E-03	3.99E-04	8.38E-03
Cadmium (food)	0.00E+00	1.29E-02	6.44E-03	1.93E-02
Chromium	0.00E+00	1.08E-01	5.41E-03	1.14E-01
Cobalt	1.41E+01	6.55E-02	3.28E-03	6.88E-02
Lead	3.50E-06	0.00E+00	0.00E+00	0.00E+00
Manganese	6.92E-02	8.42E-02	2.53E-03	8.67E-02
Mercury	1.18E-05	7.88E-03	1.58E-04	8.03E-03
Methylene chloride	4.23E-11	0.00E+00	0.00E+00	0.00E+00
Nickel	0.00E+00	2.94E-01	1.47E-02	3.08E-01
Selenium	0.00E+00	3.93E-03	3.14E-03	7.07E-03
Silver	0.00E+00	5.05E-03	2.52E-04	5.30E-03
Thallium	0.00E+00	6.41E-02	6.41E-02	1.28E-01
Toluene	4.13E-10	0.00E+00	0.00E+00	0.00E+00
Uranium	0.00E+00	2.44E+00	1.22E-01	2.56E+00
Vanadium	0.00E+00	6.83E-01	3.41E-02	7.17E-01
Zinc	0.00E+00	9.15E-04	1.83E-04	1.10E-03

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TABLE D.II-16

RADIOLOGICAL ILCR: OFF-PROPERTY RESIDENT FARMER SOIL/AIR PATHWAYS, CURRENT LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Pb-210 + 2 dtrs	4.1E-09	1.1E-08	2.3E-10	7.8E-10	1.5E-08
Ra-226 + 5 dtrs	1.6E-08	8.7E-09	1.9E-10	1.4E-09	2.6E-08
Ra-228 + 1 dtr	1.5E-09	2.8E-09	4.0E-11	2.8E-10	4.6E-09
Rn-222 + 4 dtrs	2.3E-06	[a]	[a]	[a]	2.3E-06
Sr-90 + 1 dtr	1.9E-10	1.1E-08	8.6E-10	1.8E-08	3.0E-08
Tc-99	1.3E-11	2.2E-09	3.6E-09	1.7E-08	2.2E-08
Th-228 + 7 dtrs[b]	1.8E-08	1.6E-10	4.8E-14	1.6E-13	1.8E-08
Th-230	2.8E-07	1.5E-09	6.6E-13	2.2E-12	2.8E-07
Th-232	9.6E-09	5.4E-11	2.3E-14	7.5E-14	9.9E-09
U-234	1.7E-07	1.6E-09	2.3E-11	2.8E-10	1.7E-07
U-238 + 2 dtrs	1.1E-06	9.5E-09	1.3E-10	1.6E-09	1.2E-06

[a] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.

[b] Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.

TABLE D.II-17

CHEMICAL ILCR: OFF-PROPERTY RESIDENT FARMER AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Milk	Ingestion of Meat	Chemical-Specific Risk Across Pathways
SILO INTACT					
Benzo(a)anthracene	3.16E-09	1.06E-13	3.02E-14	2.39E-14	3.16E-09
Benzo(a)pyrene	2.88E-09	1.76E-13	1.05E-13	8.33E-14	2.88E-09
Benzo(b)fluoranthene	4.35E-09	8.76E-14	2.77E-13	2.19E-13	4.35E-09
Beryllium	8.17E-09	5.99E-14	7.42E-18	2.06E-15	8.17E-09
Cadmium	3.80E-08	0.00E+00	0.00E+00	0.00E+00	3.80E-08
Chromium	9.06E-07	0.00E+00	0.00E+00	0.00E+00	9.06E-07
Chrysene	3.16E-09	1.06E-13	3.02E-14	2.39E-14	3.16E-09
Dibenzo(a,h)anthracene	1.98E-09	5.20E-14	3.75E-14	2.96E-14	1.98E-09
Indeno(1,2,3-c,d)pyrene	3.56E-09	5.79E-14	2.46E-12	1.95E-12	3.56E-09
Nickel	2.93E-08	0.00E+00	0.00E+00	0.00E+00	2.93E-08

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TABLE D.II-18

NONCANCER HI: OFF-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Beryllium	0.00E+00	2.79E-12	9.59E-14	3.45E-16	2.88E-12
Cadmium	0.00E+00	8.91E-10	2.16E-11	1.57E-10	1.07E-09
Chromium	0.00E+00	6.88E-11	1.10E-11	1.21E-11	9.19E-11
Nickel	0.00E+00	9.36E-11	1.10E-11	7.34E-12	1.12E-10

TABLE D.II-19

RADIOLOGICAL ILCR: OFF-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Ac-227 + 7 dtrs	5.0E-05	3.2E-06	5.0E-09	1.6E-08	5.3E-05
Pa-231	3.0E-05	1.0E-06	7.2E-10	1.4E-09	3.1E-05
Pb-210 + 2 dtrs	1.7E-05	4.4E-05	9.6E-07	3.2E-06	6.3E-05
Ra-226 + 5 dtrs	1.0E-05	5.7E-06	1.3E-07	9.0E-07	1.7E-05
Ra-228 + 1 dtr	2.6E-07	4.8E-07	6.7E-09	4.8E-08	7.7E-07
Rn-222 + 4 dtrs	2.3E-04	[a]	[a]	[a]	2.3E-04
Sr-90 + 1 dtr	1.4E-10	7.6E-09	6.1E-10	1.2E-08	2.1E-08
Tc-99	9.6E-12	1.6E-09	2.6E-09	1.2E-08	1.6E-08
Th-228 + 7 dtrs	6.1E-05	7.8E-07	2.4E-10	8.2E-10	6.2E-05
Th-230	1.6E-03	8.4E-06	3.6E-09	1.2E-08	1.6E-03
Th-232	2.2E-05	1.4E-07	5.8E-11	1.9E-10	2.3E-05
U-234	4.5E-05	4.2E-07	6.0E-09	7.2E-08	4.5E-05
U-235 + 1 dtr	2.6E-06	2.5E-08	3.6E-10	4.4E-09	2.6E-06
U-238 + 2 dtrs	8.4E-05	7.0E-07	9.7E-09	1.2E-07	8.5E-05

[a] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.

TABLE D.II-20

CHEMICAL ILCR: OFF-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Arsenic	2.38E-05	2.17E-11	4.60E-12	5.52E-13	2.38E-05
Benzo(a)anthracene	2.37E-09	3.17E-14	1.79E-14	2.27E-14	2.37E-09
Benzo(a)pyrene	2.09E-09	5.12E-14	6.06E-14	7.67E-14	2.09E-09
Benzo(b)fluoranthene	3.16E-09	2.55E-14	1.59E-13	2.01E-13	3.16E-09
Beryllium	1.29E-07	3.79E-13	3.26E-14	1.17E-16	1.29E-07
Cadmium (food)	3.25E-07	0.00E+00	0.00E+00	0.00E+00	3.25E-07
Chromium	9.01E-06	0.00E+00	0.00E+00	0.00E+00	9.01E-06
Chrysene	2.37E-09	3.17E-14	1.79E-14	2.27E-14	2.37E-09
Dibenzo(a,h)anthracene	1.58E-09	1.66E-14	2.37E-14	3.00E-14	1.58E-09
Indeno(1,2,3-cd)pyrene	2.37E-09	1.55E-14	1.30E-12	1.64E-12	2.37E-09
Nickel	1.83E-06	0.00E+00	0.00E+00	0.00E+00	1.83E-06

TABLE D.II-21

NONCANCER HI: OFF-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Antimony	0.00E+00	1.31E-10	1.82E-11	7.27E-12	1.57E-10
Arsenic	0.00E+00	4.13E-08	8.76E-09	1.05E-09	5.11E-08
Barium	9.26E-04	2.51E-11	5.70E-13	5.32E-12	9.26E-04
Beryllium	0.00E+00	1.76E-11	1.52E-12	5.45E-15	1.91E-11
Cadmium (food)	0.00E+00	3.06E-09	1.85E-10	1.34E-09	4.58E-09
Chromium	0.00E+00	2.74E-10	1.10E-10	1.20E-10	5.03E-10
Cobalt	4.80E+00	1.77E-10	2.90E-10	1.16E-10	4.80E+00
Manganese	2.36E-02	4.68E-10	2.35E-11	8.21E-11	2.36E-02
Mercury	3.77E-06	8.93E-11	2.81E-09	2.02E-11	3.77E-06
Nickel	0.00E+00	2.33E-09	6.86E-10	4.57E-10	3.48E-09
Selenium	0.00E+00	2.74E-10	2.28E-10	2.44E-10	7.46E-10
Silver	0.00E+00	7.82E-11	2.69E-11	7.17E-10	8.22E-10
Thallium	0.00E+00	2.48E-09	8.01E-09	1.60E-09	1.21E-08
Vanadium	0.00E+00	1.49E-09	2.77E-10	0.00E+00	1.76E-09
Zinc	0.00E+00	3.63E-10	2.29E-09	0.00E+00	2.66E-09

TABLE D.II-22

RADIOLOGICAL ILCR: OFF-PROPERTY RESIDENT FARMER GROUNDWATER PATHWAYS, CURRENT LAND USE

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE[a]					
U-234	2.9E-06	1.1E-06	7.8E-09	9.7E-08	4.1E-06
U-235 + 1 dtr	2.5E-07	9.6E-08	6.7E-10	8.3E-09	3.5E-07
U-238 + 2 dtrs	4.6E-06	1.7E-06	1.2E-08	1.5E-07	6.3E-06

[a]The groundwater concentration used to calculate these ILCRs were from the sum of the impacts of Silos 1, 2, and 3 as shown in Table D.3-8.

TABLE D.II-23

CHEMICAL HI: OFF-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS, CURRENT LAND USE

Chemical	Ingestion of Drinking Water	Dermal Exposure While Bathing	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOCs from Home Water Use	Hazard Indices Across Pathways
AQUIFER							
Uranium	9.13E-02	4.58E-04	2.91E-02	2.50E-04	3.09E-03	0.00E+00	1.24E-01

TABLE D.II-24

RADIOLOGICAL ILCR: OFF-PROPERTY USER OF SURFACE WATER
SURFACE WATER PATHWAYS, CURRENT LAND USE

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Risks Across Pathways
SILOS INTACT						
Pb-210 + 2 dtrs	3.0E-11	1.1E-11	1.5E-13	5.1E-13	3.4E-11	7.7E-11
Ra-226 + 5 dtrs	3.4E-11	1.1E-11	1.3E-13	9.9E-13	2.0E-11	7.0E-11
Ra-228 + 1 dtr	5.4E-12	1.7E-12	1.5E-14	1.1E-13	3.1E-12	1.0E-11
Sr-90 + dtr	1.6E-10	4.4E-10	1.8E-11	3.7E-10	5.6E-11	1.0E-09
Tc-99	1.7E-10	4.9E-09	4.2E-09	1.9E-08	2.9E-11	2.9E-08
Th-230	3.1E-13	9.3E-14	2.1E-17	7.3E-17	1.1E-13	4.9E-13
Th-232	1.0E-13	3.1E-14	6.6E-18	2.2E-17	3.4E-14	1.6E-13
U-234	9.4E-10	3.6E-10	2.5E-12	3.1E-11	2.2E-11	1.3E-09
U-238 + 2 dtrs	6.2E-09	2.3E-09	1.6E-11	2.0E-10	1.4E-10	8.8E-09
SILO STRUCTURAL FAILURE						
Ac-227 + 7 dtrs	1.9E-09	5.7E-10	5.3E-13	1.8E-12	5.5E-10	3.0E-09
Pa-231	5.4E-10	1.7E-10	6.2E-14	1.3E-13	6.8E-11	7.8E-10
Pb-210 + 2 dtrs	1.7E-08	6.5E-09	8.6E-11	3.0E-10	2.0E-08	4.5E-08
Ra-226 + 5 dtrs	1.1E-08	3.6E-09	4.4E-11	3.2E-10	6.5E-09	2.3E-08
Ra-228 + 1 dtr	9.8E-10	3.0E-10	2.8E-12	2.0E-11	5.6E-10	1.9E-09
Th-228 + 7 dtrs	2.1E-10	6.2E-11	1.3E-14	4.7E-14	7.4E-11	3.5E-10
Th-230	2.2E-09	6.5E-10	1.4E-13	5.1E-13	7.5E-10	3.4E-09
Th-232	3.4E-11	1.0E-11	2.3E-15	7.5E-15	1.2E-11	5.6E-11

TABLE D.II-24
(Continued)

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Risks Across Pathways
U-234	2.8E-07	1.1E-07	7.6E-10	9.4E-09	6.5E-09	4.0E-07
U-235 + 1 dtr	1.7E-08	6.6E-09	4.6E-11	5.7E-10	4.0E-10	2.4E-08
U-238 + 2 dtrs	4.6E-07	1.7E-07	1.2E-09	1.5E-08	1.1E-08	6.6E-07

TABLE D.II-25

CHEMICAL ILCR: OFF-PROPERTY USER OF SURFACE WATER
SURFACE WATER PATHWAYS, CURRENT LAND USE

Chemical	Ingestion of Drinking Water	Dermal Exposure While Bathing	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Risks Across Pathways
SILOS INTACT							
Aroclor-1254	2.11E-13	0.00E+00	3.13E-13	1.60E-13	7.85E-14	1.83E-13	9.46E-13
Benzo(a)anthracene	7.60E-12	5.14E-12	1.15E-11	1.79E-12	3.01E-12	1.39E-12	2.77E-11
Benzo(a)pyrene	4.00E-11	2.70E-11	9.33E-11	3.62E-11	2.17E-11	2.82E-11	2.46E-10
Benzo(b)fluoranthene	1.02E-12	6.95E-13	6.24E-12	1.60E-12	3.32E-13	1.23E-12	1.11E-11
Beryllium	5.42E-11	0.00E+00	1.35E-14	2.84E-15	1.68E-11	7.70E-13	7.18E-11
Bis(2-ethylhexyl) phthalate	2.65E-14	0.00E+00	7.69E-15	3.73E-15	1.17E-14	2.91E-15	5.25E-14
Chrysene	7.00E-12	4.72E-12	1.06E-11	1.65E-12	2.77E-12	1.28E-12	2.80E-11
Dibenzo(a,h)anthracene	2.20E-12	1.48E-12	4.20E-12	1.03E-12	7.87E-13	7.94E-13	1.05E-11
Indeno(1,2,3-cd)pyrene	6.80E-14	4.58E-14	2.09E-12	1.16E-12	2.07E-14	8.90E-13	4.27E-12
Methylene chloride	6.58E-12	5.70E-13	2.18E-14	9.01E-15	2.11E-10	7.14E-15	2.18E-10
SILO STRUCTURAL FAILURE							
Arsenic	2.59E-07	1.29E-10	8.86E-08	1.25E-08	1.52E-09	3.08E-07	6.70E-07
Beryllium	9.07E-10	4.54E-12	2.81E-10	1.29E-11	4.76E-14	4.65E-10	1.67E-09

TABLE D.II-26

NONCANCER HI: OFF-PROPERTY USER OF SURFACE WATER
SURFACE WATER PATHWAYS, CURRENT LAND USE

Chemical	Ingestion of Drinking Water	Dermal Exposure While Bathing	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Hazard Indices Across Pathways
SILOS INTACT							
2-Butanone	1.86E-08	1.22E-09	1.34E-11	9.73E-12	2.22E-06	7.69E-12	2.24E-06
4-Methyl-2-pentanone	3.40E-09	0.00E+00	1.31E-12	3.99E-12	1.35E-07	3.15E-12	1.38E-07
Acetone	1.01E-07	0.00E+00	3.55E-11	3.26E-11	2.34E-05	2.58E-11	2.35E-05
Anthracene	3.29E-11	0.00E+00	1.06E-11	1.34E-12	2.46E-11	1.05E-12	7.05E-11
Antimony	5.48E-06	0.00E+00	1.37E-09	1.69E-07	2.83E-06	4.21E-07	8.90E-06
Benzoic acid	1.85E-10	0.00E+00	1.30E-12	4.66E-13	2.62E-09	3.67E-13	2.81E-09
Beryllium	2.52E-09	0.00E+00	6.30E-13	1.32E-13	7.80E-10	3.58E-11	3.34E-09
Bis(2-ethylhexyl) phthalate	9.45E-11	0.00E+00	2.75E-11	1.33E-11	4.19E-11	1.04E-11	1.88E-10
Cadmium (water)	4.11E-07	0.00E+00	1.03E-10	3.16E-07	4.75E-07	4.34E-08	1.22E-06
Chromium	5.21E-08	0.00E+00	1.30E-11	4.29E-09	1.66E-08	3.83E-09	7.68E-08
Di-n-butyl phthalate	1.21E-11	0.00E+00	6.54E-12	1.45E-12	5.59E-12	1.13E-12	2.68E-11
Fluoranthene	4.93E-11	0.00E+00	5.65E-11	7.34E-12	2.16E-11	5.70E-12	1.40E-10
Methylene chloride	1.46E-08	4.15E-10	4.84E-11	2.00E-11	4.69E-07	1.59E-11	4.84E-07
Nickel	4.52E-08	0.00E+00	1.13E-11	5.61E-09	2.52E-08	8.32E-09	8.43E-08
Phenol	1.14E-08	0.00E+00	4.99E-11	1.90E-11	2.81E-07	1.50E-11	2.92E-07
Pyrene	1.00E-10	0.00E+00	9.00E-11	1.17E-11	4.71E-11	9.10E-12	2.58E-10
Silver	2.08E-07	0.00E+00	5.21E-11	2.38E-06	1.85E-07	8.91E-08	2.86E-06

TABLE D.II-26
(Continued)

Chemical	Ingestion of Drinking Water	Dermal Exposure While Bathing	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Hazard Indices Across Pathways
Thallium	6.85E-08	0.00E+00	1.71E-11	6.90E-09	2.07E-08	3.35E-08	1.30E-07
Toluene	8.22E-11	7.24E-11	2.72E-12	4.69E-13	4.09E-10	3.71E-13	5.67E-10
Uranium	1.19E-04	0.00E+00	2.97E-08	4.01E-06	3.78E-05	3.25E-07	1.61E-04
Total Xylenes	2.74E-12	0.00E+00	2.09E-13	2.15E-16	8.85E-12	1.76E-14	1.18E-11
SILO STRUCTURAL FAILURE							
Antimony	5.21E-07	0.00E+00	1.30E-10	1.61E-08	2.69E-07	4.00E-08	8.46E-07
Arsenic	4.93E-04	0.00E+00	1.23E-07	2.89E-06	1.69E-04	2.37E-05	6.89E-04
Barium	3.05E-08	0.00E+00	7.63E-12	2.59E-09	1.32E-08	2.76E-10	4.66E-08
Beryllium	4.22E-08	0.00E+00	1.05E-11	2.21E-12	1.31E-08	5.99E-10	5.59E-08
Cadmium (water)	3.56E-06	0.00E+00	8.90E-10	2.74E-06	4.12E-06	3.76E-07	1.08E-05
Chromium	4.99E-07	0.00E+00	1.25E-10	4.11E-08	1.59E-07	3.67E-08	7.36E-07
Cobalt	8.22E-07	0.00E+00	2.05E-10	1.17E-07	2.76E-07	2.88E-07	1.50E-06
Manganese	1.94E-06	0.00E+00	4.84E-10	2.54E-07	1.20E-06	7.23E-08	3.47E-06
Mercury	2.19E-06	0.00E+00	5.48E-10	1.21E-06	3.35E-06	1.68E-04	1.75E-04
Nickel	3.15E-06	0.00E+00	7.88E-10	3.91E-07	1.76E-06	5.80E-07	5.88E-06
Selenium	6.03E-07	0.00E+00	1.51E-10	1.88E-07	2.45E-07	1.73E-07	1.21E-06
Silver	1.92E-07	0.00E+00	4.79E-11	2.19E-06	1.70E-07	8.21E-08	2.63E-06
Thallium	5.94E-06	0.00E+00	1.48E-09	5.98E-07	1.79E-06	2.90E-06	1.12E-05
Uranium	8.95E-03	0.00E+00	2.24E-06	3.02E-04	2.85E-03	2.45E-05	1.21E-02

TABLE D.II-26
(Continued)

Chemical	Ingestion of Drinking Water	Dermal Exposure While Bathing	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Hazard Indices Across Pathways
Vanadium	4.70E-06	0.00E+00	1.17E-09	8.45E-10	1.47E-06	1.49E-07	6.32E-06
Zinc	1.05E-08	0.00E+00	2.64E-12	9.49E-10	4.75E-08	5.33E-07	5.92E-07

TABLE D.II-27

RADIOLOGICAL ILCR: TRESPASSING CHILD WITH ACCESS CONTROLS
SOIL/AIR PATHWAYS, CURRENT LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Soil Ingestion	Penetrating External Radiation	Risks from Ingestion and External Radiation
SILOS INTACT				
Pb-210 + 2 dtrs	1.1E-09	4.0E-08	1.8E-10	4.1E-08
Ra-226 + 5 dtrs	3.8E-09	1.1E-08	9.9E-06	9.9E-06
Ra-228 + 1 dtr	3.4E-10	1.8E-09	9.1E-07	9.1E-07
Rn-222 + 4 dtrs	2.6E-06	[a]	[a]	NA[b]
Sr-90 + 1 dtr	4.5E-11	7.3E-10	[c]	7.3E-10
Tc-99	3.1E-12	1.6E-11	1.4E-13	1.6E-11
Th-228 + 7 dtrs	5.3E-09[d]	[e]	[e]	NA
Th-230	6.6E-08	8.0E-10	6.0E-11	8.6E-10
Th-232	2.5E-09	2.7E-10	1.0E-11	2.8E-10
U-234	4.0E-08	8.0E-10	2.7E-11	8.3E-10
U-238 + 2 dtrs	2.8E-07	5.3E-09	1.2E-07	1.3E-07

[a]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[b]NA = Not applicable.
[c]Radionuclide is a beta-particle emitter and does not emit penetrating radiation.
[d]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[e]Radionuclide is not a constituent of concern for this source term.

TABLE D.II-28

CHEMICAL ILCR: TRESPASSING CHILD WITH ACCESS CONTROLS SOIL/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil	Soil Ingestion	Risks from Ingestion and Dermal Contact Pathways
SILOS INTACT				
Aroclor-1254	0.00E+00	6.65E-08	3.28E-09	6.98E-08
Benzo(a)anthracene	1.27E-09	1.52E-05	4.30E-08	1.53E-05
Benzo(a)pyrene	1.09E-09	1.81E-05	5.10E-08	1.81E-05
Benzo(b)fluoranthene	1.71E-09	3.79E-06	5.37E-08	3.85E-06
Beryllium	2.99E-09	1.57E-06	5.17E-08	1.62E-06
Bis(2-ethylhexyl) phthalate	0.00E+00	1.27E-08	7.50E-11	1.27E-08
Chromium	3.45E-07	0.00E+00	0.00E+00	0.00E+00
Chrysene	1.15E-09	1.41E-05	4.00E-08	1.42E-05
Dibenzo(a,h)anthracene	7.36E-10	1.05E-05	2.97E-08	1.05E-05
Indeno(1,2,3-cd)pyrene	1.29E-09	1.56E-06	4.40E-08	1.60E-06
Methylene chloride	1.21E-14	1.29E-10	2.13E-12	1.31E-10
Nickel	1.11E-08	0.00E+00	0.00E+00	0.00E+00
Cadmium	1.43E-07	0.00E+00	0.00E+00	0.00E+00

TABLE D.II-29

NONCANCER HI: TRESPASSING CHILD WITH ACCESS CONTROLS
SOIL/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Soil	Soil Ingestion	Hazard Indices from Ingestion and Dermal Contact Pathways
SILOS INTACT				
2-Butanone	3.67E-11	1.83E-06	1.09E-08	1.84E-06
4-Methyl-2-pentanone	0.00E+00	8.39E-07	4.97E-09	8.44E-07
Acetone	0.00E+00	8.31E-06	4.92E-08	8.36E-06
Anthracene	0.00E+00	1.08E-05	7.63E-08	1.09E-05
Antimony	0.00E+00	6.01E-02	5.93E-03	6.61E-02
Benzoic acid	0.00E+00	2.06E-07	1.22E-09	2.08E-07
Beryllium	0.00E+00	4.26E-04	1.40E-05	4.40E-04
Bis(2-ethylhexyl) phthalate	0.00E+00	2.64E-04	1.56E-06	2.65E-04
Cadmium (food)	0.00E+00	1.35E-03	4.44E-04	1.79E-03
Chromium	0.00E+00	1.03E-02	3.38E-04	1.06E-02
Di-n-butyl phthalate	0.00E+00	2.81E-05	1.57E-07	2.83E-05
Fluoranthene	0.00E+00	3.10E-04	8.77E-07	3.11E-04
Methylene chloride	5.12E-11	1.68E-06	2.76E-08	1.70E-06
Molybdenum	0.00E+00	3.89E-04	9.74E-05	4.87E-04
Nickel	0.00E+00	3.88E-03	1.28E-04	4.01E-03
Phenol	0.00E+00	5.36E-06	3.18E-08	5.39E-06
Pyrene	0.00E+00	2.10E-04	1.24E-06	2.11E-04
Silver	0.00E+00	4.94E-03	1.63E-04	5.10E-03
Thallium	0.00E+00	6.73E-04	4.43E-04	1.12E-03
Toluene	5.00E-10	1.55E-08	3.39E-09	1.89E-08
Zinc	0.00E+00	1.63E-04	2.15E-05	1.85E-04
Total Xylenes	0.00E+00	1.13E-09	2.49E-10	1.38E-09
Uranium	0.00E+00	3.00E-02	9.86E-04	3.09E-02

TABLE D.II-30

RADIOLOGICAL ILCR: TRESPASSING CHILD WITH ACCESS CONTROLS
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Penetrating External Radiation	Ingestion of Silo Contents	Risks from External Radiation and Ingestion
SILO STRUCTURAL FAILURE				
Ac-227 + 7 dtrs	1.8E-05	1.9E-04	4.3E-06	1.9E-04
Pa-231	1.1E-05	6.9E-06	1.3E-06	8.2E-06
Pb-210 + 2 dtrs	6.4E-06	2.2E-07	4.7E-05	4.7E-05
Ra-226 + 5 dtrs	3.9E-06	6.6E-03	7.4E-06	6.6E-03
Ra-228 + 1 dtr	9.2E-08	3.4E-04	6.6E-07	3.4E-04
Rn-222 + 4 dtrs	8.6E-05	a	a	NA[b]
Sr-90 + 1 dtr	4.2E-11	c	d	NA
Tc-99	2.7E-12	c	d	NA
Th-228 + 7 dtrs	2.2E-05	2.1E-03	1.1E-06	2.1E-03
Th-230	5.9E-04	8.5E-07	1.1E-05	1.2E-05
Th-232	8.1E-06	7.3E-09	1.9E-07	2.0E-07
U-234	1.7E-05	1.6E-08	4.8E-07	5.0E-07
U-235 + 1 dtr	9.9E-07	8.2E-06	3.0E-08	8.2E-06
U-238 + 2 dtrs	3.2E-05	1.8E-05	7.9E-07	1.9E-05

[a] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[b] NA = Not applicable
[c] Radionuclide is a beta-particle emitter and does not emit penetrating radiation.
[d] Radionuclide is not a constituent of concern for this source term.

TABLE D.II-31

CHEMICAL ILCR: TRESPASSING CHILD WITH ACCESS CONTROLS
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Silo Contents	Ingestion of Silo Contents	Risks from Ingestion and Dermal Contact Pathways
SILO STRUCTURAL FAILURE				
Arsenic	1.45E-05	2.39E-04	7.87E-05	3.18E-04
Benzo(a)anthracene	1.16E-09	0.00E+00	0.00E+00	0.00E+00
Benzo(a)pyrene	9.93E-10	0.00E+00	0.00E+00	0.00E+00
Benzo(b)fluoranthene	1.58E-09	0.00E+00	0.00E+00	0.00E+00
Beryllium	7.71E-08	5.41E-05	1.78E-06	5.59E-05
Chromium	5.05E-06	0.00E+00	0.00E+00	0.00E+00
Chrysene	1.05E-09	0.00E+00	0.00E+00	0.00E+00
Dibenzo(a,h)anthracene	6.79E-10	0.00E+00	0.00E+00	0.00E+00
Methylene chloride	1.21E-14	0.00E+00	0.00E+00	0.00E+00
Nickel	1.11E-06	0.00E+00	0.00E+00	0.00E+00

TABLE D.II-32

NONCANCER HI: TRESPASSING CHILD WITH ACCESS CONTROLS
SILO CONTENTS/AIR PATHWAYS, CURRENT LAND USE

Chemical	Inhalation of Fugitive Dust and VOCs	Dermal Contact with Silo Contents	Ingestion of Silo Contents	Hazard Indices from Ingestion and Dermal Contact Pathways
SILO STRUCTURAL FAILURE				
2-Butanone	3.67E-11	0.00E+00	0.00E+00	0.00E+00
Antimony	0.00E+00	1.15E-02	1.14E-03	1.27E-02
Arsenic	0.00E+00	2.66E+00	8.74E-01	3.53E+00
Barium	3.29E-03	4.88E-05	1.07E-05	5.95E-05
Beryllium	0.00E+00	1.47E-02	4.83E-04	1.52E-02
Cadmium (food)	0.00E+00	2.37E-02	7.79E-03	3.15E-02
Chromium	0.00E+00	1.99E-01	6.54E-03	2.05E-01
Cobalt	1.70E+01	1.03E-01	3.40E-03	1.07E-01
Lead	4.23E-06	0.00E+00	0.00E+00	0.00E+00
Manganese	8.37E-02	1.55E-01	3.05E-03	1.58E-01
Mercury	1.43E-05	2.07E-05	4.08E-07	2.11E-05
Methylene chloride	5.12E-11	0.00E+00	0.00E+00	0.00E+00
Nickel	0.00E+00	5.40E-01	1.78E-02	5.57E-01
Silver	0.00E+00	9.28E-03	3.05E-04	9.58E-03
Thallium	0.00E+00	1.18E-01	7.75E-02	1.95E-01
Toluene	5.00E-10	0.00E+00	0.00E+00	0.00E+00
Selenium	0.00E+00	4.81E+00	6.33E-02	4.88E+00
Uranium	0.00E+00	4.48E+00	1.47E-01	4.63E+00
Vanadium	0.00E+00	1.10E-01	5.78E-02	1.68E-01
Zinc	0.00E+00	1.68E-03	2.21E-04	1.90E-03

TABLE D.II-33

RADIOLOGICAL ILCR: TRESPASSING CHILD WITH ACCESS CONTROLS
SURFACE WATER PATHWAYS, CURRENT LAND USE

Radionuclide	Ingestion of Surface Water	Risks Across Pathways
SILOS INTACT		
Pb-210 + 2 dtrs	3.1E-11	3.1E-11
Ra-226 + 5 dtrs	3.6E-11	3.6E-11
Ra-228 + 1 dtr	5.7E-12	5.7E-12
Sr-90 + dtr	1.7E-10	1.7E-10
Tc-99	1.8E-10	1.8E-10
Th-230	3.2E-13	3.2E-13
Th-232	1.0E-13	1.0E-13
U-234	9.4E-10	9.4E-10
U-238 + 2 dtrs	6.3E-09	6.3E-09
SILO STRUCTURAL FAILURE		
Ac-227 + 7 dtrs	4.1E-09	4.1E-09
Pa-231	1.1E-09	1.1E-09
Pb-210 + 2 dtrs	3.7E-08	3.7E-08
Ra-226 + 5 dtrs	2.3E-08	2.3E-08
Ra-228 + 1 dtr	2.1E-09	2.1E-09
Th-228 + 7 dtrs	4.6E-10	4.6E-10
Th-230	4.6E-09	4.6E-09
Th-232	7.2E-11	7.2E-11
U-234	6.0E-07	6.0E-07
U-235 + 1 dtr	3.6E-08	3.6E-08
U-238 + 2 dtrs	9.7E-07	9.7E-07

TABLE D.II-34

CHEMICAL ILCR: TRESPASSING CHILD WITH ACCESS CONTROLS SURFACE WATER PATHWAYS, CURRENT LAND USE

Chemical	Dermal Exposure While Swimming	Ingestion of Surface Water	Risks Across Pathways
SILOS INTACT			
Aroclor-1254	3.03E-10	1.79E-13	3.03E-10
Benzo(a)anthracene	2.01E-08	6.68E-12	2.01E-08
Benzo(a)pyrene	1.57E-07	3.39E-11	1.57E-07
Benzo(b)fluoranthene	1.06E-08	8.67E-13	1.06E-08
Beryllium	2.74E-10	4.52E-11	3.19E-10
Bis(2-ethylhexyl) phthalate	6.34E-12	2.29E-14	6.37E-12
Chrysene	1.80E-08	5.98E-12	1.80E-08
Dibenzo(a,h)anthracene	7.21E-09	1.89E-12	7.21E-09
Indeno(1,2,3-cd)pyrene	3.53E-09	5.78E-14	3.53E-09
Methylene chloride	1.57E-11	5.53E-12	2.12E-11
SILO STRUCTURAL FAILURE			
Arsenic	1.35E-07	2.22E-07	3.57E-07
Beryllium	4.62E-09	7.63E-10	5.38E-09

TABLE D.II-35

NONCANCER HI: TRESPASSING CHILD WITH ACCESS CONTROLS
SURFACE WATER PATHWAYS, CURRENT LAND USE

Chemical	Ingestion of Surface Water	Dermal Exposure While Swimming	Risks Across Pathways
SILOS INTACT			
2-Butanone	9.08E-08	6.21E-08	1.53E-07
4-Methyl-2-pentanone	1.75E-08	6.43E-09	2.39E-08
Acetone	5.02E-07	1.72E-07	6.74E-07
Anthracene	1.62E-10	1.04E-07	1.04E-07
Antimony	2.79E-05	5.63E-05	8.42E-05
Benzoic acid	9.16E-10	6.12E-09	7.04E-09
Beryllium	1.23E-08	7.44E-08	8.67E-08
Bis(2-ethylhexyl) phthalate	4.78E-10	1.32E-07	1.33E-07
Cadmium (food)	1.04E-06	6.28E-06	7.32E-06
Cadmium (water)	2.07E-06	1.25E-05	1.46E-05
Chromium	2.55E-07	1.54E-06	1.80E-06
Di-n-butyl phthalate	5.97E-11	3.27E-08	3.27E-08
Fluoranthene	2.39E-10	5.44E-07	5.44E-07
Methylene chloride	7.17E-08	2.03E-07	2.75E-07
Nickel	2.23E-07	1.35E-06	1.58E-06
Phenol	5.58E-08	2.32E-07	2.88E-07
Pyrene	4.78E-10	4.08E-07	4.08E-07
Silver	1.04E-06	3.93E-07	1.43E-06
Thallium	3.32E-07	1.01E-07	4.32E-07
Toluene	3.98E-10	1.13E-08	1.17E-08
Uranium	5.84E-04	3.54E-03	4.12E-03
Total Xylenes	1.35E-11	8.85E-10	8.98E-10
SILO STRUCTURAL FAILURE			
Antimony	7.84E-07	1.73E-05	1.81E-05
Arsenic	7.48E-04	4.94E-03	5.69E-03
Barium	4.48E-08	2.96E-06	3.00E-06

TABLE D.II-35
(Continued)

Chemical	Ingestion of Surface Water	Dermal Exposure While Swimming	Risks Across Pathways
Beryllium	6.27E-08	4.14E-06	4.20E-06
Cadmium (food)	2.65E-06	1.75E-04	1.78E-04
Cadmium (water)	5.31E-06	3.50E-04	3.55E-04
Chromium	7.24E-07	4.78E-05	4.85E-05
Cobalt	1.25E-06	8.22E-05	8.35E-05
Manganese	2.93E-06	3.22E-04	3.25E-04
Mercury	3.22E-06	5.30E-04	5.33E-04
Nickel	4.71E-06	3.10E-04	3.15E-04
Selenium	8.69E-07	3.59E-06	4.46E-06
Silver	2.90E-07	1.91E-05	1.94E-05
Thallium	8.85E-06	2.92E-05	3.81E-05
Uranium	1.37E-02	9.02E-01	9.16E-01
Vanadium	6.89E-06	4.56E-04	4.63E-04
Zinc	1.57E-08	2.59E-07	2.75E-07

TABLE D.II-36

RADIOLOGICAL ILCR: CT ON-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion[a]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Pb-210 + 2 dtrs	4.5E-09	9.7E-09	2.3E-10	7.7E-10	1.6E-08
Ra-226 + 5 dtrs	1.6E-08	7.3E-09	1.7E-10	1.2E-09	2.4E-08
Ra-228 + 1 dtr	1.4E-09	2.3E-09	3.4E-11	2.4E-10	4.1E-09
Rn-222 + 4 dtrs	1.1E-05	b	b	b	1.1E-05
Sr-90 + 1 dtr	1.9E-10	9.1E-09	7.7E-10	1.5E-08	2.5E-08
Tc-99	1.3E-11	1.8E-09	3.1E-09	1.5E-08	2.0E-08
Th-228 + 7 dtrs[c]	2.2E-08	1.7E-10	5.3E-14	1.8E-13	2.2E-08
Th-230	2.8E-07	1.3E-09	6.0E-13	2.0E-12	2.8E-07
Th-232	1.0E-08	4.7E-11	2.2E-14	7.3E-14	1.0E-08
U-234	1.7E-07	1.3E-09	2.0E-11	2.4E-10	1.7E-07
U-238 + 2 dtrs	1.1E-06	8.0E-09	1.2E-10	1.4E-09	1.1E-06

TABLE D.II-36
(Continued)

	Ingestion, External Radiation, Root Uptake[d]					
Radionuclide	Ingestion of Soil	Penetrating External Radiation	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT						
Pb-210 + 2 dtrs	6.4E-07	2.6E-09	4.4E-06	2.6E-07	8.8E-07	6.4E-06
Ra-226 + 5 dtrs	1.7E-07	1.4E-04	2.0E-07	2.7E-08	1.9E-07	1.4E-04
Ra-228 + 1 dtr	2.8E-08	1.3E-05	3.1E-08	4.1E-09	3.0E-08	1.3E-05
Sr-90 + 1 dtr	1.2E-08	e	2.2E-06	2.2E-07	4.3E-06	6.8E-06
Tc-99	2.6E-10	2.0E-12	3.1E-07	5.3E-07	2.5E-06	3.4E-06
Th-230	1.3E-08	8.8E-10	8.4E-10	2.1E-11	6.8E-11	1.5E-08
Th-232	4.2E-09	1.4E-10	2.8E-10	6.7E-12	2.2E-11	4.6E-09
U-234	1.3E-08	3.8E-10	3.8E-08	1.2E-09	1.4E-08	6.7E-08
U-238 + 2 dtrs	8.3E-08	1.7E-06	2.6E-07	7.7E-09	9.2E-08	2.2E-06

[a] Contamination of foodstuff and forage due to deposition from air.
[b] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[c] Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d] Contamination of foodstuff and forage due to root uptake.
[e] Radionuclide is a beta-particle emitter and does not emit penetrating radiation.

TABLE D.II-37

CHEMICAL ILCR: CT ON-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Benzo(a)anthracene	3.24E-09	9.38E-14	2.21E-14	2.80E-14	3.24E-09
Benzo(a)pyrene	2.78E-09	1.48E-13	7.29E-14	9.22E-14	2.78E-09
Benzo(b)fluoranthene	4.38E-09	7.66E-14	2.00E-13	2.52E-13	4.39E-09
Beryllium	7.66E-09	4.88E-14	1.75E-15	6.30E-18	7.66E-09
Chromium	8.81E-07	0.00E+00	0.00E+00	0.00E+00	8.81E-07
Chrysene	2.94E-09	8.53E-14	2.01E-14	2.54E-14	2.94E-09
Dibenzo(a,h)anthracene	1.88E-09	4.30E-14	2.55E-14	3.23E-14	1.88E-09
Methylene chloride	3.09E-14	6.31E-16	4.81E-12	6.07E-12	3.15E-14
Nickel	2.85E-08	0.00E+00	0.00E+00	0.00E+00	2.85E-08

TABLE D.II-37
(Continued)

Chemical	Ingestion, Dermal Contact, Root Uptake					
	Dermal Contact with Soil	Ingestion of Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks from Across Pathways
SILOS INTACT						
Aroclor-1254	6.20E-09	3.20E-09	4.24E-07	3.57E-07	3.04E-07	1.09E-06
Benzo(a)anthracene	1.42E-06	4.19E-08	7.33E-06	1.17E-06	1.48E-06	1.14E-05
Benzo(a)pyrene	1.68E-06	4.97E-07	2.18E-05	8.38E-06	1.06E-05	4.29E-05
Benzo(b)fluoranthene	3.54E-07	5.23E-08	2.52E-06	3.76E-06	4.76E-06	1.14E-05
Beryllium	1.47E-07	5.04E-08	9.90E-07	6.30E-08	2.27E-10	1.25E-06
Bis(2-ethylhexyl) phthalate	1.18E-09	7.31E-11	1.91E-08	1.53E-09	1.93E-09	2.38E-08
Chrysene	1.32E-06	3.90E-08	6.81E-06	1.09E-06	1.38E-06	1.06E-05
Dibenzo(a,h)anthracene	9.80E-07	2.90E-08	3.10E-06	1.16E-06	1.47E-06	6.74E-06
Indeno(1,2,3-cd)pyrene	1.45E-07	4.29E-08	4.86E-07	8.95E-06	1.13E-05	2.09E-05
Methylene chloride	1.21E-11	2.07E-12	1.19E-07	8.50E-13	1.07E-12	1.19E-07

TABLE D.II-38

NONCANCER HI: CT ON-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, FUTURE LAND USE

Inhalation and Air Dispersion					
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
2-Butanone	1.25E-10	1.22E-11	9.48E-18	1.20E-17	1.37E-10
Beryllium	0.00E+00	1.76E-11	6.33E-13	2.28E-15	1.83E-11
Chromium	0.00E+00	4.51E-10	7.56E-11	8.25E-11	6.09E-10
Methylene chloride	1.75E-10	1.09E-11	8.31E-17	1.05E-16	1.85E-10
Nickel	0.00E+00	6.13E-10	7.52E-11	5.01E-11	7.39E-10
Toluene	1.71E-09	6.11E-13	1.30E-16	1.64E-16	1.71E-09

Ingestion, Dermal Contact, Root Uptake						
Chemical	Dermal Contact with Soil	Soil Ingestion	Ingestion of Vegetables/Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT						
2-Butanone	2.28E-07	1.41E-08	3.01E-03	2.21E-09	2.79E-09	3.02E-03
4-Methyl-2-pentanone	1.04E-07	6.46E-09	4.57E-04	2.26E-09	2.86E-09	4.57E-04
Acetone	1.03E-06	6.39E-08	2.66E-02	6.18E-09	7.79E-09	2.66E-02
Anthracene	1.34E-06	9.92E-08	8.05E-05	9.13E-07	1.16E-06	8.40E-05
Antimony	7.48E-03	7.71E-03	3.03E+00	1.93E-01	7.71E-02	3.32E+00
Benzoic acid	2.57E-08	1.59E-09	3.97E-05	1.18E-09	1.50E-09	3.98E-05
Beryllium	5.30E-05	1.82E-05	3.58E-04	2.28E-05	8.20E-08	4.52E-04

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TABLE D.II-38
(Continued)

Ingestion, Dermal Contact, Root Uptake						
Chemical	Dermal Contact with Soil	Soil Ingestion	Ingestion of Vegetables/Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Bis(2-ethylhexyl) phthalate	3.28E-05	2.03E-06	5.31E-04	4.26E-05	5.37E-05	6.62E-04
Cadmium (food)	1.68E-04	5.77E-04	8.90E-01	2.18E-02	1.59E-01	1.07E+00
Chromium	1.28E-03	4.40E-04	1.67E-02	2.27E-03	2.47E-03	2.31E-02
Di-n-butyl phthalate	3.50E-06	2.05E-07	6.09E-05	3.89E-06	4.92E-06	7.34E-05
Fluoranthene	3.86E-05	1.14E-06	2.86E-04	2.46E-05	3.12E-05	3.82E-04
Methylene chloride	2.08E-07	3.58E-08	2.05E-03	1.47E-08	1.85E-08	2.05E-03
Molybdenum	4.84E-05	1.27E-04	8.17E-02	2.37E-02	2.37E-02	1.29E-01
Nickel	4.82E-04	1.66E-04	7.76E-02	7.46E-03	4.98E-03	9.07E-02
Phenol	6.67E-07	4.13E-08	1.81E-03	2.05E-08	2.60E-08	1.81E-03
Pyrene	2.61E-05	1.61E-06	4.94E-04	3.01E-05	3.80E-05	5.90E-04
Silver	6.14E-04	2.11E-04	2.24E-01	3.17E-02	8.45E-01	1.10E+00
Thallium	8.37E-05	5.75E-04	3.73E-03	1.15E-02	2.30E-03	1.82E-02
Toluene	1.92E-09	4.41E-09	3.72E-05	7.32E-09	9.27E-09	3.72E-05
Zinc	2.03E-05	2.79E-05	2.11E-01	5.23E-01	2.09E-01	9.43E-01
Total Xylenes	1.41E-10	3.23E-10	1.71E-06	7.52E-10	0.00E+00	1.71E-06
Uranium	3.73E-03	1.28E-03	4.54E-02	2.72E-04	3.27E-03	5.39E-02

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TABLE D.II-39

RADIOLOGICAL ILCR: CT ON-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion[a]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Ac-227 + 7 dtrs	7.6E-05	4.3E-06	7.0E-09	2.2E-08	8.0E-05
Pa-231	4.6E-05	1.3E-06	1.0E-09	2.1E-09	4.8E-05
Pb-210 + 2 dtrs	2.7E-05	5.8E-05	1.4E-06	4.5E-06	9.2E-05
Ra-226 + 5 dtrs	1.6E-05	7.6E-06	1.8E-07	1.3E-06	2.5E-05
Ra-228 + 1 dtr	4.0E-07	6.2E-07	9.2E-09	6.6E-08	1.1E-06
Rn-222 + 4 dtrs	3.6E-04	b	b	b	3.6E-04
Sr-90 + 1 dtr	1.7E-10	8.3E-09	7.0E-10	1.4E-08	2.3E-08
Tc-99	1.2E-11	1.6E-09	2.7E-09	1.3E-08	1.8E-08
Th-228 + 7 dtrs	9.4E-05	1.1E-06	3.5E-10	1.2E-09	9.5E-05
Th-230	2.5E-03	1.1E-05	5.1E-09	1.7E-08	2.5E-03
Th-232	3.4E-05	1.8E-07	8.2E-11	2.7E-10	3.4E-05
U-234	7.0E-05	5.6E-07	8.4E-09	9.9E-08	7.1E-05
U-235 + 1 dtr	4.2E-06	3.4E-08	5.1E-10	6.1E-09	4.2E-06
U-238 + 2 dtrs	1.3E-04	9.3E-07	1.4E-08	1.6E-07	1.3E-04

TABLE D.II-39
(Continued)

	Ingestion, External Radiation, Root Uptake[d]					
Radionuclide	Soil Ingestion	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Penetrating External Exposure	Risks Across Pathways
SILO STRUCTURAL FAILURE						
Ac-227 + 7 dtrs	6.9E-05	1.9E-05	5.8E-07	1.8E-06	2.7E-03	2.8E-03
Pa-231	2.1E-05	4.1E-06	6.6E-08	1.3E-07	9.3E-05	1.2E-04
Pb-210 + 2 dtrs	7.5E-04	5.2E-03	3.1E-04	1.0E-03	3.0E-06	7.5E-03
Ra-226 + 5 dtrs	1.2E-04	1.4E-04	1.8E-05	1.3E-04	9.4E-02	9.4E-02
Ra-228 + 1 dtr	1.0E-05	1.1E-05	1.5E-06	1.1E-05	4.9E-03	4.9E-03
Th-228 + 7 dtrs	1.8E-05	1.1E-06	2.7E-08	9.5E-08	2.9E-02	2.9E-02
Th-230	1.8E-04	1.2E-05	3.0E-07	9.7E-07	1.3E-05	2.1E-04
Th-232	3.0E-06	2.0E-07	4.8E-09	1.6E-08	9.9E-08	3.3E-06
U-234	7.6E-06	2.3E-05	7.0E-07	8.4E-06	2.3E-07	4.0E-05
U-235 + 1 dtr	4.8E-07	1.4E-06	4.4E-08	5.3E-07	1.2E-04	1.2E-04
U-238 + 2 dtrs	1.2E-05	4.0E-05	1.2E-06	1.4E-05	2.5E-04	3.2E-04

[a]Contamination of foodstuff and forage due to deposition from air.

[b]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.

[c]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.

[a]Contamination of foodstuff and forage due to root uptake.

TABLE D.II-40

CHEMICAL ILCR: TYPICAL ON-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

Inhalation and Air Dispersion					
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Arsenic	3.71E-05	7.33E-11	6.48E-12	7.78E-13	3.71E-05
Benzo(a)anthracene	2.97E-09	8.62E-14	2.03E-14	2.57E-14	2.97E-09
Benzo(a)pyrene	2.54E-09	1.35E-13	6.67E-14	8.44E-14	2.54E-09
Benzo(b)fluoranthene	4.03E-09	7.05E-14	1.83E-13	2.32E-13	4.03E-09
Beryllium	1.97E-07	1.26E-12	4.51E-14	1.62E-16	1.97E-07
Cadmium	4.92E-07	0.00E+00	0.00E+00	0.00E+00	4.92E-07
Chromium	1.29E-05	0.00E+00	0.00E+00	0.00E+00	1.29E-05
Chrysene	2.68E-09	7.76E-14	1.83E-14	2.31E-14	2.68E-09
Dibenzo(a,h)anthracene	1.74E-09	3.96E-14	2.35E-14	2.98E-14	1.74E-09
Indeno(1,2,3-c,d)pyrene	3.03E-09	4.28E-14	1.50E-12	1.90E-12	3.03E-09
Methylene chloride	3.09E-14	6.31E-16	4.81E-21	6.07E-21	3.15E-14
Nickel	2.84E-06	0.00E+00	0.00E+00	0.00E+00	2.84E-06

Ingestion, Dermal Contact, Root Uptake						
Chemical	Dermal Contact with Soil	Ingestion of Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE						
Arsenic	2.23E-05	7.67E-05	6.03E-03	7.67E-04	9.20E-05	6.99E-03
Beryllium	5.04E-06	1.73E-06	3.41E-05	2.17E-06	7.80E-09	4.30E-05

TABLE D.II-41

NONCANCER HI: CT ON-PROPERTY RESIDENT FARMER
AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
2-Butanone	1.25E-10	1.22E-11	9.48E-18	1.20E-17	1.37E-10
Antimony	0.00E+00	3.41E-09	1.97E-10	7.89E-11	3.69E-09
Arsenic	0.00E+00	1.09E-06	9.61E-08	1.15E-08	1.19E-06
Barium	1.12E-02	6.61E-10	6.26E-12	5.84E-11	1.12E-02
Beryllium	0.00E+00	4.55E-10	1.63E-11	5.87E-14	4.71E-10
Cadmium	0.00E+00	7.80E-08	1.97E-09	1.43E-08	9.43E-08
Chromium	0.00E+00	6.62E-09	1.11E-09	1.21E-09	8.94E-09
Cobalt	5.82E+01	4.66E-09	3.18E-09	1.27E-09	5.82E+01
Manganese	2.85E-01	1.23E-08	2.57E-10	9.00E-10	2.85E-01
Mercury	4.89E-05	2.51E-09	3.30E-08	2.37E-10	4.89E-05
Methylene chloride	1.75E-10	1.09E-11	8.31E-17	1.05E-16	1.85E-10
Nickel	0.00E+00	6.11E-08	7.49E-09	4.99E-09	7.36E-08
Selenium	0.00E+00	7.19E-09	2.50E-09	2.67E-09	1.24E-08
Silver	0.00E+00	2.05E-09	2.95E-10	7.86E-09	1.02E-08
Thallium	0.00E+00	6.51E-08	8.78E-08	1.76E-08	1.70E-07
Toluene	1.71E-09	6.11E-13	1.30E-16	1.64E-16	1.71E-09
Vanadium	0.00E+00	3.91E-08	3.03E-09	0.00E+00	4.21E-08

TABLE D.II-41
(Continued)

Inhalation and Air Dispersion					
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Zinc	0.00E+00	9.55E-09	2.51E-08	0.00E+00	3.47E-08

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Silo Contents	Dermal Contact with Silo Contents	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE						
Antimony	1.48E-03	1.44E-03	5.82E-01	3.70E-02	1.48E-02	6.37E-01
Arsenic	1.14E+00	3.30E-01	8.93E+01	1.14E+01	1.36E+00	1.03E+02
Beryllium	6.27E-04	1.82E-03	1.23E-02	7.84E-04	2.82E-06	1.56E-02
Cadmium (food)	1.01E-02	2.95E-03	1.56E+01	3.83E-01	2.79E+00	1.88E+01
Chromium	8.49E-03	2.47E-02	3.22E-01	4.38E-02	4.78E-02	4.47E-01
Nickel	2.31E-02	6.71E-02	1.08E+01	1.04E+00	6.92E-01	1.26E+01
Silver	3.97E-04	1.15E-03	4.21E-01	5.95E-02	1.59E+00	2.07E+00
Thallium	1.01E-01	1.46E-02	6.54E-01	2.01E+00	4.03E-01	3.19E+00
Zinc	2.88E-04	2.09E-04	2.18E+00	5.39E+00	2.16E+00	9.73E+00
Barium	3.97E-04	1.16E-03	9.67E-02	1.12E-03	1.04E-02	1.10E-01
Cobalt	5.15E-03	1.50E-02	3.44E-01	2.57E-01	1.03E-01	7.24E-01
Manganese	3.97E-03	1.92E-02	2.29E+00	4.96E-02	1.74E-01	2.54E+00
Mercury	2.48E-04	1.80E-03	5.48E-01	6.96E+00	5.01E-02	7.56E+00

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TABLE D.II-41
(Continued)

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Silo Contents	Dermal Contact with Silo Contents	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Selenium	4.94E-03	8.98E-04	9.63E-01	2.32E-01	2.47E-01	1.45E+00
Vanadium	5.36E-02	1.56E-01	1.38E+00	9.22E-02	2.95E-03	1.69E+00
Uranium	1.92E-01	5.57E-01	6.78E+00	4.07E-02	4.88E-01	8.06E+00

TABLE D.II-42

RADIOLOGICAL ILCR: CT ON-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS, FUTURE LAND USE

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE[a]					
U-234	1.4E-06	4.8E-07	3.6E-09	4.6E-08	2.0E-06
U-235 + 1 dtr	1.2E-07	4.1E-08	3.1E-10	3.9E-09	1.7E-07
U-238 + 2 dtr	2.2E-06	7.7E-07	5.7E-09	7.0E-08	3.0E-06

[a] The groundwater concentrations used to calculate these ILCRs were from the sum of the impacts of Silos 1. 2. amd 3. as shown in Table D.3-8.

TABLE D.II-43

NONCANCER HI: TYPICAL ON-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS, FUTURE LAND USE

Chemical	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Dermal Contact While Bathing	Inhalation of VOCs from Home Water Use	Risks Across Pathways
SILO STRUCTURAL FAILURE							
Uranium	3.44E-01	1.00E-01	8.99E-04	1.11E-02	1.67E-03	0.00E+00	4.58E-01

TABLE D.II-44

RADIOLOGICAL ILCR: RME ON-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion[a]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Pb-210 + 2 dtrs	6.0E-08	1.6E-07	3.4E-09	1.1E-08	2.2E-07
Ra-226 + 5 dtrs	2.1E-07	1.2E-07	2.6E-09	1.8E-08	3.5E-07
Ra-228 + 1 dtr	1.9E-08	3.6E-08	5.0E-10	3.6E-09	5.8E-08
Rn-222 + 4 dtrs	1.4E-04	b	b	b	1.4E-04
Sr-90 + 1 dtr	2.5E-09	1.4E-07	1.1E-08	2.3E-07	3.9E-07
Tc-99	1.7E-10	2.9E-08	4.7E-08	2.2E-07	2.9E-07
Th-228 + 7 dtrs[c]	3.0E-07	2.6E-09	7.9E-13	2.7E-12	3.0E-07
Th-230	3.7E-06	2.1E-08	9.0E-12	3.0E-11	3.7E-06
Th-232	1.4E-07	7.7E-10	3.3E-13	1.1E-12	1.4E-07
U-234	2.3E-06	2.1E-08	3.0E-10	3.6E-09	2.3E-06
U-238 + 2 dtrs	1.5E-05	1.3E-07	1.7E-09	2.1E-08	1.5E-05

TABLE D.II-44
(Continued)

	Ingestion, External Radiation, Root Uptake[d]					
Radionuclide	Ingestion of Soil	Penetrating External Radiation	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT						
Pb-210 + 2 dtrs	3.2E-05	2.6E-08	7.2E-05	4.0E-06	1.3E-05	1.2E-04
Ra-226 + 5 dtrs	8.4E-06	1.4E-03	3.1E-06	4.0E-07	2.9E-06	1.4E-03
Ra-228 + 1 dtr	1.3E-06	1.3E-04	4.8E-07	6.1E-08	4.4E-07	1.3E-04
Sr-90 +1 dtr	5.3E-07	[e]	3.5E-05	3.3E-06	6.4E-05	1.0E-04
Tc-99	1.3E-08	2.1E-11	4.8E-06	8.0E-06	3.7E-05	5.0E-05
Th-230	6.2E-07	8.8E-09	1.3E-08	3.1E-10	1.0E-09	6.4E-07
Th-232	2.0E-07	1.5E-09	4.2E-09	1.0E-10	3.4E-10	2.1E-07
U-234	6.2E-07	3.8E-09	6.1E-07	1.7E-08	2.1E-07	1.5E-06
U-238 + 2 dtrs	4.03-06	1.8E-05	4.0E-06	1.1E-07	1.3E-06	2.7E-05

[a] Contamination of foodstuff and forage due to deposition from air.
[b] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[c] Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d] Contamination of foodstuff and forage due to root uptake.
[e] Radionuclide is a beta-particle emitter and does not emit penetrating radiation.

TABLE D.II-45

CHEMICAL ILCR: RME ON-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, FUTURE LAND USE

Inhalation and Air Dispersion

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Benzo(a)anthracene	4.35E-08	1.45E-12	3.29E-13	4.16E-13	4.35E-08
Benzo(a)pyrene	3.74E-08	2.28E-12	1.08E-12	1.37E-12	3.74E-08
Benzo(b)fluoranthene	5.89E-08	1.19E-12	2.96E-12	3.75E-12	5.89E-08
Beryllium	1.03E-07	7.55E-13	2.60E-14	9.35E-17	1.03E-07
Chromium	1.18E-05	0.00E+00	0.00E+00	0.00E+00	1.18E-05
Chrysene	3.95E-08	1.32E-12	2.99E-13	3.78E-13	3.95E-08
Dibenzo(a,h)anthracene	2.53E-08	6.65E-13	3.79E-13	4.80E-13	2.53E-08
Methylene chloride	4.15E-13	9.77E-15	7.14E-20	9.01E-20	4.25E-13
Nickel	3.83E-07	0.00E+00	0.00E+00	0.00E+00	3.83E-07

Ingestion, Dermal Contact, Root Uptake

Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT						
Aroclor-1254	1.52E-06	2.11E-06	6.56E-06	5.30E-06	4.52E-06	2.00E-05
Benzo(a)anthracene	1.99E-05	4.83E-04	1.13E-04	1.74E-05	2.20E-05	6.55E-04
Benzo(a)pyrene	2.37E-05	5.72E-04	3.38E-04	1.24E-04	1.57E-04	1.21E-03

TABLE D.II-45
(Continued)

	Ingestion, Dermal Contact, Root Uptake					
Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Benzo(b)fluoranthene	2.49E-05	1.20E-04	3.90E-05	5.59E-05	7.07E-05	3.11E-04
Beryllium	2.39E-05	4.99E-05	1.53E-05	9.35E-07	3.37E-09	9.00E-05
Bis(2-ethylhexyl) phthalate	3.47E-08	4.02E-07	2.96E-07	2.28E-08	2.87E-08	7.84E-07
Chrysene	1.85E-05	4.49E-04	1.06E-04	1.62E-05	2.05E-05	6.10E-04
Dibenzo(a,h)anthracene	1.38E-05	3.33E-04	4.79E-05	1.72E-05	2.18E-05	4.34E-04
Indeno(1,2,3-cd)pyrene	2.04E-05	4.94E-05	7.52E-06	1.33E-04	1.68E-04	3.78E-04
Methylene chloride	9.85E-10	4.10E-09	1.84E-06	1.26E-11	1.59E-11	1.84E-06

TABLE D.II-46

NONCANCER HI: RME ON-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, FUTURE LAND USE

Inhalation and Air Dispersion					
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
2-Butanone	2.16E-10	2.43E-11	1.81E-17	2.29E-17	2.40E-10
Beryllium	0.00E+00	3.51E-11	1.21E-12	4.35E-15	3.63E-11
Cadmium (food)	0.00E+00	1.15E-08	2.78E-10	2.02E-09	1.38E-08
Chromium	0.00E+00	8.99E-10	1.44E-10	1.57E-10	1.20E-09
Methylene chloride	3.01E-10	2.17E-11	1.59E-16	2.00E-16	3.23E-10
Nickel	0.00E+00	1.22E-09	1.44E-10	9.57E-11	1.46E-09
Toluene	2.95E-09	1.22E-12	2.47E-16	3.13E-16	2.95E-09

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT						
2-Butanone	1.96E-07	9.97E-06	6.00E-03	4.22E-09	5.33E-09	6.01E-03
4-Methyl-2-pentanone	8.96E-08	4.57E-06	9.10E-04	4.32E-09	5.47E-09	9.15E-04
Acetone	8.87E-07	4.52E-05	5.29E-02	1.18E-08	1.49E-08	5.30E-02
Anthracene	1.38E-06	5.87E-05	1.60E-04	1.74E-06	2.21E-06	2.24E-04
Antimony	1.07E-01	3.27E-01	6.03E+00	3.68E-01	1.47E-01	6.98E+00

TABLE D.II-46
(Continued)

Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
	Ingestion, Dermal Contact, Root Uptake					
Benzoic acid	2.20E-08	1.12E-06	7.91E-05	2.26E-09	2.87E-09	8.03E-05
Beryllium	2.53E-04	2.32E-03	7.13E-04	4.35E-05	1.57E-07	3.33E-03
Bis(2-ethylhexyl) phthalate	2.82E-05	1.44E-03	1.06E-03	8.13E-05	1.03E-04	2.70E-03
Cadmium (food)	8.00E-03	7.34E-03	1.77E+00	4.16E-02	3.03E-01	2.13E+00
Chromium	6.10E-03	5.60E-02	3.32E-02	4.33E-03	4.72E-03	1.04E-01
Di-n-butyl phthalate	2.84E-06	1.53E-04	1.21E-04	7.42E-06	9.40E-06	2.94E-04
Fluoranthene	1.58E-05	1.69E-03	5.70E-04	4.70E-05	5.96E-05	2.38E-03
Methylene chloride	4.97E-07	9.12E-06	4.08E-03	2.81E-08	3.54E-08	4.09E-03
Molybdenum	1.76E-03	2.12E-03	1.63E-01	4.53E-02	4.53E-02	2.57E-01
Nickel	2.30E-03	2.11E-02	1.55E-01	1.42E-02	9.50E-03	2.02E-01
Phenol	5.72E-07	2.92E-05	3.60E-03	3.92E-08	4.96E-08	3.63E-03
Pyrene	2.24E-05	1.14E-03	9.84E-04	5.75E-05	7.26E-05	2.28E-03
Silver	2.93E-03	2.69E-02	4.46E-01	6.05E-02	1.61E+00	2.15E+00
Thallium	7.98E-03	3.66E-03	7.43E-03	2.20E-02	4.39E-03	4.54E-02
Toluene	6.12E-08	8.42E-08	7.40E-05	1.40E-08	1.77E-08	7.41E-05
Zinc	3.87E-04	8.87E-04	4.21E-01	9.98E-01	3.99E-01	1.82E+00
Total Xylenes	4.48E-09	6.17E-09	0.00E+00	1.44E-09	0.00E+00	1.21E-08
Uranium	1.78E-02	1.63E-01	9.03E-02	5.20E-04	6.24E-03	2.78E-01

TABLE D.II-47

RADIOLOGICAL ILCR: ON-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion[a]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruit	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Ac-227 + 7 dtrs	1.0E-03	6.6E-05	1.0E-07	3.4E-07	1.1E-03
Pa-231	6.3E-04	2.1E-05	1.5E-08	3.0E-08	6.5E-04
Pb-210 + 2 dtrs	3.5E-04	9.2E-04	2.0E-05	6.7E-05	1.3E-03
Ra-226 + 5 dtrs	2.2E-04	1.2E-04	2.6E-06	1.9E-05	3.6E-04
Ra-228 + 1 dtr	5.3E-06	9.9E-06	1.4E-07	9.9E-07	1.6E-05
Rn-222 + 4 dtrs	4.8E-03	b	b	b	4.8E-03
Sr-90 + 1 dtr	2.3E-09	1.3E-07	1.0E-08	2.1E-07	3.5E-07
Tc-99	1.5E-10	2.6E-08	4.2E-08	1.9E-07	2.6E-07
Th-228 + 7 dtrs	1.3E-03	1.7E-05	5.3E-09	1.8E-08	1.3E-03
Th-230	3.3E-02	1.7E-04	7.5E-08	2.5E-07	3.3E-02
Th-232	4.5E-04	2.9E-06	1.2E-09	4.0E-09	4.5E-04
U-234	9.6E-04	8.7E-06	1.2E-07	1.5E-06	9.6E-04
U-235 + 1 dtr	5.5E-05	5.3E-07	7.6E-09	9.1E-08	5.5E-05
U-238 + 2 dtrs	1.7E-03	1.5E-05	2.0E-07	2.4E-06	1.8E-03

TABLE D.II-47
(Continued)

	Ingestion, External Radiation, Root Uptake[d]					
Radionuclide	Soil Ingestion	Ingestion of Vegetables/ Fruit	Ingestion of Meat	Ingestion of Milk	Penetrating External Radiation	Risks Across Pathways
SILO STRUCTURAL FAILURE						
Ac-227 + 7 dtrs	3.2E-03	2.8E-04	8.7E-06	2.8E-05	2.8E-02	3.1E-02
Pa-231	1.0E-03	6.4E-05	1.0E-06	2.0E-06	1.0E-03	2.1E-03
Pb-210 + 2 dtrs	3.7E-02	8.5E-02	4.7E-03	1.6E-02	3.1E-05	1.4E-01
Ra-226 + 5 dtrs	5.3E-03	2.1E-03	2.7E-04	2.0E-03	9.8E-01	9.8E-01
Ra-228 + 1 dtr	4.8E-04	1.8E-04	2.3E-05	1.6E-04	4.9E-02	4.9E-02
Th-228 + 7 dtrs	8.8E-04	1.7E-05	4.2E-07	1.4E-06	3.0E-01	3.0E-01
Th-230	8.8E-03	1.9E-04	4.4E-06	1.5E-05	1.3E-04	9.1E-03
Th-232	1.4E-04	3.0E-06	7.1E-08	2.4E-07	1.1E-06	1.4E-04
U-234	3.6E-04	3.6E-04	1.0E-05	1.2E-04	2.3E-06	8.7E-04
U-235 + 1 dtr	2.3E-05	2.3E-05	6.5E-07	7.8E-06	1.2E-03	1.2E-03
U-238 + 2 dtrs	6.2E-04	5.9E-04	1.7E-05	2.0E-04	2.7E-03	4.1E-03

[a] Contamination of foodstuff and forage due to deposition from air.
[b] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[c] Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d] Contamination of foodstuff and forage due to root uptake.

TABLE D.II-48

CHEMICAL ILCR: RME ON-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Arsenic	4.99E-04	1.13E-09	9.63E-11	1.16E-11	4.99E-04
Benzo(a)anthracene	3.99E-08	1.33E-12	3.02E-13	3.82E-13	3.99E-08
Benzo(a)pyrene	3.42E-08	2.09E-12	9.93E-13	1.25E-12	3.42E-08
Benzo(b)fluoranthene	5.42E-08	1.09E-12	2.72E-12	3.45E-12	5.42E-08
Beryllium	2.65E-06	1.95E-11	6.69E-13	2.41E-15	2.65E-06
Cadmium	6.61E-06	0.00E+00	0.00E+00	0.00E+00	6.61E-06
Chromium	1.74E-04	0.00E+00	0.00E+00	0.00E+00	1.74E-04
Chrysene	3.60E-08	1.20E-12	2.72E-13	3.44E-13	3.60E-08
Dibenzo(a,h)anthracene	2.33E-08	6.13E-13	3.49E-13	4.42E-13	2.33E-08
Indeno(1,2,3-c,d)pyrene	4.07E-08	6.63E-13	2.23E-11	2.82E-11	4.08E-08
Methylene chloride	4.15E-13	9.77E-15	7.14E-20	9.01E-20	4.25E-13
Nickel	3.81E-05	0.00E+00	0.00E+00	0.00E+00	3.81E-05

TABLE D.II-48
(Continued)

Chemical	Ingestion of Silo Contents	Dermal Contact with Silo Contents	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
	Ingestion, Dermal Contact, Root Uptake					
SILO STRUCTURAL FAILURE						
Arsenic	8.27E-03	7.59E-03	9.33E-02	1.14E-02	1.37E-03	1.22E-01
Beryllium	1.87E-04	1.72E-03	5.28E-04	3.22E-05	1.16E-07	2.46E-03

TABLE D.II-49

NONCANCER HI: RME ON-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
2-Butanone	2.16E-10	2.43E-11	1.81E-17	2.29E-17	2.40E-10
Antimony	0.00E+00	6.79E-09	3.77E-10	1.51E-10	7.32E-09
Arsenic	0.00E+00	2.16E-06	1.83E-07	2.20E-08	2.37E-06
Barium	1.94E-02	1.32E-09	1.19E-11	1.11E-10	1.94E-02
Beryllium	0.00E+00	9.05E-10	3.11E-11	1.12E-13	9.36E-10
Cadmium	0.00E+00	1.55E-07	3.76E-09	2.73E-08	1.86E-07
Chromium	0.00E+00	1.32E-08	2.12E-09	2.31E-09	1.76E-08
Cobalt	1.00E+02	9.27E-09	6.07E-09	2.43E-09	1.00E+02
Manganese	4.93E-01	2.45E-08	4.91E-10	1.72E-09	4.93E-01
Mercury	8.44E-05	5.00E-09	6.29E-08	4.53E-10	8.45E-05
Methylene chloride	3.01E-10	2.17E-11	1.59E-16	2.00E-16	3.23E-10
Nickel	0.00E+00	1.22E-07	1.43E-08	9.53E-09	1.45E-07
Selenium	0.00E+00	1.43E-08	4.78E-09	5.09E-09	2.42E-08
Silver	0.00E+00	4.09E-09	5.62E-10	1.50E-08	1.96E-08
Thallium	0.00E+00	1.30E-07	1.68E-07	3.35E-08	3.31E-07
Toluene	2.95E-09	1.22E-12	2.47E-16	3.13E-16	2.95E-09
Vanadium	0.00E+00	7.78E-08	5.79E-09	0.00E+00	8.36E-08

TABLE D.II-49
(Continued)

Inhalation and Air Dispersion					
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Zinc	0.00E+00	1.90E-08	4.80E-08	0.00E+00	6.70E-08

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Silo Contents	Dermal Contact with Silo Contents	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE						
Antimony	2.05E-02	6.28E-02	1.16E+00	7.06E-02	2.83E-02	1.34E+00
Arsenic	1.58E+01	1.45E+01	1.78E+02	2.17E+01	2.60E+00	2.32E+02
Beryllium	8.70E-03	7.98E-02	2.45E-02	1.50E-03	5.39E-06	1.15E-01
Cadmium (food)	1.40E-01	1.29E-01	3.11E+01	7.31E-01	5.32E+00	3.75E+01
Chromium	1.18E-01	1.08E+00	6.41E-01	8.36E-02	9.12E-02	2.01E+00
Nickel	3.20E-01	2.94E+00	2.15E+01	1.98E+00	1.32E+00	2.81E+01
Silver	5.50E-03	5.05E-02	8.38E-01	1.14E-01	3.03E+00	4.04E+00
Thallium	1.40E+00	6.41E-01	1.30E+00	3.85E+00	7.69E-01	7.95E+00
Zinc	3.99E-03	9.15E-03	4.34E+00	1.03E+01	4.12E+00	1.88E+01
Barium	5.51E-03	5.06E-02	1.92E-01	2.13E-03	1.99E-02	2.71E-01
Cobalt	7.14E-02	6.55E-01	6.84E-01	4.92E-01	1.97E-01	2.10E+00
Manganese	5.51E-02	8.42E-01	4.56E+00	9.47E-02	3.32E-01	5.88E+00
Mercury	3.43E-03	7.88E-02	1.09E+00	1.33E+01	9.57E-02	1.46E+01
Selenium	6.85E-02	3.93E-02	1.92E+00	4.42E-01	4.71E-01	2.94E+00

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TABLE D.II-49
(Continued)

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Silo Contents	Dermal Contact with Silo Contents	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Vanadium	7.44E-01	6.83E+00	2.75E+00	1.76E-01	5.63E-03	1.05E+01
Uranium	2.66E+00	2.44E+01	1.35E+01	7.77E-02	9.32E-01	4.15E+01

TABLE D.II-50

RADIOLOGICAL ILCR: RME ON-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS, FUTURE LAND USE

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
AQUIFER[a]					
U-234	2.0E-05	7.6E-06	5.4E-08	6.6E-07	2.8E-05
U-235 + 1 dtr	1.7E-06	6.6E-07	4.6E-09	5.7E-08	2.4E-06
U-238 + 2 dtrs	3.2E-05	1.2E-05	8.4E-08	1.0E-06	4.3E-05
PERCHED WATER					
Ac-227 + 7 dtrs	4.8E-04				
Pa-231	2.7E-04				
Pb-210 + 2 dtrs	9.0E-01				
Ra-226 + 5 dtrs	1.7E-03				
Ra-228 + 1 dtr	1.5E-04				
Th-228 + 7 dtrs[b]	7.4E-05				
Th-232	1.6E-15				
U-234	7.9E-06				
U-235 + 1 dtr	3.5E-07				
U-238 + 2 dtrs	1.3E-05				

[a]The groundwater concentrations used to calculate these ILCRs were from the sum of the impacts of Silos 1, 2, and 3, as shown in Table D.3-8.
[b]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.

TABLE D.II-51

CHEMICAL ILCR: RME ON-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS, FUTURE LAND USE

Chemical	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Dermal Exposure While Bathing	Inhalation of VOCs from Home Water Use	Risks Across Pathways
PERCHED WATER							
Arsenic	1.26E-02	4.33E-03	6.09E-04	7.42E-05	6.32E-06	0.00E+00	1.77E-02
Beryllium	7.96E-07	2.46E-07	1.13E-08	4.17E-11	3.98E-09	0.00E+00	1.05E-06

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TABLE D.II-52

NONCANCER HI: RME ON-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS, FUTURE LAND USE

Chemical	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Dermal Exposure While Bathing	Inhalation of VOCs from Home Water Use	Risks Across Pathways
AQUIFER							
Uranium	6.26E-01	1.99E-01	1.72E-03	2.12E-02	3.12E-03	0.00E+00	8.51E-01
PERCHED WATER							
Antimony	3.64E-02	1.88E-02	2.80E-03	1.12E-03	6.07E-05	0.00E+00	5.92E-02
Arsenic	2.41E+01	8.24E+00	1.16E+00	1.41E-01	1.20E-02	0.00E+00	3.36E+01
Barium	5.11E-06	2.21E-06	4.62E-08	4.34E-07	2.56E-08	0.00E+00	7.83E-06
Beryllium	3.70E-05	1.14E-05	5.25E-07	1.94E-09	1.85E-07	0.00E+00	4.91E-05
Boron	6.12E-04	6.12E-03	6.50E-04	4.88E-03	3.06E-06	0.00E+00	1.23E-02
Cadmium (water)	1.95E+00	2.25E+00	2.06E-01	1.50E+00	9.74E-03	0.00E+00	5.92E+00
Chromium	9.76E-06	3.12E-06	7.18E-07	8.05E-07	4.88E-08	0.00E+00	1.45E-05
Cobalt	1.68E-01	5.63E-02	5.87E-02	2.40E-02	8.40E-04	0.00E+00	3.08E-01
Manganese	1.69E-05	1.05E-05	6.31E-07	2.22E-06	1.41E-07	0.00E+00	3.04E-05
Mercury	1.54E-03	2.35E-03	1.18E-01	8.50E-04	1.92E-05	0.00E+00	1.23E-01
Molybdenum	2.06E-03	1.35E-03	1.15E-03	1.15E-03	1.35E-06	0.00E+00	5.71E-03
Nickel	2.53E-02	1.41E-02	4.65E-03	3.14E-03	1.26E-04	0.00E+00	4.73E-02
Selenium	3.62E-01	1.47E-01	1.04E-01	1.13E-01	1.13E-04	0.00E+00	7.26E-01
Silver	2.12E-03	1.88E-03	9.07E-04	2.43E-02	1.06E-05	0.00E+00	2.92E-02
Thallium	3.19E+00	9.62E-01	1.56E+00	3.21E-01	7.97E-04	0.00E+00	6.03E+00
Uranium	2.60E-01	8.27E-02	7.13E-04	8.79E-03	1.30E-03	0.00E+00	3.54E-01

TABLE D.II-52
(Continued)

Chemical	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Dermal Exposure While Bathing	Inhalation of VOCs from Home Water Use	Risks Across Pathways
Vanadium	1.69E+00	5.28E-01	5.37E-02	1.77E-03	8.44E-03	0.00E+00	2.28E+00
Zinc	5.65E-05	2.55E-04	2.85E-03	1.14E-03	7.05E-08	0.00E+00	4.31E-03

TABLE D.II-53

RADIOLOGICAL ILCR: ON-PROPERTY RESIDENT CHILD SOIL/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion[a]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Pb-210 + 2 dtrs	1.8E-09	1.1E-08	1.1E-10	2.9E-09	1.6E-08
Ra-226 + 5 dtrs	6.1E-09	8.5E-09	8.5E-11	4.7E-09	2.0E-08
Ra-228 + 1 dtr	5.8E-10	2.4E-09	1.7E-11	9.4E-10	4.1E-09
Rn-222 + 4 dtrs	4.3E-06	b	b	b	4.3E-06
Sr-90 + 1 dtr	7.7E-11	9.8E-09	3.9E-10	6.0E-08	7.0E-08
Tc-99	5.2E-12	2.0E-09	1.5E-09	5.6E-08	5.9E-08
Th-228 + 7 dtrs[c]	8.9E-09	1.8E-10	2.6E-14	6.9E-13	9.2E-09
Th-230	1.1E-07	1.5E-09	3.0E-13	7.7E-12	1.1E-07
Th-232	4.2E-09	5.6E-11	1.1E-14	2.8E-13	4.3E-09
U-234	6.8E-08	1.5E-09	9.8E-12	9.0E-10	7.1E-08
U-238 + 2 dtrs	4.5E-07	9.0E-09	5.8E-11	5.3E-09	4.8E-07

TABLE D.II-53
(Continued)

	Ingestion, External Radiation, Root Uptake[d]					
Radionuclide	Ingestion of Soil	Penetrating External Radiation	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT						
Pb-210 + 2 dtrs	1.1E-06	2.0E-09	5.2E-06	1.3E-07	3.4E-06	9.6E-06
Ra-226 + 5 dtrs	2.9E-07	1.1E-04	2.2E-07	1.3E-08	7.4E-07	1.1E-04
Ra-228 + 1 dtr	4.6E-08	9.9E-06	3.4E-08	2.0E-09	1.1E-07	1.0E-05
Sr-90 + dtr	2.0E-08	[e]	2.5E-06	1.1E-07	1.7E-05	1.9E-05
Tc-99	4.5E-10	1.6E-12	3.4E-07	2.6E-07	9.8E-06	9.8E-06
Th-230	2.2E-08	6.8E-10	9.6E-10	1.0E-11	2.7E-10	2.4E-08
Th-232	7.0E-09	1.1E-10	3.1E-10	3.4E-12	8.7E-11	7.6E-09
U-234	2.1E-08	3.0E-10	4.5E-08	5.8E-10	5.4E-08	1.2E-07
U-238 + 2 dtrs	1.4E-07	1.3E-06	2.9E-07	3.8E-09	3.5E-07	2.2E-06

[a]Contamination of foodstuff and forage due to deposition from air.
[b]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[c]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d]Contamination of foodstuff and forage due to root uptake.
[e]Radionuclide is a beta-emitter and does not emit penetrating radiation.

TABLE D.II-54

CHEMICAL ILCR: ON-PROPERTY RESIDENT CHILD
SOIL/AIR PATHWAYS, FUTURE LAND USE

Inhalation and Air Dispersion					
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Benzo(a)anthracene	6.10E-09	4.84E-13	5.08E-14	4.99E-13	6.10E-09
Benzo(a)pyrene	5.25E-09	7.60E-13	1.67E-13	1.65E-12	5.25E-09
Benzo(b)fluoranthene	8.27E-09	3.95E-13	4.58E-13	4.50E-12	8.27E-09
Beryllium	1.44E-08	2.51E-13	4.02E-15	1.12E-16	1.44E-08
Chromium	1.66E-06	0.00E+00	0.00E+00	0.00E+00	1.66E-06
Chrysene	5.55E-09	4.40E-13	4.62E-14	4.53E-13	5.55E-09
Dibenzo(a,h)anthracene	3.55E-09	2.21E-13	5.86E-14	5.76E-13	3.55E-09
Methylene chloride	5.82E-14	3.25E-15	1.10E-20	1.08E-19	6.15E-14
Nickel	5.37E-08	0.00E+00	0.00E+00	0.00E+00	5.37E-08

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks from Ingestion and Dermal Contact Pathways
SILOS INTACT						
Aroclor-1254	2.53E-07	3.04E-07	2.18E-06	8.19E-07	5.42E-06	8.98E-06
Benzo(a)anthracene	3.32E-06	6.95E-05	3.77E-05	2.70E-06	2.65E-05	1.40E-04
Benzo(a)pyrene	3.94E-06	8.24E-05	1.13E-04	1.92E-05	1.89E-04	4.07E-04

TABLE D.II-54
(Continued)

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks from Ingestion and Dermal Contact Pathways
Benzo(b)fluoranthene	4.14E-06	1.73E-05	1.30E-05	8.64E-06	8.48E-05	1.28E-04
Beryllium	3.99E-06	7.18E-06	5.10E-06	1.45E-07	4.04E-09	1.64E-05
Bis(2-ethylhexyl) phthalate	5.79E-09	5.79E-08	9.84E-08	3.52E-09	3.45E-08	2.00E-07
Chrysene	3.09E-06	6.46E-05	3.51E-05	2.51E-06	2.46E-05	1.30E-04
Dibenzo(a,h)anthracene	2.29E-06	4.80E-05	1.60E-05	2.67E-06	2.62E-05	9.51E-05
Indeno(1,2,3-cd)pyrene	3.40E-06	7.12E-06	2.50E-06	2.05E-05	2.01E-04	2.35E-04
Methylene chloride	1.64E-10	5.91E-10	6.12E-07	1.95E-12	1.91E-11	6.12E-07

TABLE D.II-55

NONCANCER HI: ON-PROPERTY RESIDENT CHILD
SOIL/AIR PATHWAYS, FUTURE LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
2-Butanone	3.54E-10	9.43E-11	3.27E-17	3.20E-16	4.48E-10
Beryllium	0.00E+00	1.36E-10	2.18E-12	6.09E-14	1.39E-10
Chromium	0.00E+00	3.49E-09	2.60E-10	2.20E-09	5.95E-09
Methylene chloride	4.94E-10	8.43E-11	2.86E-16	2.80E-15	5.78E-10
Nickel	0.00E+00	4.74E-09	2.59E-10	1.34E-09	6.34E-09
Toluene	4.82E-09	4.72E-12	4.46E-16	4.38E-15	4.83E-09

Ingestion, Dermal Contact, Root Uptake

Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT						
2-Butanone	1.68E-06	1.68E-05	2.33E-02	7.61E-09	7.46E-08	2.33E-02
4-Methyl-2-pentanone	7.67E-07	7.67E-06	3.53E-03	7.80E-09	7.66E-08	3.54E-03
Acetone	7.60E-06	7.60E-05	2.05E-01	2.13E-08	2.08E-07	2.06E-01
Anthracene	1.18E-05	9.87E-05	6.22E-04	3.15E-06	3.09E-05	7.66E-04
Antimony	9.16E-01	5.50E-01	2.34E+01	6.64E-01	2.06E+00	2.76E+01
Benzoic acid	1.89E-07	1.89E-06	3.07E-04	4.08E-09	4.01E-08	3.09E-04
Beryllium	2.16E-03	3.90E-03	2.77E-03	7.85E-05	2.19E-06	8.91E-03

TABLE D.II-55
(Continued)

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Soil	Dermal Contact with Soil	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Bis(2-ethylhexyl) phthalate	2.41E-04	2.41E-03	4.10E-03	1.47E-04	1.44E-03	8.34E-03
Cadmium (food)	6.85E-02	1.23E-02	6.88E+00	7.51E-02	4.24E+00	1.13E+01
Chromium	5.22E-02	9.40E-02	1.29E-01	7.81E-03	6.61E-02	3.49E-01
Di-n-butyl phthalate	2.43E-05	2.57E-04	4.71E-04	1.34E-05	1.32E-04	8.97E-04
Fluoranthene	1.35E-04	2.83E-03	2.21E-03	8.49E-05	8.34E-04	6.10E-03
Methylene chloride	4.26E-06	1.53E-05	1.59E-02	5.06E-08	4.96E-07	1.59E-02
Molybdenum	1.50E-02	3.56E-03	6.32E-01	8.17E-02	6.34E-01	1.37E+00
Nickel	1.97E-02	3.55E-02	6.00E-01	2.57E-02	1.33E-01	8.14E-01
Phenol	4.90E-06	4.90E-05	1.40E-02	7.07E-08	6.94E-07	1.40E-02
Pyrene	1.92E-04	1.92E-03	3.82E-03	1.04E-04	1.02E-03	7.05E-03
Silver	2.51E-02	4.52E-02	1.73E+00	1.09E-01	2.26E+01	2.45E+01
Thallium	6.84E-02	6.15E-03	2.89E-02	3.96E-02	6.15E-02	2.05E-01
Toluene	5.24E-07	1.41E-07	2.87E-04	2.52E-08	2.48E-07	2.88E-04
Zinc	3.31E-03	1.49E-03	1.63E+00	1.80E+00	5.59E+00	9.03E+00
Total Xylenes	3.84E-08	1.04E-08	1.32E-05	2.59E-09	0.00E+00	1.32E-05
Uranium	1.52E-01	2.74E-01	3.51E-01	9.38E-04	8.73E-02	8.65E-01

TABLE D.II-56

RADIOLOGICAL ILCR: ON-PROPERTY RESIDENT CHILD
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion[a]				
Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Ac-227 + 7 dtrs	3.1E-05	4.8E-06	3.4E-09	8.6E-08	3.6E-05
Pa-231	1.9E-05	1.5E-06	5.0E-10	7.8E-09	2.1E-05
Pb-210 + 2 dtrs	1.1E-05	6.3E-05	6.7E-07	1.7E-05	9.2E-05
Ra-226 + 5 dtrs	6.3E-06	8.8E-06	8.8E-08	4.9E-06	2.0E-05
Ra-228 + 1 dtr	1.6E-07	6.6E-07	4.6E-09	2.6E-07	1.1E-06
Rn-222 + 4 dtrs	1.5E-04	b	b	b	1.5E-04
Sr-90 + 1 dtr	7.0E-11	9.0E-09	3.5E-10	5.4E-08	6.4E-08
Tc-99	4.6E-12	1.8E-09	1.4E-09	5.0E-08	5.3E-08
Th-228 + 7 dtrs	3.8E-05	1.2E-06	1.8E-10	4.6E-09	6.0E-05
Th-230	9.8E-04	1.3E-05	2.5E-09	6.4E-08	9.9E-04
Th-232	1.4E-05	2.1E-07	4.0E-11	1.0E-09	1.4E-05
U-234	2.9E-05	6.2E-07	4.0E-09	3.7E-07	3.0E-05
U-235 + 1 dtr	1.7E-06	3.8E-08	2.5E-10	2.3E-08	1.7E-06
U-238 + 2 dtrs	5.2E-05	1.0E-06	6.7E-09	6.1E-07	5.5E-05

TABLE D.II-56
(Continued)

	Ingestion, External Radiation, Root Uptake[d]					
Radionuclide	Soil Ingestion	Ingestion of Vegetables and Fruit	Ingestion of Meat	Ingestion of Milk	Penetrating External Radiation	Risks Across Pathways
SILO STRUCTURAL FAILURE						
Ac-227 + 7 dtrs	1.2E-04	2.1E-05	2.8E-07	7.0E-06	2.1E-03	2.2E-03
Pa-231	3.6E-05	4.6E-06	3.3E-08	5.0E-07	7.5E-05	1.2E-04
Pb-210 + 2 dtrs	1.3E-03	6.1E-03	1.6E-04	4.0E-03	2.4E-06	1.1E-02
Ra-226 + 5 dtrs	2.0E-04	1.5E-04	9.0E-06	5.1E-04	7.4E-02	7.4E-02
Ra-228 + 1 dtr	1.7E-05	1.3E-05	7.4E-07	4.1E-05	3.7E-03	3.8E-03
Th-228 + 7 dtrs	3.0E-05	1.2E-06	1.4E-08	3.6E-07	2.2E-02	2.2E-02
Th-230	3.1E-04	1.4E-05	1.5E-07	3.8E-06	9.7E-06	3.4E-04
Th-232	5.0E-06	2.2E-07	2.4E-09	6.1E-08	8.0E-08	5.3E-06
U-234	1.3E-05	2.7E-05	3.4E-07	3.2E-05	1.8E-07	7.0E-05
U-235 + 1 dtr	8.0E-07	1.7E-06	2.2E-08	2.0E-06	9.0E-05	9.5E-05
U-238 + 2 dtrs	2.2E-05	4.3E-05	5.8E-07	5.2E-05	2.0E-04	3.2E-04

[a] Contamination of foodstuff and forage due to deposition from air.
[b] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[c] Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.
[d] Contamination of foodstuff and forage due to root uptake.

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TABLE D.II-57

CHEMICAL ILCR: ON-PROPERTY RESIDENT CHILD AIR CONTENTS PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Arsenic	7.00E-05	3.78E-10	1.49E-11	1.39E-11	7.00E-05
Benzo(a)anthracene	5.60E-09	4.44E-13	4.67E-14	4.58E-13	5.60E-09
Benzo(a)pyrene	4.81E-09	6.95E-13	1.53E-13	1.50E-12	4.81E-09
Benzo(b)fluoranthene	7.60E-09	3.63E-13	4.21E-13	4.13E-12	7.61E-09
Beryllium	3.72E-07	6.48E-12	1.04E-13	2.89E-15	3.72E-07
Cadmium	9.28E-07	0.00E+00	0.00E+00	0.00E+00	9.28E-07
Chromium	2.44E-05	0.00E+00	0.00E+00	0.00E+00	2.44E-05
Chrysene	5.05E-09	4.00E-13	4.20E-14	4.12E-13	5.05E-09
Dibenzo(a,h)anthracene	3.27E-09	2.04E-13	5.40E-14	5.31E-13	3.27E-09
Indeno(1,2,3-c,d)pyrene	5.71E-09	2.21E-13	3.45E-12	3.38E-11	5.75E-09
Methylene chloride	5.82E-14	3.25E-15	1.10E-20	1.08E-19	6.15E-14
Nickel	5.35E-06	0.00E+00	0.00E+00	0.00E+00	5.35E-06

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TABLE D.II-57
(Continued)

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Silo Contents	Dermal Contact With Silo Contents	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Arsenic	6.07E-03	1.09E-03	3.11E-02	1.76E-03	1.64E-03	4.16E-02
Beryllium	1.37E-04	2.47E-04	1.76E-04	4.98E-06	1.39E-07	5.65E-04

TABLE D.II-58

NONCANCER HI: ON-PROPERTY RESIDENT CHILD
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

	Inhalation and Air Dispersion				
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
2-Butanone	3.54E-10	9.43E-11	3.27E-17	3.20E-16	4.48E-10
Antimony	0.00E+00	2.64E-08	6.80E-10	2.11E-09	2.92E-08
Arsenic	0.00E+00	8.39E-06	3.31E-07	3.08E-07	9.03E-06
Barium	3.18E-02	5.11E-09	2.16E-11	1.56E-09	3.18E-02
Beryllium	0.00E+00	3.51E-09	5.62E-11	1.57E-12	3.57E-09
Cadmium	0.00E+00	6.03E-07	6.78E-09	3.83E-07	9.92E-07
Chromium	0.00E+00	5.12E-08	3.82E-09	3.23E-08	8.73E-08
Cobalt	1.64E+02	3.60E-08	1.10E-08	3.40E-08	1.64E+02
Manganese	8.07E-01	9.50E-08	8.85E-10	2.40E-08	8.07E-01
Mercury	1.38E-04	1.94E-08	1.14E-07	6.34E-09	1.38E-04
Methylene chloride	4.94E-10	8.43E-11	2.86E-16	2.80E-15	5.78E-10
Nickel	0.00E+00	4.72E-07	2.58E-08	1.33E-07	6.31E-07
Selenium	0.00E+00	5.56E-08	8.62E-09	7.13E-08	1.36E-07
Silver	0.00E+00	1.59E-08	1.01E-09	2.10E-07	2.27E-07
Thallium	0.00E+00	5.03E-07	3.02E-07	4.69E-07	1.28E-06
Toluene	4.82E-09	4.72E-12	4.46E-16	4.38E-15	4.83E-09

TABLE D.II-58
(Continued)

Inhalation and Air Dispersion					
Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
Vanadium	0.00E+00	3.02E-07	1.05E-08	2.60E-09	3.15E-07
Zinc	0.00E+00	7.38E-08	8.66E-08	2.69E-07	4.29E-07

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Silo Contents	Dermal Contact with Silo Contents	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risk Across Pathways
SILO STRUCTURAL FAILURE						
Antimony	1.76E-01	1.05E-01	4.50E+00	1.27E-01	3.96E-01	5.30E+00
Arsenic	1.35E+02	2.43E+01	6.90E+02	3.91E+01	3.64E+01	9.25E+02
Beryllium	7.45E-02	1.34E-01	9.53E-02	2.70E-03	7.54E-05	3.07E-01
Cadmium (food)	1.20E+00	2.17E-01	1.21E+02	1.32E+00	7.44E+01	1.98E+02
Chromium	1.01E+00	1.82E+00	2.49E+00	1.51E-01	1.28E+00	6.74E+00
Nickel	2.74E+00	4.93E+00	8.34E+01	3.58E+00	1.85E+01	1.13E+02
Silver	4.71E-02	8.48E-02	3.25E+00	2.05E-01	4.24E+01	4.60E+01
Thallium	1.20E+01	1.08E+00	5.05E+00	6.94E+00	1.08E+01	3.58E+01
Zinc	3.42E-02	1.54E-02	1.69E+01	1.86E+01	5.77E+01	9.32E+01
Barium	4.72E-02	8.49E-02	7.47E-01	3.85E-03	2.79E-01	1.16E+00
Cobalt	6.12E-01	1.10E+00	2.66E+00	8.87E-01	2.75E+00	8.01E+00
Manganese	4.72E-01	1.41E+00	1.77E+01	1.71E-01	4.64E+00	2.44E+01
Mercury	2.94E-02	1.32E-01	4.24E+00	2.40E+01	1.34E+00	2.97E+01

TABLE D.II-58
(Continued)

Ingestion, Dermal Contact, Root Uptake						
Chemical	Ingestion of Silo Contents	Dermal Contact with Silo Contents	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risk Across Pathways
Selenium	5.87E-01	6.60E-02	7.44E+00	7.98E-01	6.60E+00	1.55E+01
Vanadium	6.37E+00	1.15E+01	1.07E+01	3.18E-01	7.89E-02	2.89E+01
Uranium	2.28E+01	4.10E+01	5.24E+01	1.40E-01	1.31E+01	1.29E+02

TABLE D.II-59

RADIOLOGICAL ILCR: ON-PROPERTY RESIDENT CHILD
GROUNDWATER PATHWAYS, FUTURE LAND USE

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
AQUIFER[a]					
U-234	1.2E-06	6.4E-06	2.1E-08	1.7E-07	7.6E-06
U-235 + 1 dtr	1.0E-07	5.5E-07	1.8E-09	1.5E-08	6.6E-07
U-238 + 2 dtrs	1.9E-06	9.8E-06	3.2E-08	2.7E-07	1.2E-05

[a]The groundwater concentrations used to calculate these ILCRs were from the sum of the impacts of Silos 1, 2, and 3, as shown in Table D.3-8.

TABLE D.II-60

NONCANCER HI: ON-PROPERTY RESIDENT CHILD
GROUNDWATER PATHWAYS, FUTURE LAND USE

Chemical	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Dermal Exposure While Bathing	Inhalation of VOCs from Home Water Use	Risk Across Pathways
AQUIFER							
Uranium	2.04E+00	7.73E-01	3.10E-03	2.96E-01	1.93E-02	0.00E+00	3.13E+00

TABLE D.II-61

RADIOLOGICAL ILCR: ON-PROPERTY RESIDENT CHILD
SURFACE WATER PATHWAYS, FUTURE LAND USE

Radionuclide	Ingestion of Surface Water	Risks Across Pathways
SILOS INTACT		
Pb-210 + 2 dtrs	1.6E-11	1.6E-11
Ra-226 + 5 dtrs	1.8E-11	1.8E-11
Ra-228 + 1 dtr	2.8E-12	2.8E-12
Sr-90 + dtr	8.4E-11	8.4E-11
Tc-99	8.6E-11	8.6E-11
Th-230	1.6E-13	1.6E-13
Th-232	5.1E-14	5.1E-14
U-234	4.7E-10	4.7E-10
U-238 + 2 dtrs	3.1E-09	3.1E-09
SILO STRUCTURAL FAILURE		
Ac-227 + 7 dtrs	2.0E-09	2.0E-09
Pa-231	5.7E-10	5.7E-10
Pb-210 + 2 dtrs	1.9E-08	1.9E-08
Ra-226 + 5 dtrs	1.2E-08	1.2E-08
Ra-228 + 1 dtr	1.1E-09	1.1E-09
Th-228 + 7 dtrs	2.3E-10	2.3E-10
Th-230	2.3E-09	2.3E-09
Th-232	3.6E-11	3.6E-11
U-234	3.0E-07	3.0E-07
U-235 + 1 dtr	1.8E-08	1.8E-08
U-238 + 2 dtrs	4.8E-07	4.8E-07

TABLE D.II-62

CHEMICAL ILCR: ON-PROPERTY RESIDENT CHILD SURFACE WATER PATHWAYS, FUTURE LAND USE

Chemical	Ingestion of Surface Water	Dermal Contact	Risks Across Pathways
SILO INTACT			
Aroclor-1254	2.56E-13	2.00E-10	2.00E-10
Benzo(a)anthracene	9.57E-12	1.33E-08	1.33E-08
Benzo(a)pyrene	4.86E-11	1.04E-07	1.04E-07
Benzo(b)fluoranthene	1.24E-12	7.00E-09	7.00E-09
Beryllium	6.48E-11	1.81E-10	2.46E-10
Bis(2-ethylhexyl) phthalate	3.29E-14	4.20E-12	4.23E-12
Chrysene	8.57E-12	1.19E-08	1.19E-08
Dibenzo(a,h)anthracene	2.71E-12	4.77E-09	4.77E-09
Indeno(1,2,3-cd)pyrene	8.29E-14	2.35E-09	2.35E-09
Methylene chloride	7.93E-12	1.04E-11	1.83E-11
SILO STRUCTURAL FAILURE			
Arsenic	3.18E-07	8.92E-08	4.07E-07
Beryllium	1.09E-09	3.06E-09	4.15E-09

TABLE D.II-63

NONCANCER HI: ON-PROPERTY RESIDENT CHILD
SURFACE WATER PATHWAYS, FUTURE LAND USE

Chemical	Ingestion of Surface Water	Dermal Contact	Risks Across Pathways
SILOS INTACT			
2-Butanone	2.60E-07	8.22E-08	3.42E-07
4-Methyl-2-pentanone	5.02E-08	8.52E-09	5.87E-08
Acetone	1.44E-06	2.28E-07	1.67E-06
Anthracene	4.64E-10	1.37E-07	1.38E-07
Antimony	7.99E-05	7.47E-05	1.55E-04
Benzoic acid	2.63E-09	8.11E-09	1.07E-08
Beryllium	3.52E-08	9.84E-08	1.34E-07
Bis(2-ethylhexyl) phthalate	1.37E-09	1.76E-07	1.77E-07
Cadmium (food)	2.97E-06	8.32E-06	1.13E-05
Cadmium (water)	5.94E-06	1.66E-05	2.26E-05
Chromium	7.31E-07	2.04E-06	2.77E-06
Di-n-butyl phthalate	1.71E-10	4.33E-08	4.35E-08
Fluoranthene	6.85E-10	7.23E-07	7.24E-07
Methylene chloride	2.05E-07	2.69E-07	4.75E-07
Nickel	6.39E-07	1.79E-06	2.43E-06
Phenol	1.60E-07	3.08E-07	4.68E-07
Pyrene	1.37E-09	5.40E-07	5.41E-07
Silver	2.97E-06	8.32E-06	1.13E-05
Thallium	9.51E-07	1.33E-07	1.08E-06
Toluene	1.14E-09	1.50E-08	1.61E-08
Uranium	1.67E-03	4.68E-03	6.35E-03
Total Xylenes	3.88E-11	1.17E-09	1.21E-09
SILO STRUCTURAL FAILURE			
Antimony	7.42E-06	6.93E-06	1.44E-05
Arsenic	7.08E-03	1.98E-03	9.06E-03
Barium	4.24E-07	1.19E-06	1.61E-06
Beryllium	5.94E-07	1.66E-06	2.26E-06

TABLE D.II-63
(Continued)

Chemical	Ingestion of Surface Water	Dermal Contact	Risks Across Pathways
Cadmium (food)	2.51E-05	7.04E-05	9.55E-05
Cadmium (water)	5.02E-05	1.41E-04	1.91E-04
Chromium	6.85E-06	1.92E-05	2.60E-05
Cobalt	1.18E-05	3.30E-05	4.48E-05
Manganese	2.77E-05	1.29E-04	1.57E-04
Mercury	3.04E-05	2.13E-04	2.43E-04
Nickel	4.45E-05	1.25E-04	1.69E-04
Selenium	8.22E-06	1.44E-06	9.66E-06
Silver	2.74E-06	7.68E-06	1.04E-05
Thallium	8.37E-05	1.17E-05	9.54E-05
Uranium	1.29E-01	3.62E-01	4.91E-01
Vanadium	6.52E-05	1.83E-04	2.48E-04
Zinc	1.48E-07	1.04E-07	2.52E-07

TABLE D.II-64

RADIOLOGICAL ILCR: OFF-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, FUTURE LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Pb-210 + 2 dtrs	4.1E-09	1.1E-08	2.3E-10	7.8E-10	1.5E-08
Ra-226 + 5 dtrs	1.6E-08	8.7E-09	1.9E-10	1.4E-09	2.6E-08
Ra-228 + 1 dtr	1.5E-09	2.9E-09	4.0E-11	2.9E-10	4.6E-09
Rn-222 + 4 dtrs	2.3E-06	[a]	[a]	[a]	2.3E-06
Sr-90 + 1 dtr	1.9E-10	1.1E-08	8.6E-10	1.8E-08	3.0E-08
Tc-99	1.3E-11	2.2E-09	3.6E-09	1.7E-08	2.2E-08
Th-228 + 7 dtrs[b]	1.8E-08	1.6E-10	4.8E-14	1.6E-13	1.8E-08
Th-230	2.8E-07	1.5E-09	6.6E-13	2.2E-12	2.8E-07
Th-232	9.6E-09	5.4E-11	2.3E-14	7.5E-14	9.9E-09
U-234	1.7E-07	1.6E-09	2.3E-11	2.8E-10	1.7E-07
U-238 + 2 dtrs	1.1E-06	9.5E-09	1.3E-10	1.6E-09	1.2E-06

[a]Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.
[b]Impact of Ra-224 is evaluated using URF for Th-228 + 7 dtrs (parent) and modeled Ra-224 air concentration.

TABLE D.II-65

CHEMICAL ILCR: OFF-PROPERTY RESIDENT FARMER AIR PATHWAYS, FUTURE LAND USE LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Milk	Ingestion of Meat	Chemical-Specific Risk Across Pathways
SILO INTACT					
Benzo(a)anthracene	3.16E-09	1.06E-10	3.02E-11	2.39E-11	3.32E-09
Benzo(a)pyrene	2.88E-09	1.76E-10	1.05E-10	8.33E-11	3.24E-09
Benzo(b)fluoranthene	4.35E-09	8.76E-11	2.77E-10	2.19E-10	4.93E-09
Beryllium	8.17E-09	5.99E-14	7.42E-18	2.06E-15	8.17E-09
Cadmium	3.80E-08	0.00E+00	0.00E+00	0.00E+00	3.80E-08
Chromium	9.06E-07	0.00E+00	0.00E+00	0.00E+00	9.06E-07
Chrysene	3.16E-09	1.06E-10	3.02E-11	2.39E-11	3.32E-09
Dibenzo(a,h)anthracene	1.98E-09	5.20E-11	3.75E-11	2.96E-11	2.10E-09
Indeno(1,2,3-c,d)pyrene	3.56E-09	5.79E-14	2.46E-12	1.95E-12	3.56E-09
Nickel	2.93E-08	0.00E+00	0.00E+00	0.00E+00	2.93E-08

TABLE D.II-66

NONCANCER HI: OFF-PROPERTY RESIDENT FARMER
SOIL/AIR PATHWAYS, FUTURE LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILOS INTACT					
Beryllium	0.00E+00	2.79E-12	9.59E-14	3.45E-16	2.88E-12
Cadmium	0.00E+00	8.91E-10	2.16E-11	1.57E-10	1.07E-09
Chromium	0.00E+00	6.88E-11	1.10E-11	1.21E-11	9.19E-11
Nickel	0.00E+00	9.36E-11	1.10E-11	7.34E-12	1.12E-10

TABLE D.II-67

RADIOLOGICAL ILCR: OFF-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

Radionuclide	Inhalation of Fugitive Dust and Radon	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Ac-227 + 7 dtrs	5.0E-05	3.2E-06	5.0E-09	1.6E-08	5.3E-05
Pa-231	3.0E-05	1.0E-06	7.2E-10	1.4E-09	3.1E-05
Pb-210 + 2 dtrs	1.7E-05	4.4E-05	9.6E-07	3.2E-06	6.3E-05
Ra-226 + 5 dtrs	1.0E-05	5.7E-06	1.3E-07	9.0E-07	1.7E-05
Ra-228 + 1 dtr	2.6E-07	4.8E-07	6.7E-09	4.8E-08	7.7E-07
Rn-222 + 4 dtrs	2.3E-04	a	a	a	2.3E-04
Sr-90 + 1 dtr	1.4E-10	7.6E-09	6.1E-10	1.2E-08	2.1E-08
Tc-99	9.6E-12	1.6E-09	2.6E-09	1.2E-08	1.6E-08
Th-228 + 7 dtrs	6.1E-05	7.8E-07	2.4E-10	8.2E-10	6.2E-05
Th-230	1.6E-03	8.4E-06	3.6E-09	1.2E-08	1.6E-03
Th-232	2.2E-05	1.4E-07	5.8E-11	1.9E-10	4.7E-05
U-234	4.5E-05	4.2E-07	6.0E-09	7.2E-08	4.5E-05
U-235 + 1 dtr	2.6E-06	2.5E-08	3.6E-10	4.4E-09	2.6E-06
U-238 + 2 dtrs	8.4E-05	7.0E-07	9.7E-09	1.2E-07	8.5E-05

[a] Radon risks calculated for inhalation pathway only, except for inclusion in the risk from Ra-226 + 5 dtrs by ingestion and external exposure.

TABLE D.II-68

CHEMICAL ILCR: OFF-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
SILO STRUCTURAL FAILURE					
Arsenic	2.38E-05	2.17E-11	4.60E-12	5.52E-13	2.38E-05
Benzo(a)anthracene	2.37E-09	3.17E-14	1.79E-14	2.27E-14	2.37E-09
Benzo(a)pyrene	2.09E-09	5.12E-14	6.06E-14	7.67E-14	2.09E-09
Benzo(b)fluoranthene	3.16E-09	2.55E-14	1.59E-13	2.01E-13	3.16E-09
Beryllium	1.29E-07	3.79E-13	3.26E-14	1.17E-16	1.29E-07
Cadmium	3.25E-07	0.00E+00	0.00E+00	0.00E+00	3.25E-07
Chromium	9.01E-06	0.00E+00	0.00E+00	0.00E+00	9.01E-06
Chrysene	2.37E-09	3.17E-14	1.79E-14	2.27E-14	2.37E-09
Dibenzo(a,h)anthracene	1.58E-09	1.66E-14	2.37E-14	3.00E-14	1.58E-09
Indeno(1,2,3-c,d)pyrene	2.37E-09	1.55E-14	1.30E-12	1.64E-12	2.37E-09
Nickel	1.83E-06	0.00E+00	0.00E+00	0.00E+00	1.83E-06

TABLE D.II-69

NONCANCER HI: OFF-PROPERTY RESIDENT FARMER
SILO CONTENTS/AIR PATHWAYS, FUTURE LAND USE

Chemical	Inhalation of Fugitive Dust	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathway
SILO STRUCTURAL FAILURE					
Antimony	0.00E+00	1.31E-10	1.82E-11	7.27E-12	1.57E-10
Arsenic	0.00E+00	4.13E-08	8.76E-09	1.05E-09	5.11E-08
Barium	9.26E-04	2.51E-11	5.70E-13	5.32E-12	9.26E-04
Beryllium	0.00E+00	1.76E-11	1.52E-12	5.45E-15	1.91E-11
Cadmium	0.00E+00	3.06E-09	1.85E-10	1.34E-09	4.58E-09
Chromium	0.00E+00	2.74E-10	1.10E-10	1.20E-10	5.03E-10
Cobalt	4.80E+00	1.77E-10	2.90E-10	1.16E-10	4.80E+00
Manganese	2.36E-02	4.68E-10	2.35E-11	8.21E-11	2.36E-02
Mercury	3.77E-06	8.93E-11	2.81E-09	2.02E-11	3.77E-06
Nickel	0.00E+00	2.33E-09	6.86E-10	4.57E-10	3.48E-09
Selenium	0.00E+00	2.74E-10	2.28E-10	2.44E-10	7.46E-10
Silver	0.00E+00	7.82E-11	2.69E-11	7.17E-10	8.22E-10
Thallium	0.00E+00	2.48E-09	8.01E-09	1.60E-09	1.21E-08
Vanadium	0.00E+00	1.49E-09	2.77E-10	0.00E+00	1.76E-09
Zinc	0.00E+00	3.63E-10	2.29E-09	0.00E+00	2.66E-09

TABLE D.II-70

RADIOLOGICAL ILCR: OFF-PROPERTY RESIDENT FARMER GROUNDWATER PATHWAYS, FUTURE LAND USE

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Risks Across Pathways
AQUIFER[a]					
U-234	2.9E-06	1.1E-06	7.8E-09	9.7E-08	4.1E-06
U-235 + 1 dtr	2.5E-07	9.6E-08	6.7E-10	8.3E-09	3.5E-07
U-238 + 2 dtrs	4.6E-06	1.7E-06	1.2E-08	1.5E-07	6.3E-06

a The groundwater concentrations used to calculate these ILCRs were from the sum of the impacts of Silos 1, 2, and 3, as shown on Table D.3-8.

TABLE D.II-71

CHEMICAL HI: OFF-PROPERTY RESIDENT FARMER
GROUNDWATER PATHWAYS, FUTURE LAND USE

Chemical	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Dermal Exposure While Bathing	Inhalation of VOCs from Home Water Use	Risks Across Pathways
AQUIFER							
Uranium	9.14E-02	2.91E-02	2.51E-04	3.09E-03	4.58E-04	0.00E+00	1.24E-01

TABLE D.II-72

RADIOLOGICAL ILCR: OFF-PROPERTY USER OF SURFACE WATER
SURFACE WATER PATHWAYS, FUTURE LAND USE

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Risks Across Pathways
SILOS INTACT						
Pb-210 + 2 dtrs	3.0E-11	1.1E-11	1.5E-13	5.1E-13	3.4E-11	7.7E-11
Ra-226 + 5 dtrs	3.4E-11	1.1E-11	1.3E-13	9.9E-13	2.0E-11	7.0E-11
Ra-228 + 1 dtr	5.4E-12	1.7E-12	1.5E-14	1.1E-13	3.1E-12	1.0E-11
Sr-90 + 1 dtr	1.6E-10	4.4E-10	1.8E-11	3.7E-10	5.6E-11	1.0E-09
Tc-99	1.7E-10	4.9E-09	4.2E-09	1.9E-08	2.9E-11	2.9E-08
Th-230	3.1E-13	9.3E-14	2.1E-17	7.3E-17	1.1E-13	4.9E-13
Th-232	1.0E-13	3.1E-14	6.6E-18	2.2E-17	3.4E-14	1.6E-13
U-234	9.4E-10	3.6E-10	2.5E-12	3.1E-11	2.2E-11	1.3E-09
U-238 + 2 dtrs	6.2E-09	2.3E-09	1.6E-11	2.0E-10	1.4E-10	8.8E-09
SILO STRUCTURAL FAILURE						
Ac-227 + 7 dtrs	1.9E-09	5.7E-10	5.3E-13	1.8E-12	5.5E-10	3.0E-09
Pa-231	5.4E-10	1.7E-10	6.2E-14	1.3E-13	6.8E-11	7.8E-10
Pb-210 + 2 dtrs	1.7E-08	6.5E-09	8.6E-11	3.0E-10	2.0E-08	4.5E-08
Ra-226 + 5 dtrs	1.1E-08	3.6E-09	4.4E-11	3.2E-10	6.5E-09	2.3E-08
Ra-228 + 1 dtr	9.8E-10	3.0E-10	2.8E-12	2.0E-11	5.6E-10	1.9E-09
Th-228 + 7 dtrs	2.1E-10	6.2E-11	1.3E-14	4.7E-14	7.4E-11	3.5E-10
Th-230	2.2E-09	6.5E-10	1.4E-13	5.1E-13	7.5E-10	3.4E-09
Th-232	3.4E-11	1.0E-11	2.3E-15	7.5E-15	1.2E-11	5.6E-11

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TABLE D.II-72
(Continued)

Radionuclide	Ingestion of Drinking Water	Ingestion of Vegetables/ Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Risks Across Pathways
U-234	2.8E-07	1.1E-07	7.6E-10	9.4E-09	6.5E-09	4.0E-07
U-235 + 1 dtr	1.7E-08	6.6E-09	4.6E-11	5.7E-10	4.0E-10	2.4E-08
U-238 + 2 dtrs	4.6E-07	1.7E-07	1.2E-09	1.5E-08	1.1E-08	6.6E-07

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TABLE D.II-73

CHEMICAL ILCR: OFF-PROPERTY USER OF SURFACE WATER
SURFACE WATER PATHWAYS, FUTURE LAND USE

Chemical	Drinking Water Ingestion	Ingestion of Vegetables/ Fruits	Ingestion of Milk	Ingestion of Meat	Ingestion of Fish	Dermal Exposure While Bathing	Inhalation of VOCs from Home Water Use	Risks Across Pathways
SILOS INTACT								
Aroclor-1254	2.11E-13	7.85E-14	1.60E-13	1.83E-13	5.70E-10	4.17E-13	0.00E+00	5.71E-10
Benzo(a)anthracene	7.60E-12	3.01E-12	1.79E-12	1.39E-12	2.07E-09	2.67E-11	0.00E+00	2.10E-09
Benzo(a)pyrene	4.00E-11	2.17E-11	3.62E-11	2.82E-11	2.23E-08	2.17E-10	0.00E+00	2.26E-08
Benzo(b)fluoranthene	1.02E-12	3.32E-13	1.60E-12	1.23E-12	1.60E-09	1.45E-11	0.00E+00	1.62E-09
Beryllium	5.42E-11	1.68E-11	2.84E-15	7.70E-13	2.78E-11	2.70E-13	0.00E+00	9.98E-11
Bis(2-ethylhexyl) phthalate	2.65E-14	1.17E-14	3.73E-15	2.91E-15	6.07E-13	8.54E-15	0.00E+00	6.60E-13
Chrysene	7.00E-12	2.77E-12	1.65E-12	1.28E-12	2.01E-09	2.47E-11	0.00E+00	2.05E-09
Dibenzo(a,h)anthracene	2.20E-12	7.87E-13	1.03E-12	7.94E-13	1.21E-09	9.77E-12	0.00E+00	1.22E-09
Indeno(1,2,3-cd)pyrene	6.80E-14	2.07E-14	1.16E-12	8.90E-13	7.16E-10	4.86E-12	0.00E+00	7.23-10
Methylene chloride	6.58E-12	2.11E-10	9.01E-15	7.14E-15	8.88E-13	2.18E-14	5.30E-12	2.19E-10
SILO STRUCTURAL FAILURE								
Arsenic	2.59E-07	8.86E-08	1.52E-09	1.25E-08	3.08E-07	1.29E-10	0.00E+00	6.70E-07
Beryllium	9.07E-10	2.81E-10	4.76E-14	1.29E-11	4.65E-10	4.54E-12	0.00E+00	1.67E-09

TABLE D.II-74

NONCANCER HI: OFF-PROPERTY USER OF SURFACE WATER
SURFACE WATER PATHWAYS, FUTURE LAND USE

Chemical	Drinking Water Ingestion	Dermal Exposure While Bathing	Ingestion of Vegetables/ Fruits	Ingestion of Milk	Ingestion of Meat	Ingestion of Fish	Inhalation of Volatiles Released from Household Water Use	Risks Across Pathways
SILOS INTACT								
2-Butanone	1.86E-08	1.49E-11	2.22E-06	9.73E-12	7.69E-12	0.00E+00	1.20E-08	2.23E-06
4-Methyl-2-pentanone	3.40E-09	2.12E-12	1.35E-07	3.99E-12	3.15E-12	3.64E-10	0.00E+00	1.38E-07
Acetone	1.01E-07	3.94E-11	2.34E-05	3.26E-11	2.58E-11	1.06E-09	0.00E+00	2.35E-05
Anthracene	3.29E-11	2.47E-11	2.46E-11	1.34E-12	1.05E-12	8.14E-10	0.00E+00	8.99E-10
Antimony	5.48E-06	9.13E-09	2.83E-06	1.69E-07	4.21E-07	1.48E-07	0.00E+00	9.06E-06
Benzoic acid	1.85E-10	1.44E-12	2.62E-09	4.66E-13	3.67E-13	7.74E-11	0.00E+00	2.89E-09
Beryllium	2.52E-09	1.26E-11	7.80E-10	1.32E-13	3.58E-11	1.29E-09	0.00E+00	4.64E-09
Bis(2-ethylhexyl) phthalate	9.45E-11	3.06E-11	4.19E-11	1.33E-11	1.04E-11	2.17E-09	0.00E+00	2.36E-09
Cadmium (water)	4.11E-07	2.06E-09	4.75E-07	3.16E-07	4.34E-08	8.99E-07	0.00E+00	2.15E-06
Chromium	5.21E-08	2.60E-10	1.66E-08	4.29E-09	3.83E-09	2.25E-08	0.00E+00	9.96E-08
Di-n-butyl phthalate	1.21E-11	7.69E-12	5.59E-12	1.45E-12	1.13E-12	1.72E-09	0.00E+00	1.75E-09
Fluoranthene	4.93E-11	1.31E-10	2.16E-11	7.34E-12	5.70E-12	1.53E-09	0.00E+00	1.74E-09
Methylene chloride	1.46E-08	4.84E-11	4.69E-07	2.00E-11	1.59E-11	1.97E-09	3.80E-09	4.86E-07
Nickel	4.52E-08	2.26E-10	2.52E-08	5.61E-09	8.32E-09	5.74E-08	0.00E+00	1.42E-07
Phenol	1.14E-08	5.54E-11	2.81E-07	1.90E-11	1.50E-11	4.32E-10	0.00E+00	2.93E-07
Pyrene	1.00E-10	1.00E-10	4.71E-11	1.17E-11	9.10E-12	7.32E-09	0.00E+00	7.59E-09

TABLE D.II-74
(Continued)

Chemical	Drinking Water Ingestion	Dermal Exposure While Bathing	Ingestion of Vegetables/ Fruits	Ingestion of Milk	Ingestion of Meat	Ingestion of Fish	Inhalation of Volatiles Released from Household Water Use	Risks Across Pathways
Silver	2.08E-07	1.04E-09	1.85E-07	2.38E-06	8.91E-08	1.73E-05	0.00E+00	2.02E-05
Thallium	6.85E-08	1.71E-11	2.07E-08	6.90E-09	3.35E-08	0.00E+00	0.00E+00	1.30E-07
Toluene	8.22E-11	2.72E-12	4.09E-10	4.69E-13	3.71E-13	2.37E-11	5.60E-10	5.91E-10
Uranium	1.19E-04	5.94E-07	3.78E-05	4.01E-06	3.25E-07	0.00E+00	0.00E+00	1.62E-04
Total Xylenes	2.74E-12	2.09E-13	8.85E-12	2.15E-16	1.76E-14	8.88E-12	0.00E+00	2.07E-11
SILO STRUCTURAL FAILURE								
Antimony	5.21E-07	8.67E-10	2.69E-07	1.61E-08	4.00E-08	1.41E-08	0.00E+00	8.61E-07
Arsenic	4.93E-04	2.46E-07	1.69E-04	2.89E-06	2.37E-05	5.86E-04	0.00E+00	1.27E-03
Barium	3.05E-08	1.53E-10	1.32E-08	2.59E-09	2.76E-10	0.00E+00	0.00E+00	4.67E-08
Beryllium	4.22E-08	2.10E-10	1.31E-08	2.21E-12	5.99E-10	2.16E-08	0.00E+00	7.77E-08
Cadmium (water)	3.56E-06	1.78E-08	4.12E-06	2.74E-06	3.76E-07	7.79E-06	0.00E+00	1.86E-05
Chromium	4.99E-07	2.50E-09	1.59E-07	4.11E-08	3.67E-08	2.15E-07	0.00E+00	9.53E-07
Cobalt	8.22E-07	4.10E-09	2.76E-07	1.17E-07	2.88E-07	0.00E+00	0.00E+00	1.51E-06
Manganese	1.94E-06	1.61E-08	1.20E-06	2.54E-07	7.23E-08	0.00E+00	0.00E+00	3.48E-06
Mercury	2.19E-06	2.74E-08	3.35E-06	1.21E-06	1.68E-04	3.25E-04	0.00E+00	5.01E-04
Nickel	3.15E-06	1.58E-08	1.76E-06	3.91E-07	5.80E-07	4.00E-06	0.00E+00	9.90E-06
Selenium	6.03E-07	1.89E-10	2.45E-07	1.88E-07	1.73E-07	2.60E-07	0.00E+00	1.47E-06
Silver	1.92E-07	9.58E-10	1.70E-07	2.19E-06	8.21E-08	1.59E-05	0.00E+00	1.86E-05
Thallium	5.94E-06	1.48E-09	1.79E-06	5.98E-07	2.90E-06	0.00E+00	0.00E+00	1.12E-05

TABLE D.II-74
(Continued)

Chemical	Drinking Water Ingestion	Dermal Exposure While Bathing	Ingestion of Vegetables/ Fruits	Ingestion of Milk	Ingestion of Meat	Ingestion of Fish	Inhalation of Volatiles Released from Household Water Use	Risks Across Pathways
Uranium	8.95E-03	4.48E-05	2.85E-03	3.02E-04	2.45E-05	0.00E+00	0.00E+00	1.22E-02
Vanadium	4.70E-06	2.34E-08	1.47E-06	8.45E-10	1.49E-07	0.00E+00	0.00E+00	6.34E-06
Zinc	1.05E-08	1.32E-11	4.75E-08	9.49E-10	5.33E-07	1.34E-08	0.00E+00	6.05E-07

ATTACHMENT D.III

ASSESSMENT OF THE IMPACTS FROM REVISIONS TO DATA SUMMARY STATISTICS

ATTACHMENT D.III

ASSESSMENT OF THE IMPACTS FROM REVISIONS TO DATA SUMMARY STATISTICS

Following calculation of the fate and transport source terms and risk assessment exposure point concentrations used in this report, some revisions were made to the database. Also, the methods used to compare site data to background data and to calculate summary statistics were revised. The concentrations representing the upper 95 percent confidence interval (UCL) of the mean are used for both fate and transport modeling source terms (Appendix E) and exposure point concentrations (Appendix D). The revisions mentioned above resulted in some changes to the calculated UCLs in Appendices D and E, which are shown in Table D.III-1.

In the K-65 silo data, UCLs for Th-230, U-235/U-236, 2-hexanone, PCB-1254, bis(2-ethylhexyl)phthalate, cadmium, chromium, n-nitroso-di-n-propylamine, thallium, and vanadium increased, but by no more than a factor of 1.8. The remaining UCLs either did not change measurably or decreased. Some decreased by more than two orders of magnitude (e.g., methylene chloride).

Butanoic acid methylester, chloroform, styrene, and 3-methyl-2-butanone were not selected as COCs in the revised data set, while Aroclor-1248 and di-n-butylphthalate were selected as COCs in the revised data set but were not included in the source term and exposure point concentration data set. The potential impacts of any added COCs are presented in Table D.III-2. In the K-65 data, the addition of Aroclor-1248 and di-n-butylphthalate would not change the results of the risk assessment.

In the Silo 3 data, the UCL for Ac-227 increased slightly. Two COCs were added: 2-nitrophenol and 4-nitrophenol. Neither of these two compounds would impact the results of the risk assessment because the toxicity data are inadequate for quantitative risk assessment (EPA 1992b).

In the surface soil and berm fill data, UCLs for acenaphthylene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, bis(2-ethylhexyl)phthalate, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and total xylenes increased slightly, by no more than a factor of 1.1. The remaining UCLs either did not change or decreased. Benzo(a)pyrene decreased by an order of magnitude. (For pathways involving surface soil and berm fill, the revised UCL for benzo(a)pyrene was used.)

Three chemicals that had been COCs were not selected in the revised data set: 2-hexanone and 4-methyl-2-pentanone and lead. Arsenic, molybdenum, vanadium, and zinc were added to the list of COCs in the revised data. The potential impact of adding these COCs is presented in Table D.III-2. Using the RME farmer scenario, arsenic would result in an ILCR of 3.4×10^{-4}. This should be

TABLE D.III-1

SUMMARY OF CHANGES TO SOURCE TERMS AND EXPOSURE POINT CONCENTRATIONS

Constituent of Concern	UCL Used in Quantitative Risk Assessment[a]	Revised UCL	Ratio of Revised UCL/UCL Used in Quantitative Risk Assessment
K-65 Silos			
Th-228	975	641	0.66
Th-230	57300	68700	1.2
U-234	959	963	1.0
U-235/236	62.5	69.5	1.1
U-238	964	972	1.0
2-Butanone	0.061	0.00942	0.15
2-Hexanone	0.008	0.0138	1.7
3-Methyl-2-butanone	0.75	--[b]	NA[c]
Acetone	4.96	0.0738	0.015
Antimony	31.7	30.4	0.96
Aroclor-1248	--	1.59	NA
Aroclor-1254	5.00	8.98	1.8
Aroclor-1260	3.50	2.61	0.75
Arsenic	692	671	0.97
Barium	11400	11600	1.0
Beryllium	1.73	1.71	0.99
Bis(2-ethylhexyl)phthalate	0.58	0.960	1.7
Boron	52.0	53.0	1.0
Butanoic acid, methylester	0.62	--	NA
Cadmium	7.09	8.15	1.1
Carbon tetrachloride	0.012	0.00631	0.53
Chloroform	0.032	--	NA
Chromium	51.3	88.8	1.7
Cobalt	1850	1860	1.0
Copper	796	461	0.58
Cyanide	3.36	3.39	1.0
Di-n-butylphthalate	--	0.057	NA
Di-n-octylphthalate	0.315	0.281	0.89
Di-ethylphthalate	0.282	0.288	1.0
Heptachlor epoxide	0.20	0.169	0.84
Lead	200,000	195000	0.98
Mercury	1.14	1.06	0.93
Methylene Chloride	7.19	0.0276	0.0038

TABLE D.III-1
(Continued)

Constituent of Concern	UCL Used in Quantitative Risk Assessment[a]	Revised UCL	Ratio of Revised UCL/UCL Used in Quantitative Risk Assessment
Nickel	1820	1860	1.0
N-nitroso-di-n-propylamine	0.22	0.260	1.2
Phenol	0.277	0.280	1.0
Selenium	493	217	0.44
Silver	15.6	15.5	0.99
Styrene	0.022	--	NA
Tetrachloroethene	0.012	0.00614	0.51
Thallium	0.817	0.871	1.1
Toluene	0.25	0.0139	0.056
Total xylenes	0.022	0.0030	0.14
Vanadium	211	228	1.1
Zinc	52.6	52.3	0.99
Silo 3			
Ac-227	640	793	1.2
2-Nitrophenol	--	0.052	NA
4-Nitrophenol	--	0.045	NA
Thallium	56.2	56.1	1.0
Surface Soil and Berm Fill			
2-Butanone	0.00655	0.00659	1.0
2-Hexanone	0.0050	--	NA
4-Methyl-2-pentanone	0.003	--	NA
Acenaphthylene	0.315	0.333	1.1
Acetone	0.0594	0.0189	0.32
Anthracene	0.277	0.288	1.0
Arsenic	--	7.27	NA
Benzo(a)anthracene	0.415	0.453	1.1
Benzo(a)pyrene	5.20	0.492	0.095
Benzo(b)fluoranthene	0.518	0.577	1.1
Benzo(g,h,i)perylene	0.451	0.495	1.1
Bis(2-ethylhexyl)phthalate	0.377	0.407	1.1
Chrysene	0.386	0.418	1.1
Dibenzo(a,h)anthracene	0.287	0.300	1.0
Fluoranthene	0.424	0.465	1.1
Indeno(1,2,3-cd)pyrene	0.425	0.463	1.1
Lead	13.6	--	NA
Methylene chloride	0.02	0.00891	0.45

TABLE D.III-1
(Continued)

Constituent of Concern	UCL Used in Quantitative Risk Assessment[a]	Revised UCL	Ratio of Revised UCL/UCL Used in Quantitative Risk Assessment
Molybdenum	--	4.42	NA
Phenanthrene	0.376	0.405	1.1
Pyrene	0.449	0.496	1.1
Toluene	0.0082	0.00718	0.88
Total xylenes	0.00601	0.00643	1.1
Vanadium	--	25.3	NA
Zinc	--	51.8	NA
Berm Fill Only			
Arsenic	--	8.00	NA
Toluene	0.151	0.200	1.3
Total xylenes	0.0416	0.0690	1.7
Surface Soil Only			
2-Butanone	0.00599	0.00607	1.0
2-Hexanone	0.0050	--	NA
4-Methyl-2-pentanone	0.003	--	NA
Acetone	0.0629	0.0185	0.29
Benzo(a)pyrene	5.2	0.632	0.12
Methylene chloride	0.0204	0.0105	0.51

[a] Upper 95% confidence interval. Revisions to the data summary statistics and selected constituents of potential concern (COC) were due to revisions in analytical data, elimination of the risk-based concentration level screen for nondetects, and revised COC selection criteria including a comparison of the mean of the site data to the mean of the background data.
[b] Constituent not selected as a COC.
[c] Not applicable; ratio could not be calculated because constituent was selected as a COC in only one instance.

TABLE D.III-2

SCREENING-LEVEL RISK CALCULATIONS
FOR ADDITIONAL CONSTITUENTS OF CONCERN

Chemical	UCL[a]	UTF[b]	HI	URF[b]	ILCR
Surface Soil and Berm Fill					
Arsenic	7.27	9.0E-02	0.65	4.7E-05	3.4E-04
Molybdenum	5.88	4.5E-02	0.24	NA[c]	NA
Vanadium	25.3	3.7E-03	0.094	NA	NA
Zinc	51.8	3.5E-02	1.8	NA	NA
Silo 3					
2-Nitrophenol	0.0520	ND[d]	ND	ND	ND
4-Nitrophenol	0.0450	ND	ND	ND	ND
Silos 1 and 2					
PCB-1248	1.59	e	e	e	e
Di-n-butylphthalate	0.057	1.6E-03	9.12E-05	NA	NA

[a] From 4/93 data summaries, mg/kg
[b] Unit toxicity factor or unit risk factor for RME farmer; pathways include incidental ingestion, dermal contact, root uptake with ingestion of meat, milk, and vegetables.
[c] Not applicable - chemicals are not carcinogens
[d] Not determined. Toxicity data inadequate for quantitative risk assessment.
[e] Because Aroclor-1254 and Aroclor-1260 at similar levels were screened out in previous groundwater modeling, the concentration is below any level of concern.

compared to the total risk for the RME farmer soil pathways of 4.2×10^{-3}. Zinc would result in a hazard index of 1.8. The total HI for this pathway is 15.

For the berm fill data, UCLs for toluene and total xylenes increased by up to a factor of 1.7. Arsenic was added as a COC in the revised data set. For the surface soil data, UCLs either did not change or decreased. Benzo(a)pyrene again decreased by an order of magnitude. Two chemicals that had been COCs were not selected in the revised data set: 2-hexanone and 4-methyl-2-pentanone.

Overall, any increases to UCLs are well within the levels of uncertainty inherent in the fate and transport and risk calculations, and decreases to the UCLs show where the results of the risk assessment would be conservatively health protective.

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LIST OF ACRONYMS

BBS	bulletin board system
COC	chemical of concern
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EF_{TSP}	Emission Flux of Total Suspended Particulate
FEMP	Fernald Environmental Management Project
FIDLER	Field Instrument for Detection of Low Energy Radiation
ISCLT	Industrial Source Complex Long-Term
mph	miles per hour
MUSLE	Modified Universal Soil Loss Equation
NWS	National Weather Service
R_f	retardation factor
RI/FS	Remedial Investigation/Feasibility Study
SCRAM	Support Center for Regulatory Air Models
SCS	Soil Conservation Service
SOWC	Southern Ohio Water Commission
STAR	stability array
TFV	Threshold Friction Velocity
USGS	U.S. Geological Survey
WEMCO	Westinghouse Environmental Management Company of Ohio

E.1.0 AIR TRANSPORT ANALYSIS

E.1.1 INTRODUCTION

As discussed in Section 5.0 of the Remedial Investigation (RI) Report for Operable Unit 4, analysis of the transport of contaminants from Operable Unit 4 through the air pathway was conducted to support the determination of the fate of contaminants in the environment and for the baseline risk assessment. This section of the appendix describes the approach, the methodology, and the results of the air transport analysis.

The primary objective of this analysis was to determine the maximum on-property and off-property annual average ground level air concentrations of the contaminants released to the atmosphere from the Operable Unit 4 Study Area. These concentrations were to be used for the baseline risk assessment as shown in the conceptual model in Section 5 of the RI report. An additional objective of the analysis was to compare the predictions of the air dispersion model with the ambient air monitoring data collected on-property and evaluate the contribution of Operable Unit 4 on the ambient air concentrations.

The analysis was conducted as per the guidelines of U.S. Environmental Protection Agency (EPA). A regulatory air dispersion model was used to translate the air emissions from the Operable Unit 4 to annual average ground level concentrations at preselected receptors. The air dispersion model accounted for dispersion and dilution of the contaminants considering site meteorological conditions, such as wind speed, wind direction, atmospheric stability, and mixing height.

A number of pre-modeling and post-modeling steps were required to achieve the objectives of the analysis. Figure E.1-1 shows the sequential block diagram of these steps in the analysis. First, the scenarios for the air transport analysis were clearly defined. The sources of air emissions and contaminants released were then identified based on site-specific information. An appropriate EPA regulatory air dispersion model was selected which best represented the site characteristics and the objectives of the analysis. Next, model parameters such as source emission rates, meteorological data, and receptor locations were determined. Finally, the results from the air dispersion model were processed to determine the maximum on-property and off-property annual average ground level air concentrations for use in the baseline risk assessment.

Throughout the analysis, site-specific data were used wherever available. When such data were not available, conservative assumptions were made. Regulatory default options and values were used wherever applicable in the air dispersion model, and in the source emissions calculations. The intent was to make the results relevant to the site and yet conservative, so that the risk associated with this exposure pathway was not underestimated. A detailed discussion of the conservative assumptions

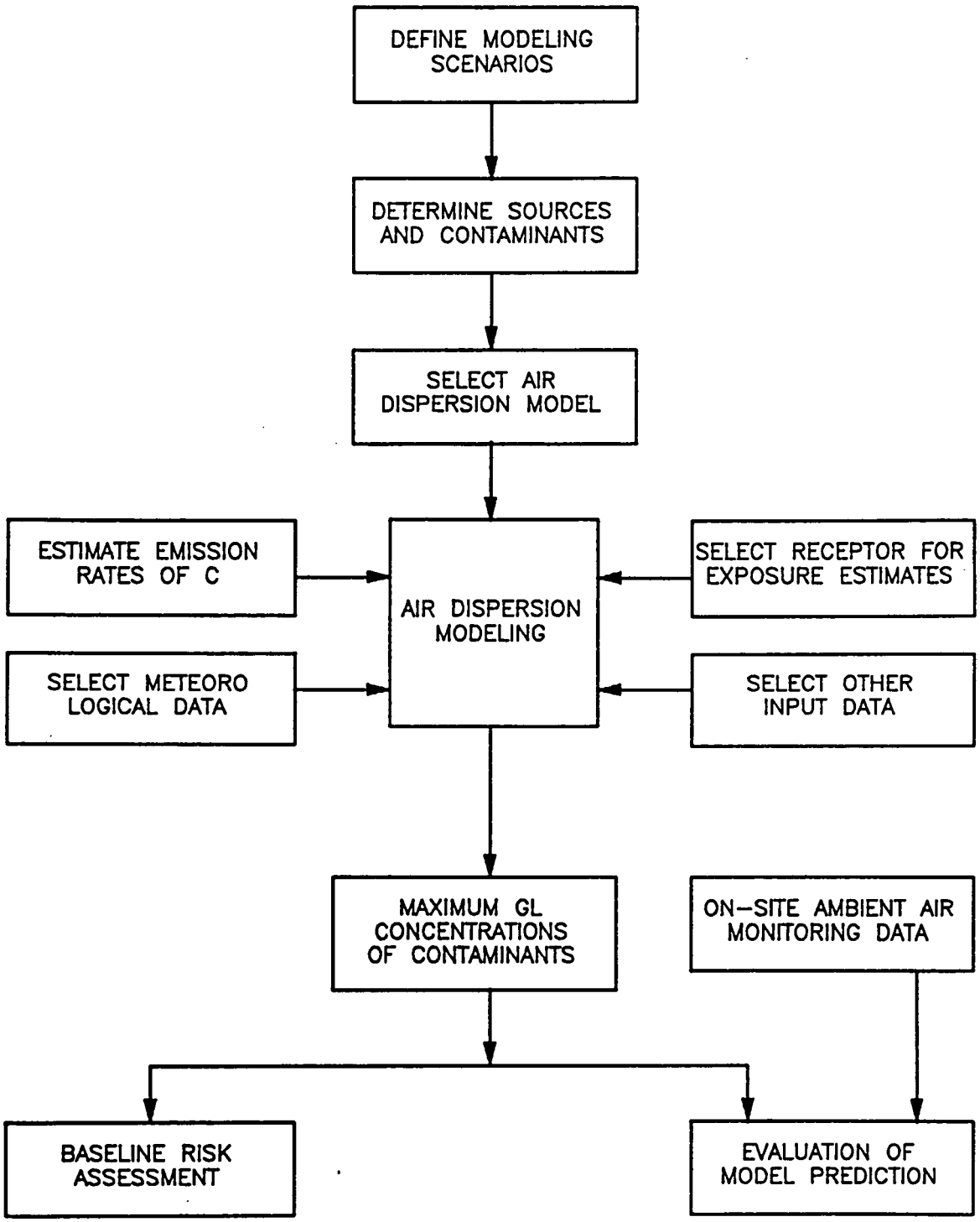

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FIGURE E1-1. SEQUENTIAL BLOCK DIAGRAM OF AIR TRANSPORT ANALYSIS FOR OPERABLE UNIT 4

considered in the analysis to counteract the uncertainties inherent in the analysis are presented in a later section of this appendix.

E.1.2 SITE DESCRIPTION

The Operable Unit 4 is one of the five operable units of the FEMP committed to Remedial Investigation/Feasibility Study (RI/FS) under a consent agreement with the EPA. A schematic layout of the Operable Unit 4 is given in Figure E.1-2. The Operable Unit 4 consists of four storage silos named as Silo 1, 2, 3, and 4.

The Silos 1 and 2 are commonly referred as the K-65 silos and contain the products of uranium ore processing activities at Fernald and other Department of Energy (DOE) facilities. A berm was constructed around these silos with filler material in 1964 to assist in preserving the structural integrity of these silos. To reduce the potential threat of radon release, the contents of the silos were covered with a bentonite clay layer in November 1991, as part of a removal action. A sectional view of the modified K-65 silos is shown in Figure E.1-3.

The Silo 3 contains dried metal oxides produced in the cold raffinate processing operations at the FEMP. At present, there are no berms or bentonite layer in this silo. A sectional view of this silo is shown in Figure E.1-3. Silo 4 contains a relatively small accumulation of water at the bottom of the silo and is not considered an air emission source for reasons mentioned in Section 4 of the RI report. As shown in Figure E.1-2, the boundaries of the Operable Unit 4 also included some soil surface around these silos, which were potentially contaminated during silo filling operations and other activities at the site.

E.1.3 SCENARIOS FOR AIR TRANSPORT ANALYSIS

Two modeling scenarios were considered in the air transport analysis. These are described in detail in Appendix D, Section D.3 of the RI report as the "Current Condition Scenario" (current scenario) and the "Future Condition Scenario" (future scenario). The scenarios are briefly described in this appendix for the sake of completeness.

In the current scenario, all the silos and contaminants were considered to remain in existing configurations, whereas the future scenario was based on the collapse of the silo structures. In the future scenario, it was assumed that the berm fill and the walls of Silos 1 and 2 would remain sufficiently intact to prevent the K-65 waste from spreading over the Operable Unit 4 Study Area. Also, following collapse of the silo domes, the bentonite cap layer covering the wastes would be spared from significant erosion because it would be partially protected by the walls of the silos. The moisture in the bentonite would be retained due to accumulated rainwater. Thus, the effectiveness of the bentonite layer will remain unchanged.

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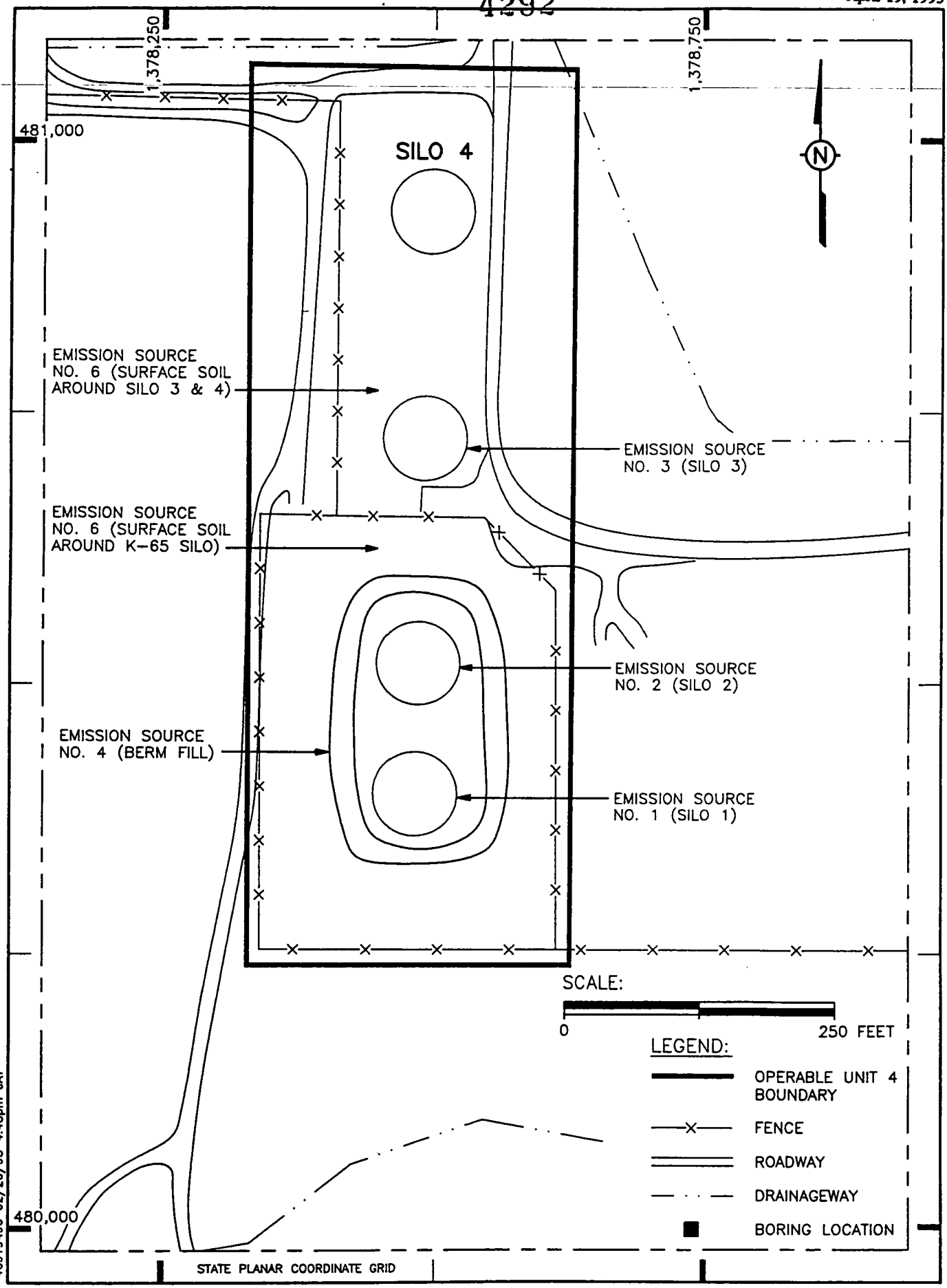

FIGURE E.1-2. OPERABLE UNIT 4

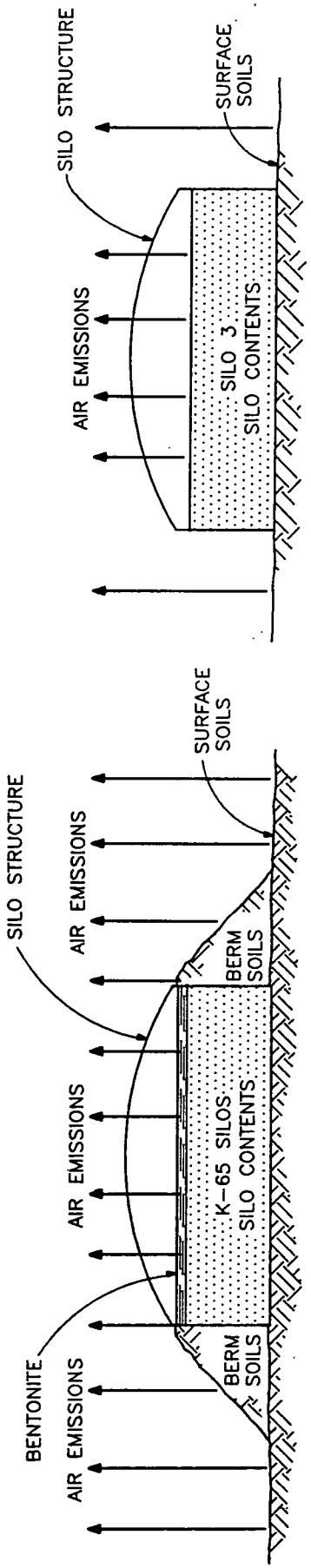

FIGURE E.1-3. SECTIONAL VIEW OF K-65 SILOS AND SILO 3

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On the other hand, since there was no berm fill around Silo 3, failure of this silo was expected to result in complete collapse of the silo structure. The metal oxide waste in the silo was assumed to spread on the Operable Unit 4 surface around the collapsed silo. With time, the material would be expected to spread over larger area due to wind erosion. For the purpose of modeling, the silo waste was assumed to be spread over ten times the surface area of Silo 3. This meant that the waste was assumed to be spread over an area approximately 250 ft in diameter from an original silo diameter of 80 ft. Based on the estimated wind erosion rate of this material, it is highly unlikely that the waste would be spread over such a large area due to wind erosion within the time frame of the future scenario. However, this assumption results in higher emission rates, which is consistent with the overall conservative approach considered in the analysis.

At the time of failure of Silos 1, 2, and 3, the radon gas within the head space of the silos is expected to be released instantaneously. The released gas can be envisaged as a puff of radon gas with dimensions corresponding to the size of the silos. The effect of this instantaneous release of radon gas from the silos was also investigated under this future scenario. Modeling was conducted using the "PUFF" model approved by EPA for this type of instantaneous release. Preliminary modeling for this instantaneous release showed that based on a 70 year time period for estimation of the risk, the effect of the combined instantaneous releases from all three silos would be insignificant compared to the effect of the continuous release for this scenario. Therefore, no further calculations were performed for the instantaneous releases of radon gas from the three silos.

E.1.4 EMISSION SOURCES AND POTENTIAL CONTAMINANTS

In the RI report, the sources of air emissions and the potential constituents of concerns (COCs) in the Operable Unit 4 were identified based on characterization studies and analysis of the source-term scenarios. These sources and the contaminants in Operable Unit 4 were:

- Release of radon gas from the contents of the Silos 1, 2, and 3
- Release of radon gas from the berm fill material and the surface soil of the Operable Unit 4 Study Area
- Emissions of particulates from the berm fill material and the surface soil of the Operable Unit 4 Study Area
- Emissions of particulates from the spread waste material of Silo 3 in the future scenario

The characterization studies showed that the berm fill material and the surface soil of the Operable Unit 4 contained organics, inorganics (metals), and radionuclides which were either adsorbed, absorbed, or were chemical constituents of these materials. Thus, emissions of particulate would result in potential emissions of these contaminants also.

Radon has a short half-life and decays to a series of additional radionuclides. Radon is released from Silos 1 and 2 as a gas. The short-lived progeny are accounted for in the risk assessement process with assumptions made on equilibrium. No additional special air modeling was performed for radon progeny.

For the purpose of this analysis, the Operable Unit 4 was considered to be comprised of six different sources. These were:

- Silo 1
- Silo 2
- Silo 3
- Berm fill material
- Surface soil around Silos 1 and 2
- Surface soil around Silo 3

In the future scenario, the Silo 3 source was characterized by the material assumed to be spread over the Operable Unit 4 Study Area around the collapsed Silo 3. All these sources were considered as "area" sources for the purpose of air dispersion modeling. The areas of these sources were determined from plant drawings.

Table E.1-1 shows the Source-Contaminant matrix of both the current and the future scenarios considered in the air transport analysis. The organics, inorganics, and the radionuclides were considered to be released as a constituent of the particulate emissions due to wind erosion from exposed surfaces.

Volatilization of the organics from the surface soil and the berm fill material was investigated as a possible source-term scenario. However, the potential for volatilization of all the organics except 1-butanone, methylene chloride, and toluene were low due to very low vapor pressures (6.33E-09 mm Hg or lower). Also, for 1-butanone, methylene chloride, and toluene, it was determined that on an annual basis, wind erosion mechanism represented a worse case emission rate than volatilization. Therefore, volatilization was not considered as a significant release mechanism for any of these organics.

E.1.5 AIR DISPERSION MODEL

The annual average ground level concentrations were determined by the EPA's computerized air dispersion model, Industrial Source Complex Long-Term Version 92273 (ISCLT2). This model is recommended by EPA for air pathway analysis for Superfund sites (EPA 1989).

The ISCLT2 model was designed by the EPA for assessing the air quality impact of emissions from a wide variety of sources. It incorporates a steady-state gaussian plume equation that is applicable for flat or gently rolling terrain, and single or multiple point, area, and volume sources. The ISCLT2

TABLE E.1-1

SOURCE CONTAMINANT MATRIX IN AIR TRANSPORT ANALYSIS OF OPERABLE UNIT 4 BASED ON RELEASE MECHANISM

CURRENT SCENARIO

Source No.	1 Silo 1	2 Silo 2	3 Silo 3	4 Berm Fill	5 Surface Silos 1 and 2	6 Surface Silo 3
Type of Source	Area	Area	Area	Area	Area	Area
Chemicals (COCs) [a]						
Organics	No	No	No	Yes	Yes	Yes
Inorganics	No	No	No	Yes	Yes	Yes
Radionuclides	No	No	No	Yes	Yes	Yes
Radon	Yes	Yes	Yes	Yes	Yes	Yes

FUTURE SCENARIO

Source No.	1 Silo 1 Cap Failure	2 Silo 2 Cap Failure	3 Silo 3 Failure	4 Berm Fill	5 Surface Soil Around Silos 1 and 2	6 Surface Soil Around Silo 3
Type of Source	Area	Area	Area	Area	Area	Area
Chemicals (COCs) [a]						
Organics	No	No	No [b]	Yes	Yes	Yes
Inorganics	No	No	Yes	Yes	Yes	Yes
Radionuclides	No	No	Yes	Yes	Yes	Yes
Radon	Yes	Yes	Yes	Yes	Yes	Yes

a The release mechanism for organics, inorganics and radionuclides is as constituents of particulate emission from exposed surfaces due to wind erosion.

b There are no significant quantities of organics in Silo 3 materials - Refer to Appendix D2.

model calculates the annual average ground level concentration due to airborne emissions at user-selected locations of interest (receptors), based on sector averaged statistical wind summaries. Data required for input to the model include emission rates from the sources; location and configuration of sources; statistical summary of wind speed, wind direction, and atmospheric stability; and locations of the receptors of interest. The following sections describe in detail the procedure followed in estimating these inputs to the ISCLT2 model.

E.1.6 ESTIMATION OF EMISSIONS OF CONTAMINANTS

As mentioned earlier, two primary types of release mechanisms were identified for the Operable Unit 4. These are: a) radon gas from the silos, the berm fill material, and the surface soil, and b) organics, inorganics, and radionuclides as constituents of particulate emissions due to wind erosion from exposed surfaces of soils, berm fill material, and the waste silo 3 material (future scenario). The methods and models used to estimate these emissions are described in this section.

E.1.6.1 Estimation of Radon Release Rates

The sources for the release of radon for both current and future scenarios were identified in Table E.1-1 mentioned earlier. The radon release rates were calculated separately for each of these sources. The release estimates were calculated as radon release rates (e.g., the radon activity released per unit time, usually picocuries per year [pCi/yr]). The emission rates were converted to emission flux (pCi/m^2-s) from the area of each source which were then used as input to the air dispersion model.

E.1.6.1.1 Silos - Current Scenario

The average annual radon release rates for each of the three silos for the current scenario were calculated individually as the product of the measured radon concentration inside the silo headspace (radioactivity per unit volume), and the calculated silo breathing rate (volume of air released per unit time). Thus,

$$ER_{radon} = C_{radon} \times BR_{silo}$$

where

ER_{radon} = Average annual emission rate of radon (pCi/yr)
C_{radon} = Annual average radon concentration in silo headspace (pCi/m^3)
BR_{silo} = Annual average breathing rate of silo (m^3/yr)

The average daily radon concentrations in the headspaces of the silos are shown in Table E.1-2. The concentrations for Silos 1 and 2 were obtained from a data set representing 31 daily average radon concentrations for these silos for the month of December 1992. The data for the month of December 1992 were considered representative of the annual average radon concentrations for the Silo 1 and 2

TABLE E.1-2

AVERAGE DAILY RADON CONCENTRATION IN HEADSPACE OF SILOS

Concentration in pCi/L	Silo1	Silo 2	Silo 3
	37,505	140,490	201,340
	20,151	125,794	244,580
	41,733	170,083	178,010
	35,057	145,994	202,840
	15,116	82,769	
	61,877	111,069	
	10,154	110,950	
	14,146	137,011	
	55,859	134,219	
	27,523	135,146	
	2574	125,723	
	2984	124,672	
	7708	133,889	
	48,556	179,909	
	86,812	209,618	
	30,595	101,589	
	33,447	160,903	
	57,667	179,144	
	45,797	117,366	
	21,254	92,121	
	73,004	111,728	
	61,055	146,631	
	15,135	89,846	
	41,828	68,921	
	40,859	54,062	
	35,897	42,734	
	62,344	95,943	
	55,412	172,334	
	76,637	171,137	
	60,022	152,207	
	17,052	110,595	
Sample size	31	31	4
Arithmetic mean (pCi/L)			
Std. dev. (pCi/L)	38,570.0	126,922.5	206,693.0
UCL (pCi/L)	22,745.1	38,407.9	27,698.0
	45,502.0	138,628.0	239,280.0

Source: FERMCO 1992

domes because the concentrations were found to remain relatively constant throughout the year since the installation of the bentonite layer inside the K-65 silos. The concentrations for Silo 3 were obtained from a data set of analytical results of four grab samples collected on four separate days in September and October 1990. In all cases, the Upper Confidence Limit (UCL) concentrations from the measurements were considered in the above equation for estimating the release rates.

The breathing rates for the silos were calculated from the initial headspace volume using the ideal gas law, assuming that the silos experienced an average daily variation in headspace air temperature. The initial headspace volume for the silos, the average daily temperature variation for the silos, and the initial headspace temperature considered in the calculations are shown in Table E.1-3. This table shows an example calculation and the calculated breathing rates for all the silos.

E.1.6.1.2 Silos - Future Scenario

The future scenario considered that dome of the K-65 Silos had collapsed and, following structural failure, the Silo 3 contents were spread on the surface of Operable Unit 4 around Silo 3. Thus, the radon was directly released from the surface of these materials to the atmosphere. For these sources, the radon release rates were calculated as the product of the estimated radon flux (radioactivity per unit area-time) from the surface of the materials and the areas available for release. Thus,

$$ER_{radon} = EF_{radon} \times S_a$$

where

ER_{radon} = Emission rate of radon from the source (pCi/yr)
EF_{radon} = Emission flux of radon from the source (pCi/m^2-yr)
S_a = Area of release (m^2)

The radon emission flux from these sources was determined by the "RAECOM" model, which is approved by the EPA for this type of application. The "RAECOM" model has two options for the source: a) a covered source option, and b) a bare source option. For Silos 1 and 2, the radon flux was based on the algorithm for covered source (i.e., a noncontaminated layer overlaying the source of radon) and was used by DOE in support of the bentonite effectiveness evaluation (DOE 1992). In the case of Silo 3, the radon flux from the surface of the metal oxide particulate waste is based on the algorithm for bare source (i.e., the source directly exposed to the atmosphere) employed in the "RAECOM" computer code. Attachment E.1-I presents details of the equation used by the "RAECOM" model to calculate the radon flux from area sources. This attachment also presents an example calculation.

TABLE E.1-3

BREATHING RATE CALCULATION OF SILOS IN CURRENT SCENARIO

	Silo 1	Silo 2	Silo 3
Initial Head Space Volume (ft^3)	27900	44800	17100
Initial Head Space Temperature ^oF)	63	63	63
Avg. Daily Temperature Variation (^oF)	5	5	20
Final Head Space Volume (ft^3)	28169	45232	17754
Breathing Rate (ft^3/day)	269	432	654
Breathing Rate (m^3/yr)	2764.2	4439.2	6720.4

Example Calculation: Silo 3

From Ideal Gas Law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$P_1 = P_2 = 1$ atm $= 2117$ lbs/ft^2
$V_1 = 17100$ ft^3
$T_1 = 63^oF = 290.2^oK$
$T_2 = (63 + 20) = 83^oF = 301.3^oK$
Solution yields $V_2 = 17754$ ft^3
Breathing Rate = Change in Volume = $V_2 - V_1 = 17754 - 17110 = 654$ ft^3/day

The surface areas of release for Silos 1 and 2 for the future scenarios were based on the silo diameter of 80 feet. For the materials from the failed Silo 3, the area of release was considered to be ten times the area of Silo 3, as mentioned in earlier Section E.1-3, "Scenarios for Air Transport Modeling."

E.1.6.1.3 Berm Fill and Surface Soils - Current and Future Scenario

In both scenarios, the radon emission flux for the berm fill and Operable Unit 4 surface soils was calculated using the "RAECOM" model. The radon release rates were then calculated from the product of radon emission flux and the surface area of the source.

Since both the berm fill material and the surfaces around the silos were not covered in any of these scenarios, the bare source option was used for these sources. The surface areas of the berm fill material and the soil surface areas around the silos were determined from the plant drawings. Attachment E.1-I gives the radon emission flux equation used by "RAECOM" and presents an example calculation of the radon emission rate.

The results of the radon release rates and the radon fluxes from the various sources in the two different scenarios are summarized in Table E.1-4.

E.1.6.2 Estimation of Release Rates of Organics, Inorganics, and Radionuclides

Since these contaminants were released as a constituent of particulate emissions from the exposed surfaces, the following general equation was used for estimating the release rates:

$$EF_c = C_c \times EF_{TSP}$$

where

EF_c = Emission flux of contaminant (g/m^2-s)
C_c = Concentration of the contaminant in the suspended particulate (g/g)
EF_{TSP} = Emission flux of total suspended particulate due to wind erosion (g/m^2-s)

E.1.6.2.1 Emission Flux of Total Suspended Particulate (EF_{TSP})

The currently available methodologies for estimating particulate emission flux due to wind erosion are based on the concept of "Threshold Friction Velocity" (TFV). The specific methodology recommended by the EPA for estimating wind erosion rates from flat soil surfaces at hazardous waste sites is described in various EPA guideline documents (EPA 1985). This approach assumes that a minimum wind speed is needed for the suspension of respirable dust from the soil and the emission rate is a nonlinear function of two factors, namely: a) TFV and b) the erosion potential of the site, which is dependent on the particle size distribution of the soil. The lower the TFV is, the higher the potential

TABLE E.1-4

RADON RELEASE RATES AND EMISSION FLUX FROM ALL SOURCES IN OPERABLE UNIT 4

Source No.	1	2	3	4	5	6
Source ID	Silo 1	Silo 2	Silo 3	Berm Fill	Soil Surface around K-65 Silos	Soil around Silo 3
A. Current Scenario						
Annual Release Rate (pCi/yr)	1.25×10^{11}	6.12×10^{11}	1.6×10^{12}	9.36×10^{11}	1.43×10^{11}	4.13×10^{11}
Total Area of Release (m^2)	467	467	467	7700	3600	10400
Radon Emission Flux (pCi/m^2-sec)	8.487	41.55	108.6	3.855	1.259	1.259
B. Future Scenario						
Annual Release Rate (pCi/yr)	3.81×10^{13}	3.81×10^{13}	4.39×10^{14}	9.36×10^{11}	2.145×10^{11}	3.41×10^{11}
Total Area of Release (m^2)	467	467	4670[a]	7700	3600	5730[b]
Radon Emission Flux (pCi/m^2-sec)	2590	2590	2981	3.855	1.89	1.89

[a] This indicates the area of Silo 3 material spread over the ground in this scenario.
[b] This indicates the soil area around Silo 3, which is not covered by the Silo 3 material in this scenario.

for erosion of the soil by wind. Similarly, for a fixed TFV, a higher wind speed results in higher particulate emission rates due to wind erosion.

The various steps in the estimation process are shown in Figure E.1-4. First, the TFV of the soil at he soil surface is determined from the modal diameter of the soil sieve analysis, using an empirical relationship derived by Gillette (EPA 1985). A correction factor (Lc) is used to correct for nonhomogeneous soil surface. The soil is then classified either as having "unlimited erosion potential" or as having "limited erosion potential," depending on whether the TFV is below or above 75 cm/s, respectively.

The Gillette model (EPA 1985) applies to soils of unlimited erosion potential (i.e., the TFV is less than 75 cm/sec). This equation takes the following form:

$$E_{10} = 0.036 \times (1-V) \times [(u/u_t)^3] \times F(y)$$

where

E_{10} = Annual average PM_{10} emission rate per unit area of contaminated surface (g/m^2-hr)
PM_{10} = Particulate matter with a diameter less than or equal to 10 microns
V = Fraction of vegetative cover
u = Mean annual wind speed (m/s)
u_t = Threshold friction velocity at the height of "u" (m/s)
y = $0.886*u_t/u$
F(y) = A function of "y"
F(y) = 1.91 if "y" < 0.5
F(y) = $0.18(y^3 + 12y)*EXP(-y^2)$ for y > 2
see Figure 4-3 (EPA 1985) for 0.5< y <2

The Cowherd model (EPA 1985) applies to the soils with limited erosion potential (i.e., when the TFV is greater than 75 cm/s). The original Cowherd model for soils with limited erosion potential takes the following form:

$$E_{10} = 0.83*(f)*(P_{u+})*(1-V)/[(PE/50)^2]$$

where

E_{10} = Annual average PM_{10} emission rate per unit area of the contaminated surface (mg/m^2-hr)
f = Frequency of disturbance per month (estimated)
$P_{(u+)}$ = Erosion potential (i.e., quantity of erodible particles present on the surface prior to the onset of wind erosion) (g/m^2)
V = Fraction of vegetative cover
PE = Thornwaite's Precipitation Evaporation index used as a measure of average soil moisture content

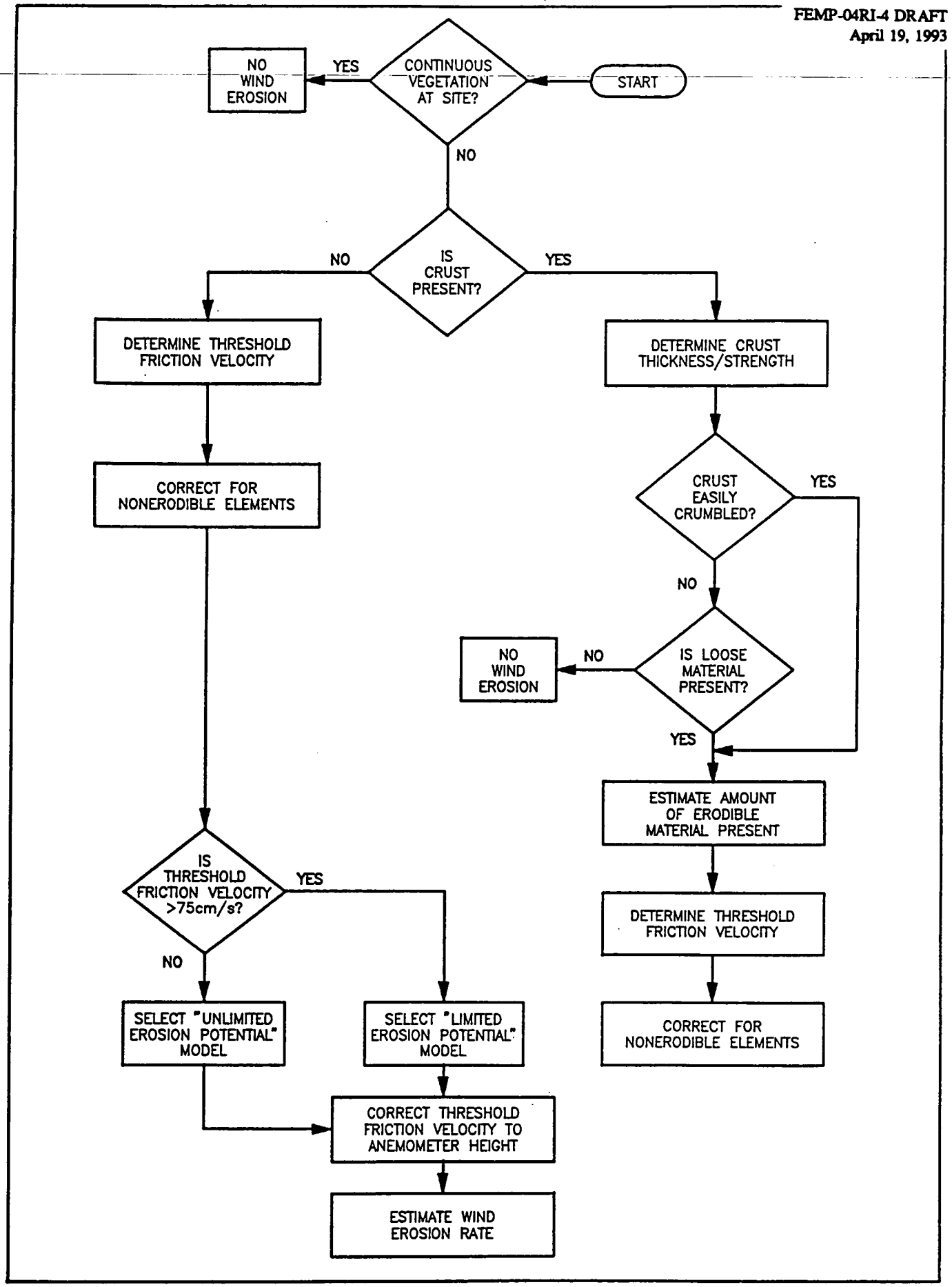

FIGURE E.1–4. DECISION FLOWCHART FOR ESTIMATING WIND EROSION RATE

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The erosion potential is determined from the fastest wind speed between the disturbances as follows:

$$P_{(u+)} = 6.7 \times (u^+ - u_t) \text{ if } u^+ > u_t, \text{ or}$$
$$P_{(u+)} = 0 \text{ if } u^+ <= u_t.$$

where

u^+ = Observed or probable fastest wind speed for the period between disturbances(m/s)

u_t = Threshold friction velocity at the same height as u^+ (m/s)

A slightly modified version of Cowherd's "Limited potential" model is as follows:

$$E_{10} = 0.5 \times N \times \Sigma P_i$$

where

E_{10} = Annual average emission rate (g/m^2-yr)

N = Number of disturbances per year

P_i = Erosion potential of the soil corresponding to the observed or probable fastest mile of wind speed for the i-th period between disturbances (g/m^2)

The erosion potential is determined as follows:

$$P_i = 58 \times (u^* - u^*_t)^2 + 25 \times (u^* - u^*_t)$$

where

u^* = Surface friction velocity (m/s)

u^*_t = Threshold friction velocity (m/s)

The surface friction velocity is determined from the fastest wind speed at anemometer height, from the following equation:

$$u^* = 0.4 \times u_z / \ln(z/z_o).$$

where

u_z = Fastest wind speed at anemometer height of "z" (m/s)

z = Anemometer height (m)

z_o = Surface roughness factor (m)

This modified Cowherd equation does not account for any vegetative cover.

Detailed calculation of the particulate emission rate due to wind erosion from the berm fill material, the surface soil, and the Silo 3 material spread over the operable unit in the future scenario is

presented in Attachment E.1-II. The Gillette unlimited erosion potential model was selected for use based on the calculated threshold friction velocity for all materials to be modeled. The annual mean wind speeds were determined from the on-property meteorological data for the years 1987-1992, and the maximum of these annual averages were considered. Though the Operable Unit 4 is at present substantially covered by vegetation, a vegetative cover factor of 50 percent was considered for the soil surface. For the material of Silo 3 spread over the operable unit surface in the future scenario, no vegetative cover was considered. The intent of these assumptions was to obtain a conservative emission rate so that the risk from this pathway would not be underestimated.

As shown in Attachment E.1-II, the estimated particulate emission flux from the soil surfaces were as follows:

- Berm fill 1.42E-05 g/m^2-s
- Surface soil 6.76E-05 g/m^2-s
- Silo 3 material 9.00E-05 g/m^2-s

E.1.6.2.2 Concentration of Contaminants in Suspended Particulate (C_c)

As part of the overall site characterization program and the Operable Unit 4 program, the surface soil at the Operable Unit 4, the berm fill, and the Silo 3 material were analyzed for potential chemical and radiological constituents. Appendix D, Section D.2, Section 3.0 and Section 4.0 of the RI report describes in detail the methods of sampling, the analytical methods, and statistical methods used in this characterization study. The sampling locations for these analyses are shown in Figures E.1-5a and E.1-5b, for the surface soil and the berm fill, respectively.

A list of the potential constituents of concern in the surface soil, the berm fill, and the material of Silo 3 have been presented in Appendix D, Section D.2 of the RI report. It was assumed that the concentration of these chemicals and radionuclides in the suspended particulates was the same as in the above samples from the source materials.

Based on the total suspended particulate emission flux and the concentration of the contaminants in the suspended particulate, the emission flux of the constituents from the individual sources in the Operable Unit 4 were determined. The results of these emission flux calculations are presented in Table E.1-5. These flux calculations were used as input to the air dispersion model.

E.1.7 METEOROLOGICAL DATA

Meteorological data which characterize the transport and dispersion conditions of an area are needed as an input to the ISCLT2 model. These data include wind speed, wind direction, atmospheric stability category, ambient air temperature, and mixing height. Measurements for all of these meteorological parameters except mixing height have been recorded at the FEMP site as part of a comprehensive environmental monitoring program since August 1986.

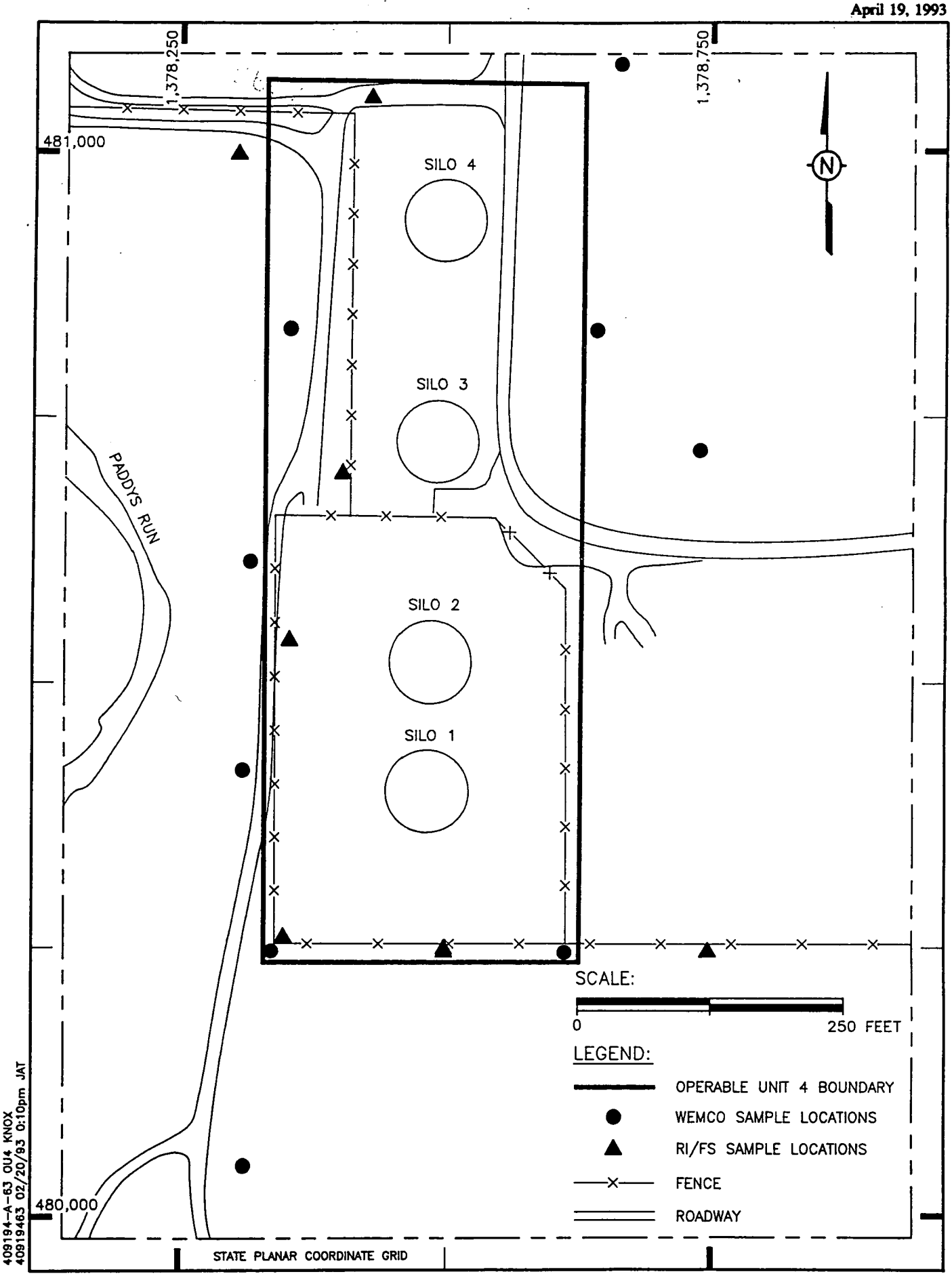

FIGURE E.1–5A. LOCATIONS OF SURFACE SOIL SAMPLES

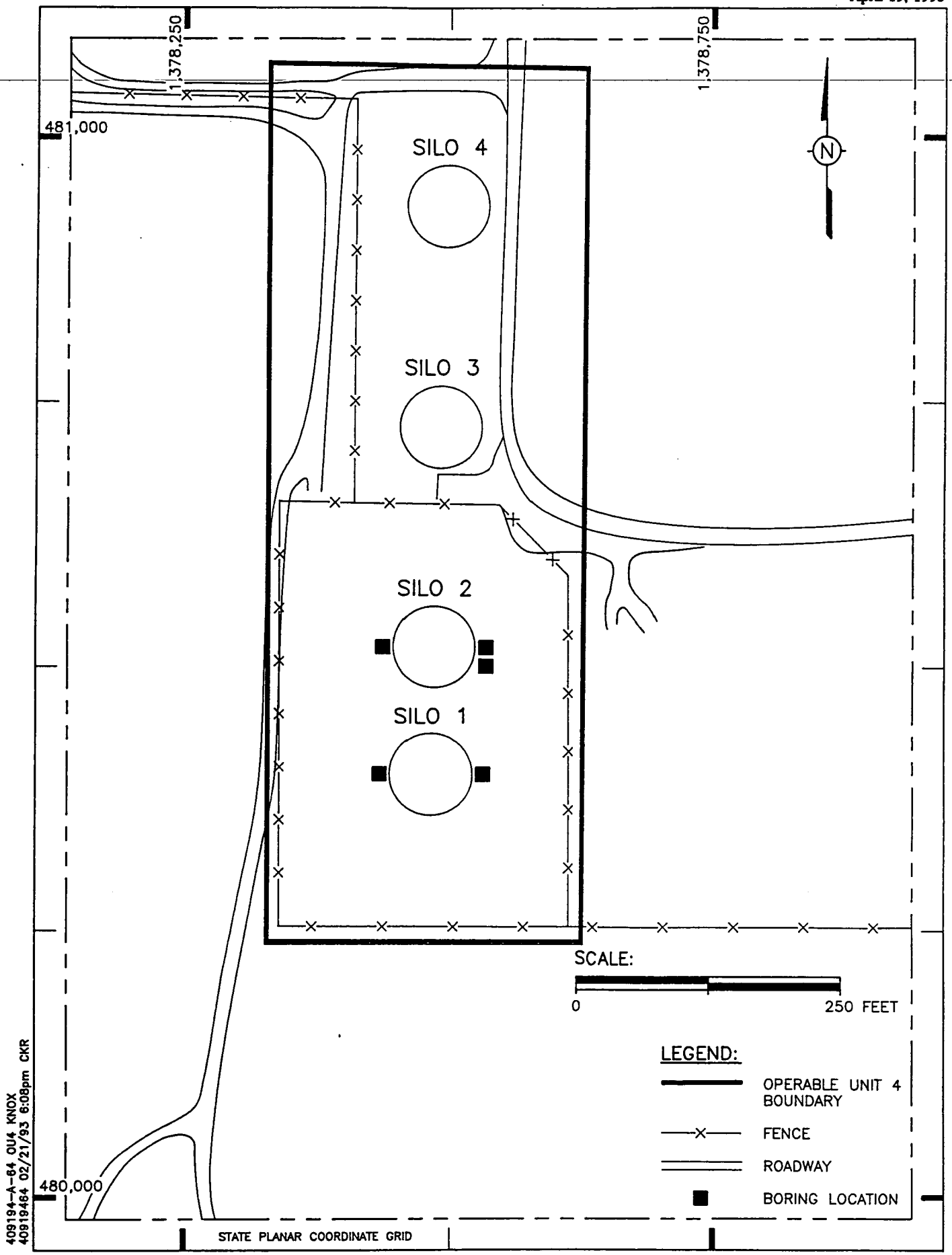

FIGURE E.1–5B. LOCATIONS OF BERM FILL BORING SAMPLES

TABLE E.1-5

EMISSION FLUX OF CHEMICAL AND RADIOLOGICAL CONTAMINANTS DUE TO WIND EROSION FROM OPERABLE UNIT 4

Contaminant	Silo 3 Materials (Future Scenario)		Berm Fill Materials (Current & Future Scenario)		Surface Soil Around Silos (Current & Future Scenario)	
	Concentration (µg/g)	Emission Flux (µg/m2-sec)	Concentration (µg/g)	Emission Flux (µg/m2-sec)	Concentration (µg/g)	Emission Flux (µg/m2-sec)
A. Organics						
2-Butanone	*	0.00	0.011	1.56×10^{-7}	0.006	4.06×10^{-7}
Benzo(a)anthracene	*	0.00	*	0.00	0.574	3.88×10^{-5}
Benzo(a)pyrene	*	0.00	*	0.00	0.632	4.27×10^{-5}
Benzo(b)fluoranthene	*	0.00	*	0.00	0.777	5.25×10^{-5}
Chrysene	*	0.00	*	0.00	0.518	3.50×10^{-5}
Dibenzo(a,h)anthracene	*	0.00	*	0.00	0.335	2.26×10^{-5}
Indeno(1,2,3,c,d)pyrene	*	0.00	*	0.00	0.585	3.95×10^{-5}
Methylene chloride	*	0.00	*	0.00	0.02	1.35×10^{-6}
Toluene	*	0.00	0.151	2.14×10^{-6}	0.001	6.76×10^{-8}
B. Metals						
Antimony	5.5	4.95×10^{-4}	*	0.00	*	0.00
Arsenic	3166.04	2.85×10^{-1}	*	0.00	*	0.00
Barium	258.31	2.32×10^{-2}	*	0.00	*	0.00
Beryllium	29.14	2.62×10^{-3}	0.85	1.21×10^{-5}	0.866	5.85×10^{-5}
Cadmium	94.09	8.47×10^{-3}	4.2	5.96×10^{-5}	5.682	3.84×10^{-4}
Chromium	394.57	3.55×10^{-2}	28.4	4.03×10^{-4}	18.584	1.26×10^{-3}
Cobalt	2870.72	2.58×10^{-1}	*	0.00	*	0.00

TABLE E.1-5
(Continued)

Contaminant	Silo 3 Materials (Future Scenario)		Berm Fill Materials (Current & Future Scenario)		Surface Soil Around Silos (Current & Future Scenario)	
	Concentration (µg/g)	Emission Flux (µg/m2-sec)	Concentration (µg/g)	Emission Flux (µg/m2-sec)	Concentration (µg/g)	Emission Flux (µg/m2-sec)
Copper	3336.91	3.00×10^{-1}	*	0.00	*	0.00
Lead	2377.27	2.14×10^{-1}	*	0.00	*	0.00
Manganese	5163.61	4.65×10^{-1}	*	0.00	*	0.00
Mercury	0.69	6.21×10^{-5}	*	0.00	*	0.00
Nickel	4286.88	3.86×10^{-1}	32.4	4.60×10^{-4}	31.986	2.16×10^{-3}
Selenium	229.45	2.07×10^{-2}	*	0.00	*	0.00
Silver	18.43	1.66×10^{-3}	*	0.00	*	0.00
Thallium	56.15	5.05×10^{-3}	*	0.00	*	0.00
Vanadium	3488.76	3.14×10^{-1}	*	0.00	*	0.00
Zinc	534.65	4.81×10^{-2}	*	0.00	*	0.00
C. Radionuclides						
Ac-227	793.249	7.14×10^{-2}	*	0.00	*	0.00
Pa-231	931	8.38×10^{-2}	*	0.00	*	0.00
Lead-210	4729.52	4.26×10^{-1}	3.979	5.65×10^{-5}	*	0.00
Polonium-210	*	0.00	4.020	5.71×10^{-5}	*	0.00
Radium-224	367.114	3.30×10^{-2}	1.020	1.45×10^{-5}	*	0.00
Radium-226	3871.63	3.48×10^{-1}	6.680	9.49×10^{-5}	2.179	1.47×10^{-4}
Radium-228	405.641	3.65×10^{-2}	*	0.00	1.258	8.50×10^{-5}
Strontium-90	*	0.00	*	0.00	1.800	1.22×10^{-4}

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TABLE E.1-5
(Continued)

Contaminant	Silo 3 Materials (Future Scenario)		Berm Fill Materials (Current & Future Scenario)		Surface Soil Around Silos (Current & Future Scenario)	
	Concentration (µg/g)	Emission Flux (µg/m2-sec)	Concentration (µg/g)	Emission Flux (µg/m2-sec)	Concentration (µg/g)	Emission Flux (µg/m2-sec)
Technetium-99	*	0.00	*	0.00	0.929	6.28×10^{-5}
Thorium-228	1339	7.88×10^{-2}	*	0.00	*	0.00
Thorium-230	56851	$5.42 \times 10^{+00}$	4.780	6.79×10^{-5}	4.800	3.24×10^{-4}
Thorium-232	984.932	7.84×10^{-2}	1.347	1.91×10^{-5}	*	0.00
Uranium-234	1935	1.75×10^{-1}	3.620	5.14×10^{-5}	3.400	2.30×10^{-4}
Uranium-235/236	117.341	1.06×10^{-2}	*	0.00	*	0.00
Uranium-238	1775.48	1.60×10^{-1}	4.170	5.92×10^{-5}	12.336	8.34×10^{-4}

*These are not constituents of concern (COC) for this source.

Note: The emission flux of total suspended particulate (TSP) is as follows:
(1) for Silo 3 materials, 9.00×10^{-5} g/m^2-sec
(2) for berm fill materials, 1.42×10^{-5} g/m^2-sec
(3) for surface soil around silos, 6.76×10^{-5} g/m^2-sec]

Direct measurements of wind speed, wind direction, and ambient air temperature are taken at a height of 10 m above the ground. The atmospheric stability category is derived from direct measurements of the standard deviation of the horizontal wind direction (σ_θ) during the daytime and the low-level temperature difference (ΔT) at night. Measurements of σ_θ are taken at a height of 60 m above the ground. The temperature difference is calculated from air temperature measurements taken at 60 m and 10 m above the ground. The key to atmospheric stability categories based on σ_θ and ΔT measurements is provided in Table E.1-6.

Mixing heights were determined from twice daily atmospheric soundings made by the National Weather Service (NWS). The nearest NWS station reporting twice daily mixing heights is located in Dayton, Ohio.

The format of the meteorological data required by the ISCLT2 model is in the form of the stability array (STAR) program output. The STAR program output is a statistical meteorological data summary which gives the joint frequency distribution of six wind speed classes by 16 wind sectors by six atmospheric stability categories. The six wind speed classes are defined as 1 to 3 miles per hour (mph); 4 to 7 mph; 8 to 12 mph; 13 to 18 mph; 19 to 24 mph; and greater than 24 mph. Calm winds are wind speeds less than 1 mph with a variable (undetermined) wind direction. To account for the calm winds measured at the FEMP, the frequency of occurrence of calm winds were equally distributed among the 16 wind direction sectors and added to the 1 to 3 mph wind speed class. The wind direction sectors are defined in 22.5° increments as follows:

Winds Blowing From	Wind Direction and Range
North	360° ± 11.25°
North-northeast	22.5° ± 11.25°
Northeast	45° ± 11.25°
East-northeast	67.5° ± 11.25°
East	90° ± 11.25°
East-southeast	112.5° ± 11.25°
Southeast	135° ± 11.25°
South-southeast	157.5° ± 11.25°
South	180° ± 11.25°
South-southwest	202.5° ± 11.25°
Southwest	225° ± 11.25°
West-southwest	247.5° ± 11.25°
West	270° ± 11.25°
West-northwest	292.5° ± 11.25°
Northwest	315° ± 11.25°
North-northwest	337.5° ± 11.25°

TABLE E.1-6

CLASSIFICATION OF ATMOSPHERIC STABILITY BY SIGMA THETA MEASUREMENTS AND TEMPERATURE CHANGE WITH HEIGHT

Stability Classification	Pasquill Categories	Daytime (°)	Nighttime Temperature Change with Height (°C/100 m)
Extremely unstable	A	$\sigma_\Theta \geq 22.5$	$\Delta T/\Delta z \leq -1.9$
Moderately unstable	B	$22.5 > \sigma_\Theta \geq 17.5$	$-1.9 \leq \Delta T/\Delta z \leq -1.7$
Slightly unstable	C	$17.5 > \sigma_\Theta \geq 12.5$	$-1.7 \leq \Delta T/\Delta z \leq -1.5$
Neutral	D	$12.5 > \sigma_\Theta \geq 7.5$	$-1.5 \leq \Delta T/\Delta z \leq -0.5$
Slightly stable	E	$7.5 > \sigma_\Theta \geq 3.8$	$-0.5 \leq \Delta T/\Delta z \leq 1.5$
Moderately stable	F	$3.8 > \sigma_\Theta \geq 2.1$	$1.5 \leq \Delta T/\Delta z \leq 4.0$
Extremely stable	G	$2.1 > \sigma_\Theta$	$4.0 < \Delta T/\Delta z$

σ_Θ - Standard deviation of the horizontal wind speed
ΔT - Temperature difference
Δz - Height

The frequency of occurrence of atmospheric stability categories A, B, C, D, E, and F are required as input to the ISCLT2 model. The frequency of occurrence of atmospheric stability category G, as defined by the ΔT method of classification, was incorporated into the F stability category.

Hourly measurements of wind speed, wind direction, and atmospheric stability category were obtained for the FEMP site for 1987 through 1992. The EPA's STAR program (version 91,008) was obtained from the Support Center for Regulatory Air Models (SCRAM) bulletin board system (BBS) and modified to process the meteorological data stored in FEMP format. Since atmospheric stability category is provided in the FEMP data set based on on-property measurements of σ_θ and ΔT as previously described, the method of defining atmospheric stability category as built into the STAR program was not used. The FEMP data files were checked for missing data (data fields coded with 999.99 for wind speed and wind direction or "*" for atmospheric stability category) or invalid data (validation codes of "I" for invalid data or "S" for stalled instrument). The data for each year were processed individually so that six joint frequency distribution tables were prepared. The percentage of valid data recovered from the FEMP meteorological monitoring program for each year is given in Table E.1-7. The annual summaries of the joint frequency distribution of wind speed, wind direction, and atmospheric stability category for 1987, 1988, 1989, 1990, 1991, and 1992 are given in Attachment E.1-III. Graphical representations of these data are provided in the wind roses of Figures E.1-6 through E.1-11 for the years 1987 through 1992, respectively.

The ambient air temperatures measured at the FEMP meteorological station and the temperatures used in the ISCLT2 model as a function of atmospheric stability category are given in Tables E.1-8a, and E.1-8b. Assignments of temperatures to stability categories were made as per EPA (1986) recommendations. The annual average maximum daily temperature was assigned to the A, B, and C stability categories; the annual average temperature was assigned to the D stability category; and the annual average minimum daily temperature was assigned to the E and F stability categories.

Twice daily mixing heights for Dayton, Ohio were obtained from the SCRAM BBS. The latest 5-year record of mixing height data provided on SCRAM for Dayton are for the years 1985 through 1989. These data were processed to determine the average morning and average afternoon mixing heights for each of the six wind speed classes for each year. Assignments of mixing heights to stability categories were made as per EPA (1986) recommendations. One and one-half times the mean afternoon mixing height was assigned to the A stability category; the mean afternoon mixing height was assigned to the B, C, and D stability categories; and 5000 m was assigned to the E and F stability categories to simulate no restriction to vertical mixing. The mixing height measurements at Dayton, Ohio, and the mixing heights used in the ISCLT2 model as a function of wind speed class and atmospheric stability category are given in Tables E.1-9a, and E.1-9b.

TABLE E.1-7

VALID DATA RECOVERY RATES FOR THE FEMP METEOROLOGICAL MONITORING PROGRAM

Year	Data Recovery (%)
1987	83
1988	88
1989	95
1990	76
1991	93
1992	96

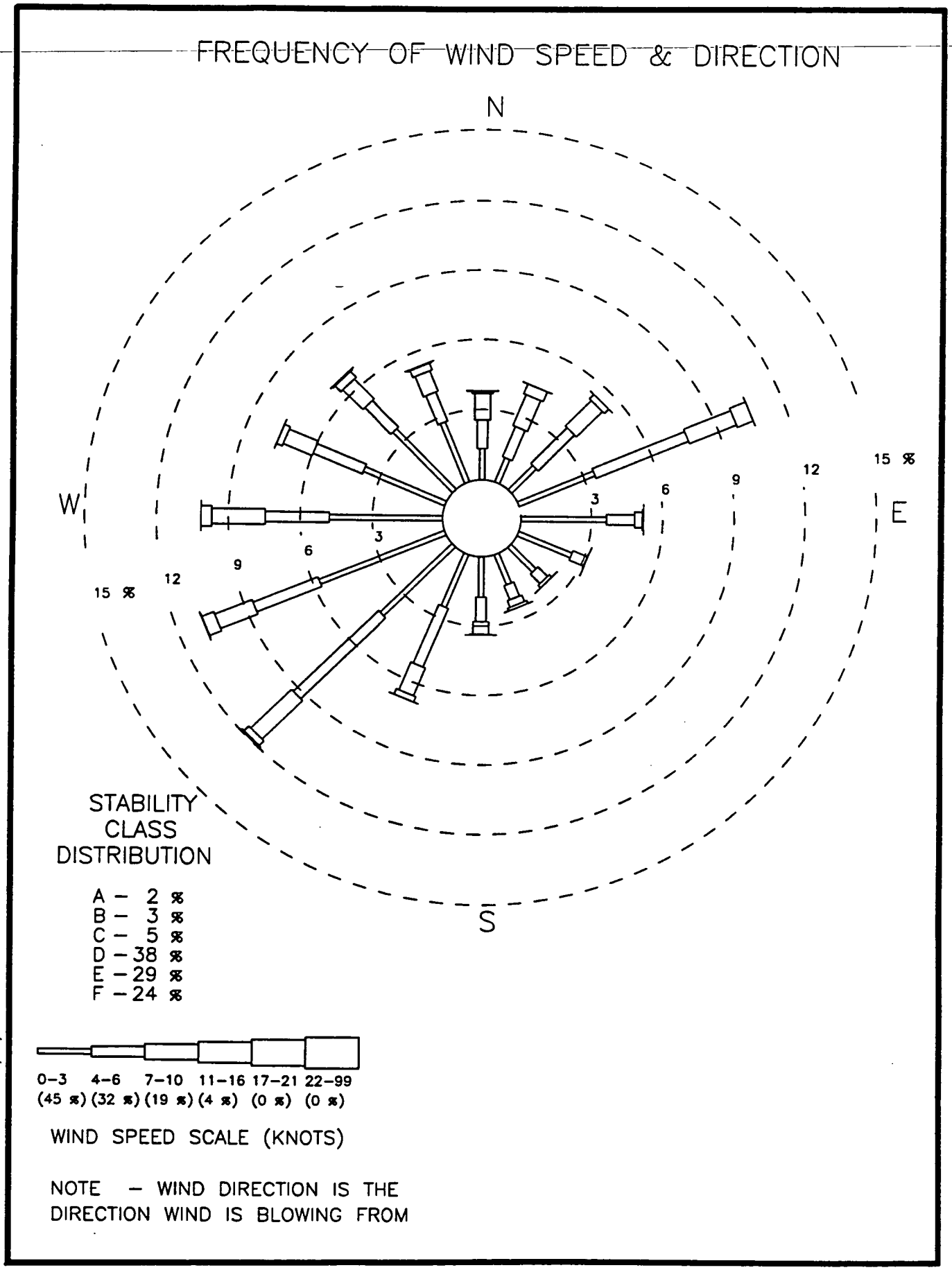

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FIGURE E.1–6. WIND ROSE FOR THE FEMP SITE YEAR–1987

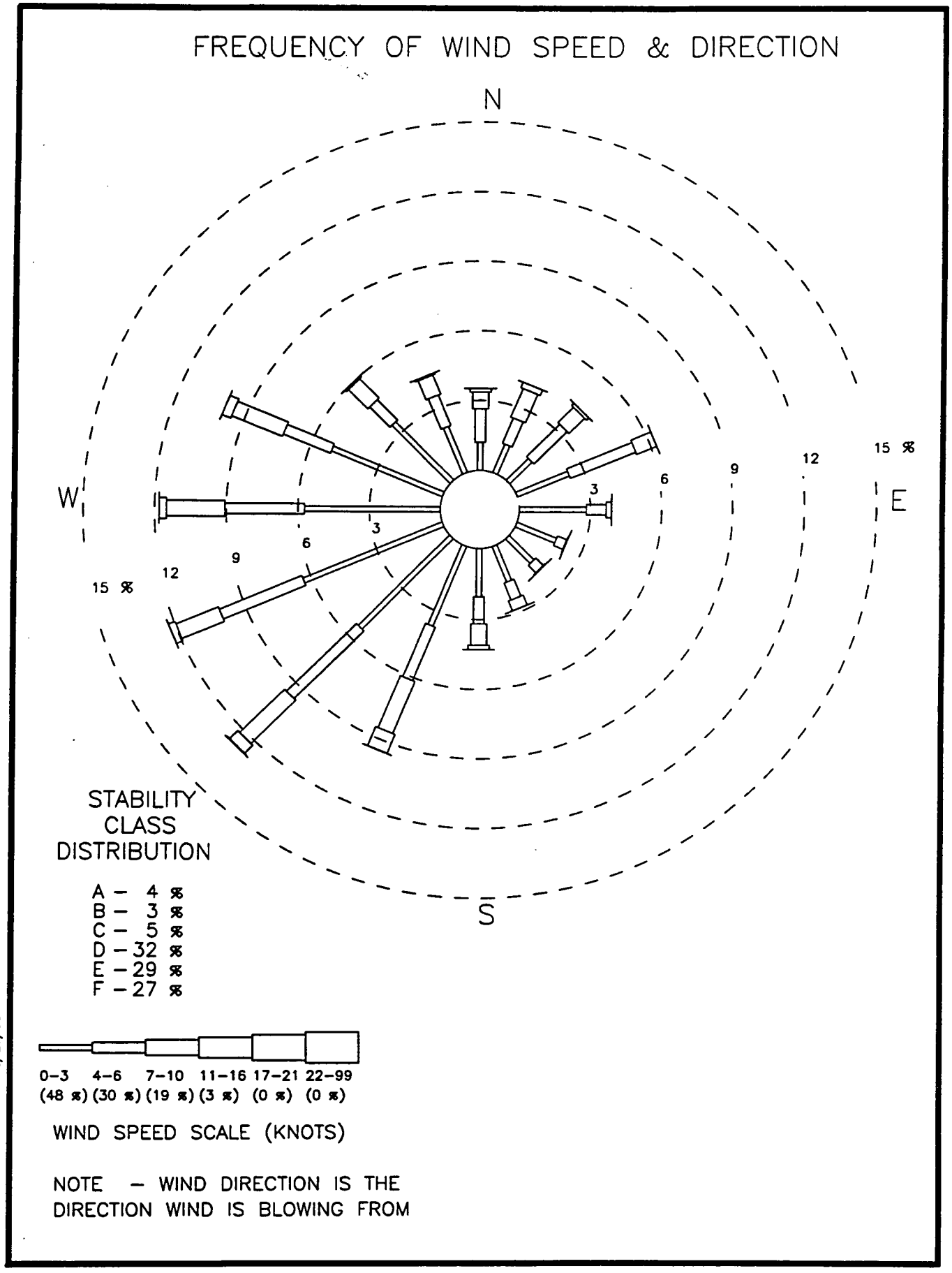

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FIGURE E.1-7. WIND ROSE FOR THE FEMP SITE YEAR-1988

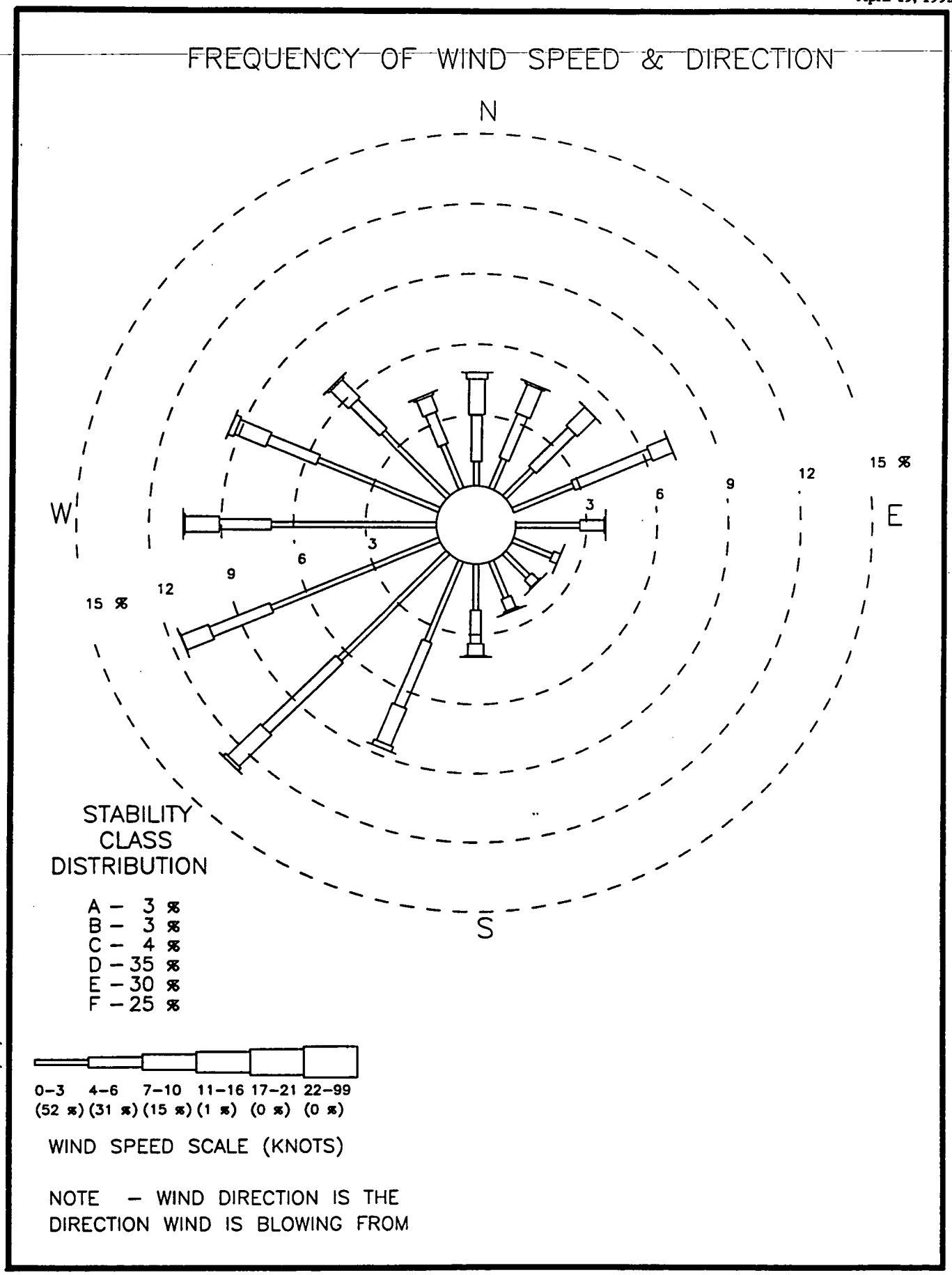

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FIGURE E.1-8. WIND ROSE FOR THE FEMP SITE YEAR-1989

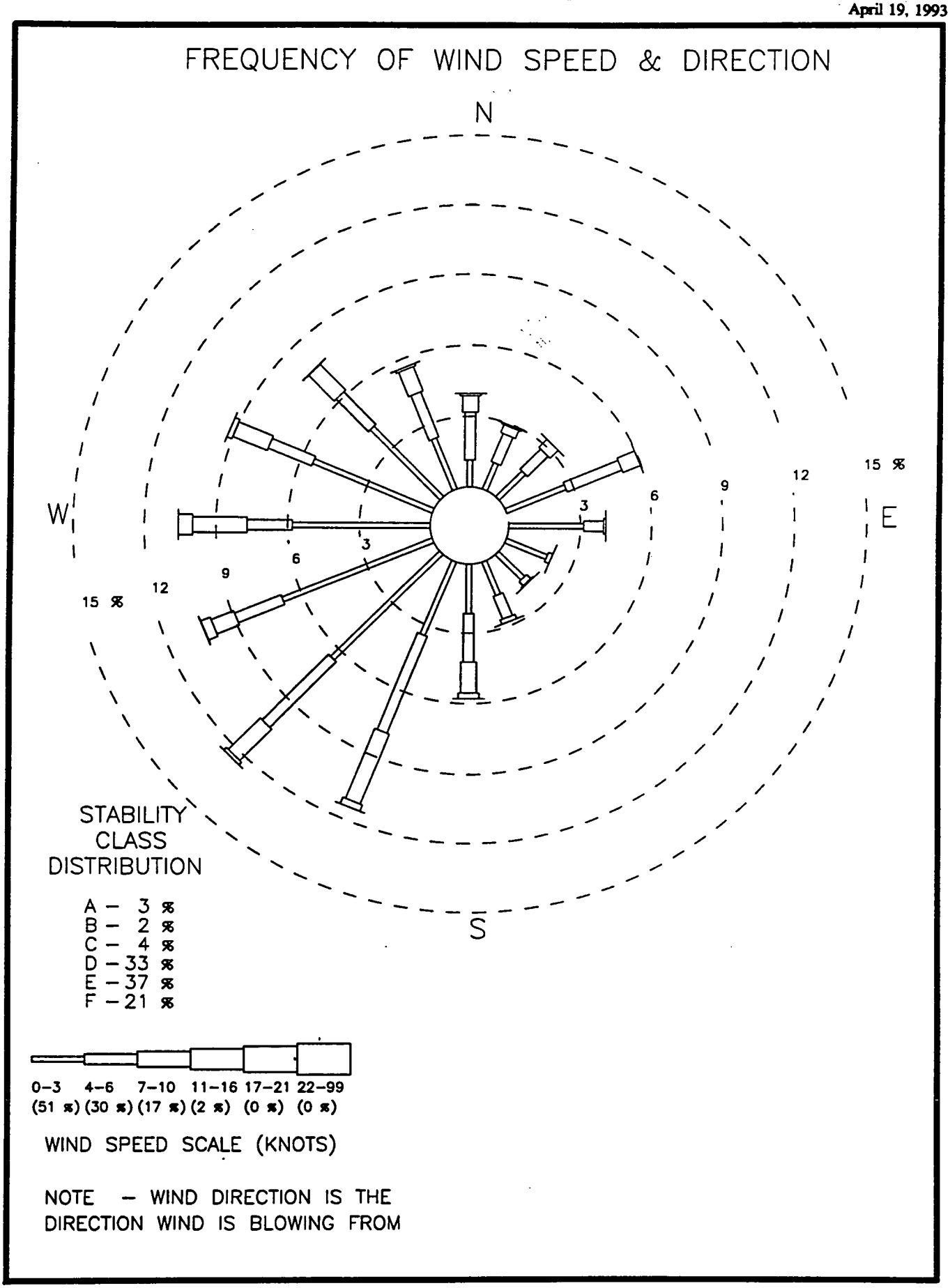

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FIGURE E.1–9. WIND ROSE FOR THE FEMP SITE YEAR–1990

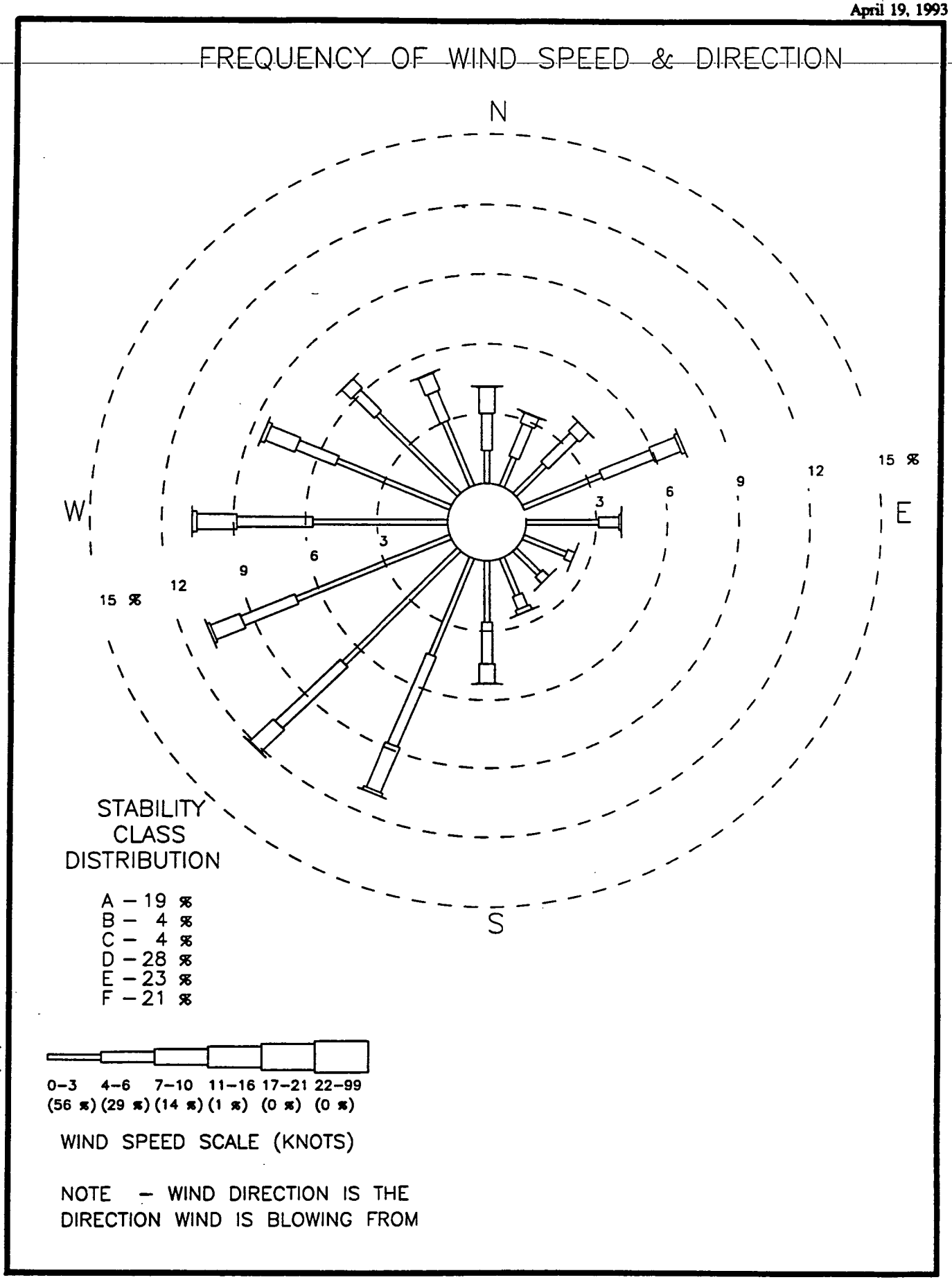

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FIGURE E.1–10. WIND ROSE FOR THE FEMP SITE YEAR–1991

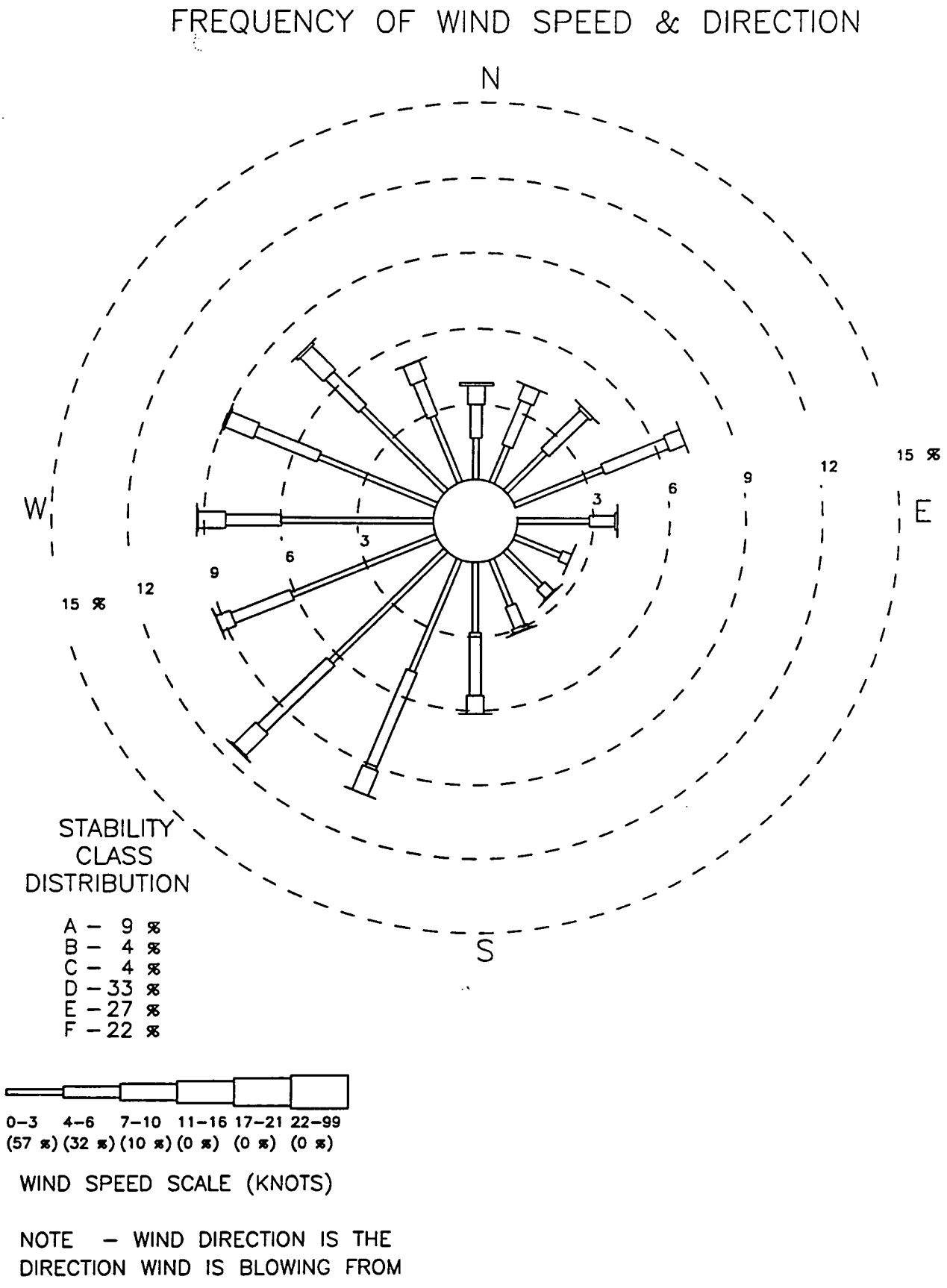

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FIGURE E.1–11. WIND ROSE FOR THE FEMP SITE YEAR–1992

TABLE E.1-8a

AMBIENT AIR TEMPERATURES MEASURED AT THE FEMP METEOROLOGICAL STATION

Year	Average Annual Temperature (°C)	Average Annual Daily Minimum Temperature (°C)	Average Annual Daily Maximum Temperature (°C)
1987	10.4	5.0	16.4
1988	11.3	5.5	17.6
1989	11.2	6.7	17.1
1990	11.4	6.2	16.9
1991	13.0	8.2	18.4
1992	11.1	6.3	16.5

TABLE E.1-8b

AMBIENT AIR TEMPERATURES (°K) USED IN THE ISCLT2 MODEL

	Stability Class					
Year	A	B	C	D	E	F
1987	290	290	290	284	278	278
1988	291	291	291	284	279	279
1989	290	290	290	284	280	280
1990	290	290	290	285	279	279
1991	292	292	292	286	281	281
1992	290	290	290	284	279	279

TABLE E.1-9a

MIXING HEIGHT MEASUREMENTS AT DAYTON, OHIO

Year	Wind Speed Class	Average Morning Mixing Height (m)	Average Afternoon Mixing Height (m)
1985	1	256	1021
	2	399	1145
	3	620	1201
	4	803	1092
	5	1269	1041
	6	2020	1418
1986	1	352	1085
	2	440	1232
	3	637	1108
	4	1000	1095
	5	1080	1155
	6	0	0
1987	1	255	1403
	2	374	1307
	3	565	1202
	4	844	1201
	5	795	1017
	6	0	1566
1988	1	199	1422
	2	326	1567
	3	615	1353
	4	926	1208
	5	1112	1110
	6	0	2170
1989	1	338	1236
	2	486	1330
	3	666	1132
	4	989	1016
	5	878	1153
	6	0	0

TABLE E.1-9b

MIXING HEIGHT VALUES (m) USED IN THE ISCLT2 MODEL

Year	Stability Class	Wind Speed Class 1	2	3	4	5	6
1987	A	2105	1961	1803	1802	1526	2349
	B	1403	1307	1202	1201	1017	1566
	C	1403	1307	1202	1201	1017	1566
	D	1403	1307	1202	1201	1017	1566
	E	5000	5000	5000	5000	5000	5000
	F	5000	5000	5000	5000	5000	5000
1988	A	2133	2351	2030	1812	1665	3255
	B	1422	1567	1353	1208	1110	2170
	C	1422	1567	1353	1208	1110	2170
	D	1422	1567	1353	1208	1110	2170
	E	5000	5000	5000	5000	5000	5000
	F	5000	5000	5000	5000	5000	5000
1989	A	1854	1995	1698	1524	1730	2313*
	B	1236	1330	1132	1016	1153	1542*
	C	1236	1330	1132	1016	1153	1542*
	D	1236	1330	1132	1016	1153	1542*
	E	5000	5000	5000	5000	5000	5000
	F	5000	5000	5000	5000	5000	5000
1990-1992*	A	1823	1991	1791	1695	1629	2313
	B	1215	1327	1194	1130	1086	1542
	C	1215	1327	1194	1130	1086	1542
	D	1215	1327	1194	1130	1086	1542
	E	5000	5000	5000	5000	5000	5000
	F	5000	5000	5000	5000	5000	5000

* - Based on 5-year average of mixing heights measured in Dayton during 1985-1987.

E.1.8 DISPERSION COEFFICIENTS

The selection of rural or urban dispersion coefficients for use in the ISCLT2 model was based on a land use typing procedure to determine whether the characteristics of the area around the FEMP are primarily rural or urban. The land use procedure first involves classifying the land use within an area circumscribed by a 3 km radius about Operable Unit 4. Urban dispersion coefficients are recommended for use if land use types of heavy industrial, light-moderate industrial, commercial, single compact residential, and multicompact residential as defined by Auer (1978) account for 50 percent or more of the area. Otherwise, rural dispersion coefficients are recommended for use.

The land use types within a 3 km radius of Operable Unit 4 were characterized based on a simplification of Auer's land use typing scheme as presented in the Boiler and Industrial Furnace Regulations (40CFR266). This simplified procedure is based on the color coding on U.S. Geological Survey (USGS) maps. The simplifying assumption is that many situations will have a clear-cut rural or urban designation. The suggested typing designations for the color codes on USGS topographic maps are given in Table E.1-10.

It was estimated from USGS maps and a site survey of the area that industrial, commercial, and compact residential land use comprise no more than 10 percent of the area within a 3 km radius of Operable Unit 4. Therefore, the area is classified as rural for the purpose of air dispersion modeling and rural dispersion coefficients were selected for use in the modeling.

E.1.9 RECEPTORS

The primary objective of the air transport analysis was to determine the maximum on-property and off-property concentration of the contaminants. The analytical equation used in the gaussian plume models such as ISCLT2 calculates the concentration only at preselected locations or receptors. A number of such receptors in all directions from the sources are required, therefore, to identify the location of the maximum concentration. In air dispersion modeling terminology, these receptors around the source of emissions are commonly referred to as the "receptor grid." A rectangular receptor grid was used for this analysis in which the locations of the receptors were expressed as "X" and "Y" coordinates on a cartesian system. The cartesian grid system was considered the midpoint of the vertical, plan view line joining the K-65 silo centers.

Both coarse and fine rectangular receptor grids were used to determine the on-property and off-property maximum concentrations and their locations. The purpose of the coarse grid was to determine the approximate location of the maximum concentrations. The resolution of the coarse grid as 100 m x 100 m for determining the on-property maximum concentration and 250 m x 250 m for determining the off-property maximum concentration. The on-property and the off-property coarse grids extended to 1500 m and 5000 m respectively on all sides of the origin. Figure E.1-12 shows the layout of the coarse receptor grid considered in the air dispersion modeling.

TABLE E.1-10

SIMPLIFIED LAND USE TYPING PROCEDURE

1. GREEN	Rural	Wooded areas
2. WHITE	Rural	White areas are generally treated as rural. This code applies to areas that are unwooded and do not have densely packed structures. Parks, unforested rural land, and industrial areas will appear as white on USGS topographic maps. Of these categories, only the industrial areas (which can be easily identified in most cases), could potentially be classified as urban. For the simplified procedure, white areas that have an industrial classification are treated as an urban area.
3. PINK	Urban	Pink areas indicate house omissions and are treated as urban areas in the simplified procedure. The effect of this simplification is to group common residential housing types into the urban fraction, thereby removing the need to consider housing types.
4. BLUE	Rural	Water areas

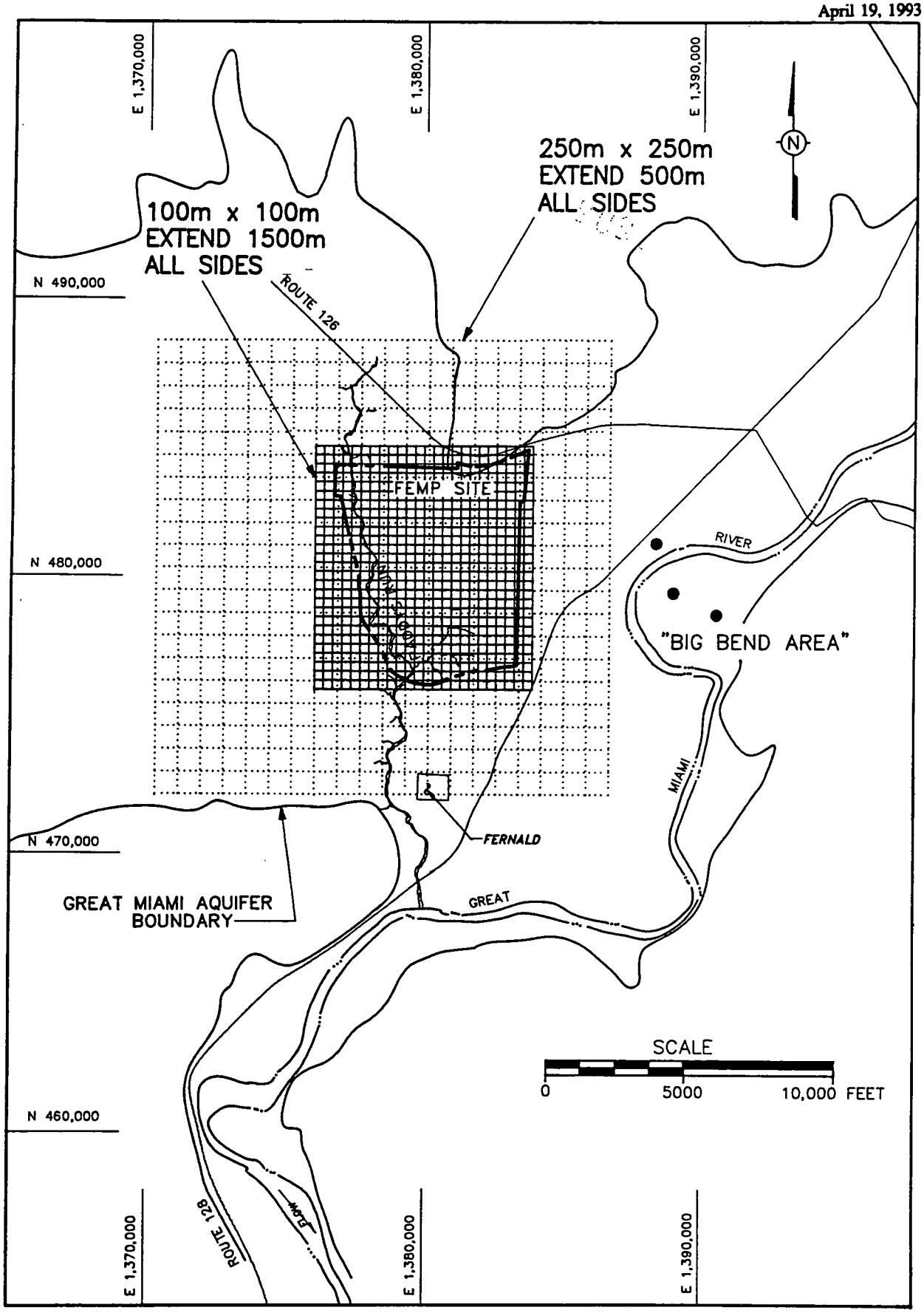

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FIGURE E.1-12. RECTANGULAR RECEPTOR GRID FOR AIR DISPERSION MODELING

In the next phase of the modeling, fine grids were used to determine the maximum concentration with a finer receptor resolution. The fine grids were placed around the locations of maximum concentrations determined from the coarse grid modeling. The resolution of the fine grid for on-property receptors was 25 m X 25 m extending 100 m on all sides of the location of the coarse grid on-property maximum concentration. For the off-property receptors, the resolution of the fine grid was 50 m x 50 m on all sides of the location of the coarse grid off-property maximum concentration.

Discrete receptor locations were also used in the modeling to account for concentrations at the FEMP fenceline and at some sensitive receptors. The locations of the fenceline receptors were determined from the intersection of the fenceline and the lines extending from the origin of the receptor grid system in thirty-six directions at 10° intervals. Seven schools and daycare centers within the modeling region were considered as sensitive receptors. These were:

1. Crosby Elementary
2. Morgan Elementary
3. Elda Elementary
4. St. John Elementary
5. Ross Middle and High School
6. Ross City Daycare
7. Venice Presbyterian Preschool

Table E.1-11 gives the coordinates of the fenceline and the sensitive receptors considered in the air dispersion modeling.

E.1.10 PROCESSING THE OUTPUT FROM THE AIR DISPERSION MODEL

The ISCLT2 modeling was performed considering emissions from six sources for 43 pollutants; for current and future scenarios; for 2685 receptor locations; and for six years of meteorological data (six wind speed classes by 16 wind direction sectors by six atmospheric stability categories). This represents a potential maximum of over 4.5 billion pollutant concentrations to be calculated in the air dispersion modeling analysis.

The air dispersion modeling analysis was simplified by running the ISCLT2 model assuming an arbitrary unit area source emission rate of 0.1 grams per square meter per second for each of the Operable Unit 4 sources. Computer programs were developed to process the unit contributions from each source for each receptor and calculate a combined concentration based on pollutant-specific source emission rates. The maximum pollutant concentrations predicted to occur due to air emissions from the Operable Unit 4 sources for current and future scenarios were summarized in computer generated reports. Figure E.1-13 has been prepared to show the major steps of the data handling process.

TABLE E.1-11

COORDINATES OF FENCELINE AND SENSITIVE RECEPTORS

A. Fence Line Receptors

ID	Angles (degrees)	Radial Distance (m)
FEMP-1	10	1077
FEMP-2	20	1130
FEMP-3	30	1230
FEMP-4	40	1456
FEMP-5	50	1984
FEMP-6	60	1741
FEMP-7	70	1551
FEMP-8	80	1486
FEMP-9	90	1469
FEMP-10	100	1498
FEMP-11	110	1572
FEMP-12	120	1718
FEMP-13	130	1753
FEMP-14	140	1562
FEMP-15	150	1470
FEMP-16	160	1433
FEMP-17	170	1322
FEMP-18	180	960
FEMP-19	190	767
FEMP-20	200	660
FEMP-21	210	558
FEMP-22	220	441
FEMP-23	230	397
FEMP-24	240	416
FEMP-25	250	339
FEMP-26	260	339
FEMP-27	270	350
FEMP-28	280	380
FEMP-29	290	418
FEMP-30	300	488
FEMP-31	310	565
FEMP-32	320	797
FEMP-33	330	1195
FEMP-34	340	1133
FEMP-35	350	1076
FEMP-36	360	1060

TABLE E.1-11
(Continued)

B. Sensitive Receptors

Receptor ID	Location	X (m)	Y (m)
SR 1	Crosby Elementary	-2800	-3400
SR 2	Morgan Elementary	-3925	3400
SR 3	Elda Elementary	6510	2450
SR 4	St. John Elementary	6260	-5660
SR 5	Ross Middle & High	6260	5660
SR 6	Ross City Daycare	3430	2830
SR 7	Venice Presb. Pre-School	2860	2260

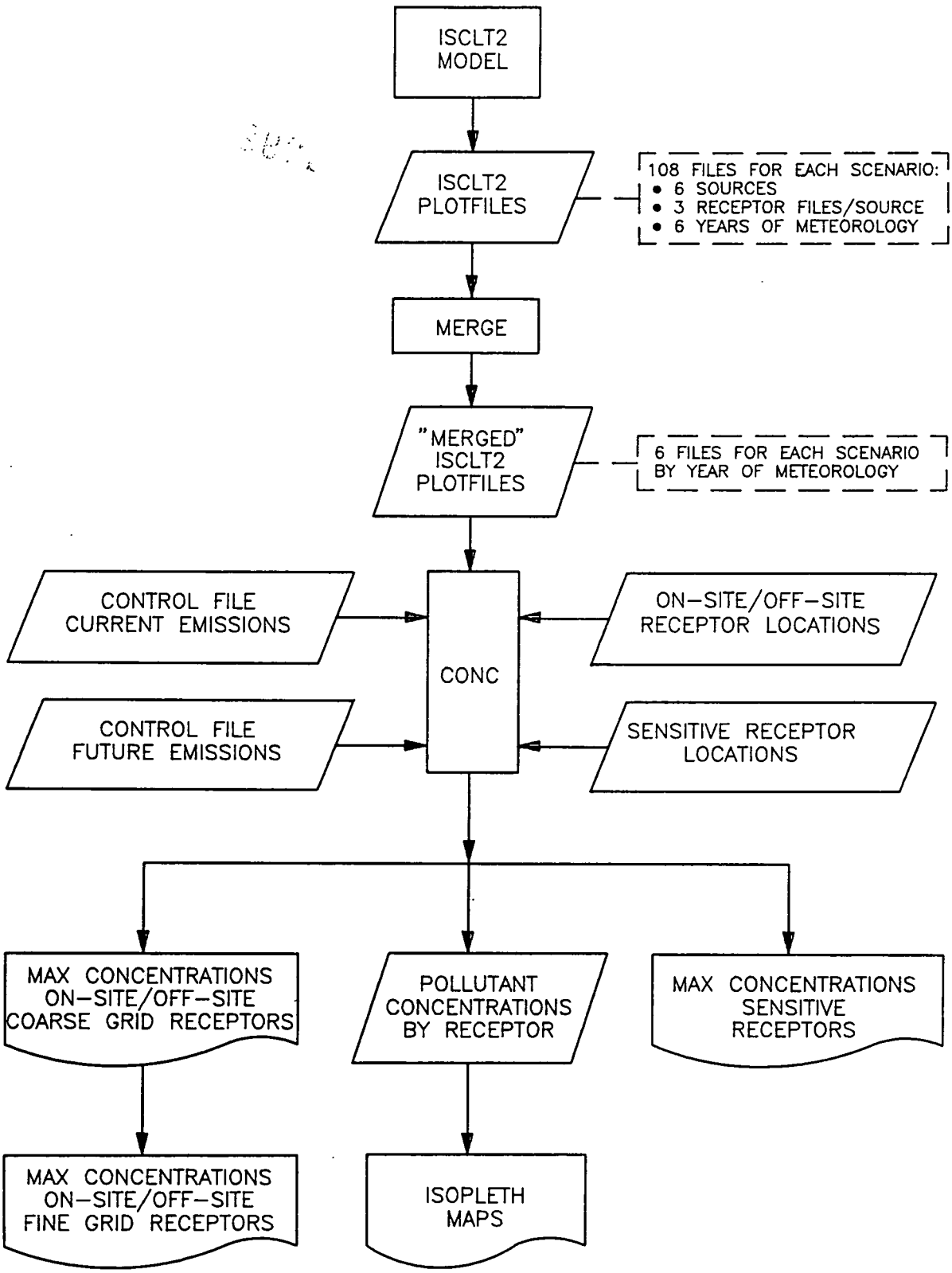

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FIGURE E.1-13. FLOW DIAGRAM OF DATA HANDLING PROCEDURES

The results of the ISCLT2 model runs were written to a computer disk file produced by specifying the "PLOTFILE" output option. One hundred eight (108) plotfiles were generated for each scenario from the ISCLT2 model runs. Stored in each of these plotfiles were the predicted unit concentrations of each of the six Operable Unit 4 sources for three receptor files per source for six years of meteorology. There are three receptor files per source since a maximum of 1200 receptors per run can be processed by the ISCLT2 model.

The computer program "MERGE" was written to combine plotfiles. Six merged files were produced for each scenario; one for each year of meteorology. Stored in each merged file are the unit concentrations of all six sources and all 2685 receptors.

The computer program "CONC" was written to calculate a combined concentration for each receptor based on pollutant-specific source emission rates. Control files were prepared as input to the CONC program which contained the area source emission rates for the six sources for 43 pollutants. Two control files were prepared, one to specify current emission conditions and one to specify future emission conditions. Receptor location files were also prepared as input to the CONC program to specify whether a receptor location was on-property, off-property, or a designated sensitive receptor. The CONC program accessed the unit concentrations stored in the merged files to calculate a combined concentration. Reports were generated by the CONC program to summarize the maximum concentrations predicted to occur on-property, off-property, and at sensitive receptors. These reports were generated for each pollutant, for each year of meteorology, and for current and future scenarios. The CONC program was also used to produce computer disk files of predicted pollutant concentrations for each receptor. These files were used to create isopleth maps which illustrate the spatial distribution of predicted pollutant concentrations.

E.1.11 RESULTS OF AIR DISPERSION MODELING

This section presents the results of the air dispersion modeling for the Operable Unit 4, based on the methodology and input data described in earlier sections of this appendix. The results for the current and future scenarios are presented separately. Copies of typical runstream input and output files of the air dispersion modeling are included in Attachment E.1-IV.

E.1.11.1 Current Scenario

Table E.1-12 presents the maximum annual average ground level concentrations for all the chemical constituents of concern from the Operable Unit 4 for the current scenario. This table includes both the on-property and the off-property maximum concentrations and the locations of these maximum concentrations. The locations are given in cartesian coordinates from the origin of the receptor grid system. These maximum on-property and off-property concentrations were considered in the baseline risk assessment for this scenario as described in Appendix D of the RI report.

TABLE E.1-12
MAXIMUM ANNUAL AVERAGE GROUND LEVEL CONCENTRATIONS FROM AIR DISPERSION MODELING CURRENT SCENARIO

Contaminant	ON-SITE RECEPTORS			OFF-SITE RECEPTORS		
	Maximum Concentration	Location[a] X (m)	Location[a] Y (m)	Maximum Concentration	Location[a] X (m)	Location[a] Y (m)
Organics ($\mu g/m^3$)						
2-Butanone	1.00×10^{-6}	50	25	0.00	b	b
Benzo(a)anthracene	1.10×10^{-4}	50	0	8.00×10^{-6}	-333.85	-58.87
Benzo(a)pyrene	1.21×10^{-4}	50	0	9.0×10^{-6}	-333.85	-58.87
Benzo(b)fluoranthene	1.49×10^{-4}	50	0	1.10×10^{-5}	-333.85	-58.87
Chrysene	1.00×10^{-4}	50	0	8.00×10^{-6}	-333.85	-58.87
Dibenzo(a,h)anthracene	6.40×10^{-5}	50	0	5.00×10^{-6}	-333.85	-58.87
Indeno(1,2,3,c,d)pyrene	1.12×10^{-4}	50	0	9.00×10^{-6}	-333.85	-58.87
Methylene chloride	4.00×10^{-6}	50	0	0.00	b	b
Toluene	5.00×10^{-6}	75	0	0.00	b	b
Metals ($\mu g/m^3$)						
Antimony	0.00	b	b	0.00	b	b
Arsenic	0.00	b	b	0.00	b	b
Barium	0.00	b	b	0.00	b	b
Beryllium	1.89×10^{-4}	50	25	1.50×10^{-05}	-333.85	-58.87
Cadmium	1.20×10^{-3}	50	25	9.30×10^{-5}	-333.85	-58.87
Chromium	4.35×10^{-3}	50	25	3.33×10^{-4}	-333.85	-58.87
Cobalt	0.00	b	b	0.00	b	b
Copper	0.00	b	b	0.00	b	b

TABLE E.1-12
(Continued)

Contaminant	ON-SITE RECEPTORS Maximum Concentration	Location[a] X (m)	Location[a] Y (m)	OFF-SITE RECEPTORS Maximum Concentration	Location[a] X (m)	Location[a] Y (m)
Lead	0.00	b	b	0.00	b	b
Manganese	0.00	b	b	0.00	b	b
Mercury	0.00	b	b	0.00	b	b
Nickel	7.03×10^{-3}	50	25	5.39×10^{-4}	-333.85	-58.87
Selenium	0.00	b	b	0.00	b	b
Silver	0.00	b	b	0.00	b	b
Thallium	0.00	b	b	0.00	b	b
Vanadium	0.00	b	b	0.00	b	b
Zinc	0.00	b	b	0.00	b	b
Radionuclides (pCi/m^3)						
Ac-227	0.00	c	c	0.00	c	c
Pa-231	0.00	c	c	0.00	c	c
Pb-210	1.27×10^{-4}	75	0	9.00×10^{-6}	-318.55	-115.94
Po-210	1.29×10^{-4}	75	0	9.00×10^{-6}	-318.55	-115.94
Ra-224	3.30×10^{-5}	75	0	2.00×10^{-6}	-318.55	-115.94
Ra-226	6.05×10^{-4}	50	25	4.60×10^{-5}	-333.85	-58.87
Ra-228	2.42×10^{-4}	50	0	1.90×10^{-5}	-333.85	-58.87
Rn	1.56×10^{2}	25	75	2.60×10^{0}	-333.85	-58.87
Sr-90	3.47×10^{-4}	50	0	2.70×10^{-5}	-333.85	-58.87
Tc-99	1.79×10^{-4}	50	0	1.40×10^{-5}	-333.85	-58.87
Th-228	0.00	c	c	0.00	c	c

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TABLE E.1-12
(Continued)

Contaminant	ON-SITE RECEPTORS			OFF-SITE RECEPTORS		
	Maximum Concentration	Location[a] X (m)	Location[a] Y (m)	Maximum Concentration	Location[a] X (m)	Location[a] Y (m)
Th-230	1.05×10^{-3}	50	25	8.10×10^{-5}	-333.85	-58.87
Th-232	4.30×10^{-5}	75	0	3.00×10^{-6}	-318.55	-115.94
U-234	7.52×10^{-4}	50	25	5.80×10^{-5}	-333.85	-58.87
U-235/236	0.00	c	c	0.00	c	c
U-238	2.47×10^{-3}	50	25	1.91×10^{-4}	-333.85	-58.87

[a] The origin is at plant coordinantes (S 42+79.89, E 19+68.45).
[b] This is not a chemical constituent of concern, the concentration is less than 1 picogram per cubic meter (pg/m^3).
[c] This is not a chemical constituent of concern, the concentration is less than 1 attocurie per cubic meter (aCi/m^3).

Figures E.1-14 to E.1-16 show isopleths of ground level concentrations around the Operable Unit 4 for three typical contaminants in this scenario (i.e., radon, benzo(a)pyrene, and uranium-238). The figures indicate that higher concentrations would occur on the northeast and east-northeast directions from the centerline of Operable Unit 4. This is consistent with the prevailing wind direction at the site as shown in Figures E.1-6 to E.1-11 under Section E.1-7 (Meteorological Data). The location of the maximum on-property concentrations are also consistent with the prevailing wind direction.

Table E.1-12 and Figures E.1-14 to E.1-16 indicate that the off-property maximum for this scenario would occur on the west of the Operable Unit 4 and on or near the fenceline. This could be explained from the fact that while the prevailing wind was toward the east to northeast, the nearest fence line was located to the west. The concentration from a source decreases drastically with distance. Thus, the farther fenceline receptors in the prevailing wind direction (on the east and northeast side) experienced a lower concentration than the west side fenceline receptor.

The annual average ground level concentrations of the contaminants at the sensitive receptors are shown in Table E.1-13. The concentrations of many of the contaminants were below 1 picogram per cubic meter (pg/m^3) for organics and metals or 1 attocurie per cubic meter (aCi/m^3) for radionuclides. These receptors were located at large distances from the Operable Unit 4.

E.1.11.2 Future Scenario

The maximum on-property and off-property annual average ground level concentrations for this scenario for the contaminants are presented in Table E.1-14. These maximum concentrations have been considered in the baseline risk assessment described in Appendix D of the RI report.

An additional source in this scenario was the emissions from the material on the surface of Operable Unit 4 from the failure of Silo 3. The isopleths of ground level concentration of three typical contaminants (i.e., radon, chromium, and thorium-230), due to emissions from the Operable Unit 4 are shown in Figures E.1-17 to E.1-19. Though the concentrations of radon are different due to the additional sources, the isopleths and the locations of the maximum on-property and off-property concentrations are consistent with the meteorology of the site. The annual average ground level concentrations of the contaminants at the sensitive receptors in this scenario are presented in Table E.1-15. For reasons mentioned earlier, the concentrations of the contaminants were low at these receptors.

E.1.12 UNCERTAINTIES IN AIR TRANSPORT ANALYSIS

All the elements of the air transport analysis have inherent uncertainties due to approximations, assumptions, and simplifications made for conserving time and resources or simply due to lack of

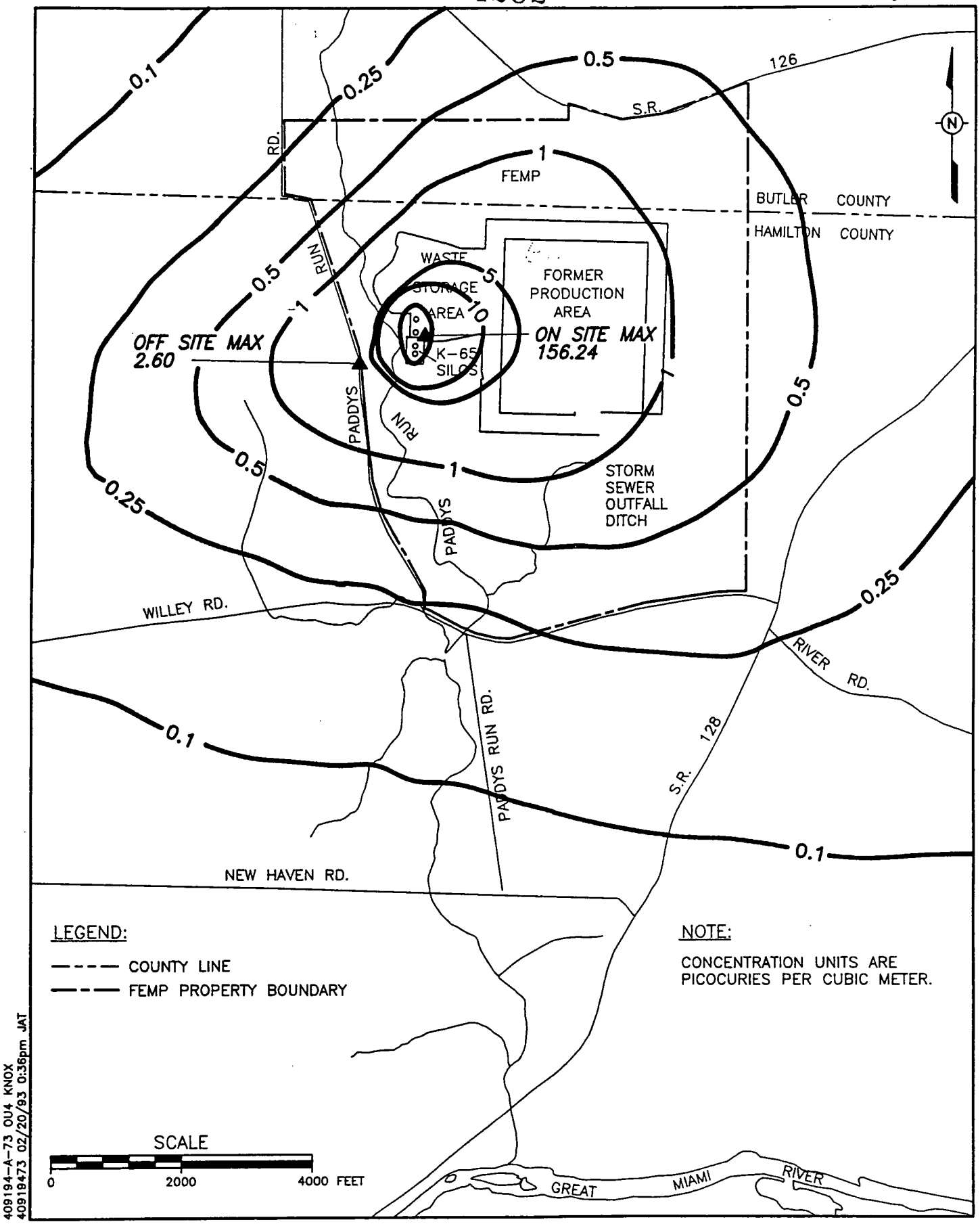

FIGURE E.1-14. ISOPLETH OF GROUND LEVEL CONCENTRATIONS OF RADON-CURRENT SCENARIO

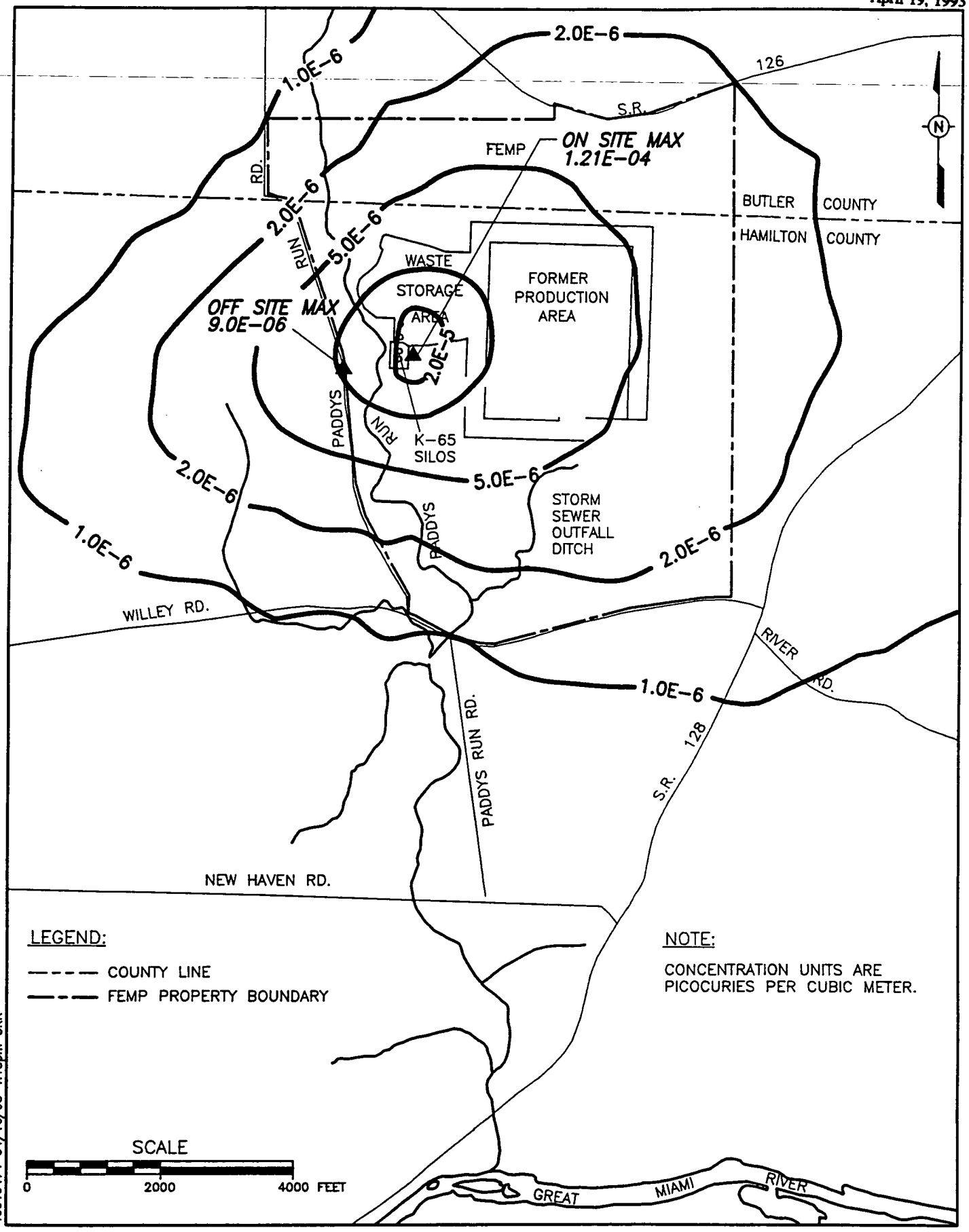

FIGURE E.1-15. ISOPLETH OF GROUND LEVEL CONCENTRATIONS OF BENZO (a) PYRENE CURRENT-SCENARIO

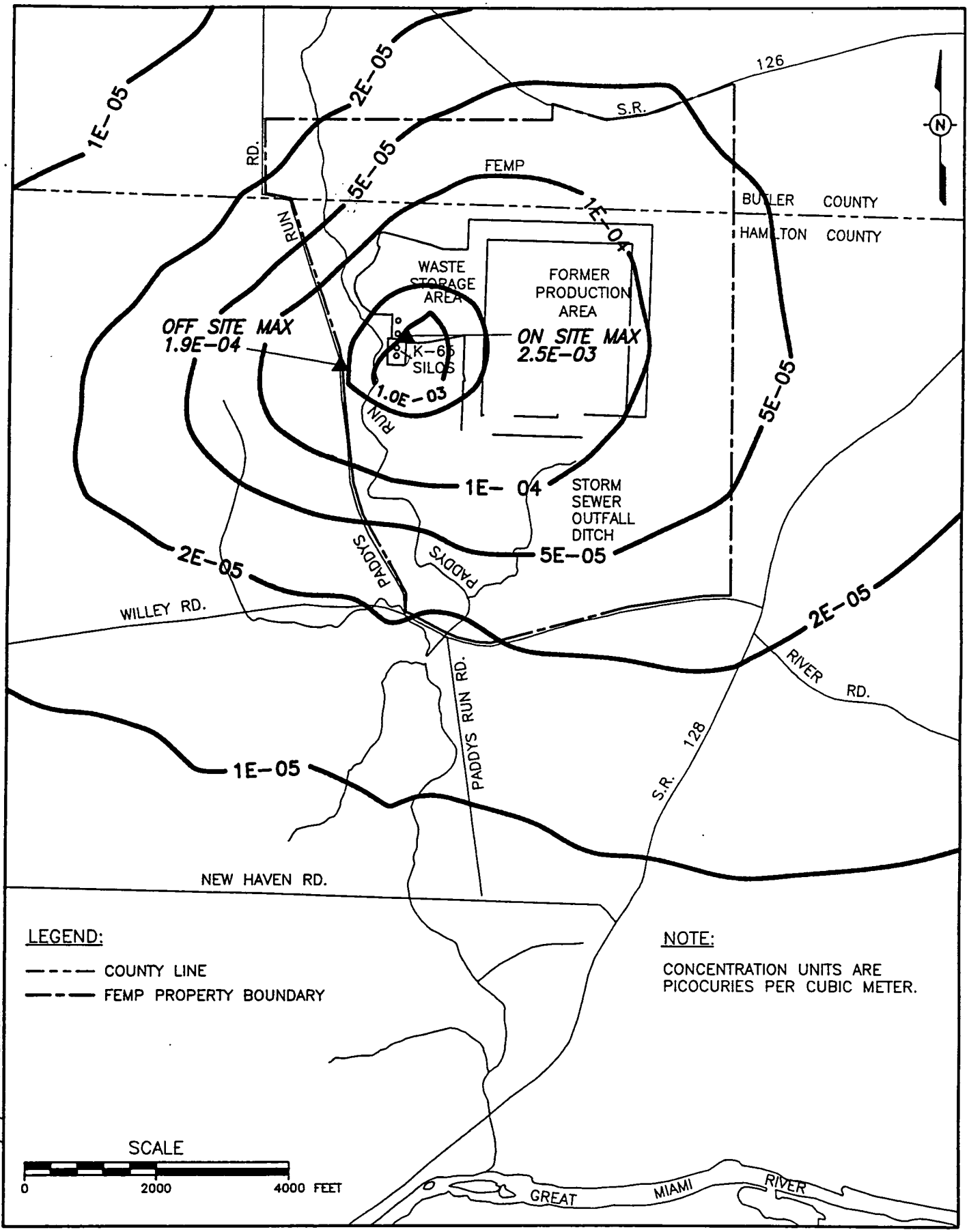

FIGURE E.1-16. ISOPLETH OF GROUND LEVEL CONCENTRATIONS OF URANIUM 238-CURRENT SCENARIO

TABLE E.1-13

MAXIMUM ANNUAL AVERAGE GROUND LEVEL CONCENTRATIONS
OF CONTAMINANTS AT SENSITIVE RECEPTORS
CURRENT SCENARIO

		SENSITIVE RECEPTOR IDENTIFICATION						
Contaminant	Units	Crosby Elementary	Morgan Elementary	Elda Elementary	St. John Elementary	Ross Middle & High	Ross City Daycare	Venice Preschool
Benzo(b)Fluoranthene	(µg/m3)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001
Beryllium	(µg/m3)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000001
Cadmium	(µg/m3)	0.000001	0.000001	0.000002	0.000001	0.000001	0.000003	0.000005
Chromium	(µg/m3)	0.000003	0.000002	0.000007	0.000003	0.000005	0.000012	0.000017
Nickel	(µg/m3)	0.000005	0.000004	0.000011	0.000005	0.000008	0.000020	0.000027
Ra-226	(pCi/m3)	0.000000	0.000000	0.000001	0.000000	0.000001	0.000002	0.000002
Ra-228	(pCi/m3)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000001
Sr-90	(pCi/m3)	0.000000	0.000000	0.000001	0.000000	0.000000	0.000001	0.000001
Tc-99	(pCi/m3)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000001
Th-230	(pCi/m3)	0.000001	0.000001	0.000002	0.000001	0.000001	0.000003	0.000004
U-234	(pCi/m3)	0.000001	0.000000	0.000001	0.000001	0.000001	0.000002	0.000003
U-238	(pCi/m3)	0.000002	0.000001	0.000004	0.000002	0.000003	0.000007	0.000010
Rn	(pCi/m3)	0.019384	0.013822	0.039947	0.018917	0.027793	0.073714	0.100293

NOTE: The contaminants that do not appear in this table either have no emissions in this scenario or the following statements apply:
(a) for organics and metals, the concentration is less than 1 picogram per cubic meter (pg/m^3),
(b) for radionuclides, the concentration is less than 1 attocurie per cubic meter (aCi/m^3).

TABLE E.1-14

MAXIMUM ANNUAL AVERAGE GROUND LEVEL CONCENTRATIONS FROM AIR DISPERSION MODELING, FUTURE SCENARIO

Contaminant	On-Site Receptors			Off-Site Receptors		
	Maximum Concentration	Location**		Maximum Concentration	Location**	
	-	X (m)	Y (m)		X (m)	Y (m)
A. ORGANICS ($\mu g/m^3$)						
2-Butanone	1.00×10^{-6}	50	25	0.00	*	*
Benzo(a)anthracene	1.01×10^{-4}	50	25	6.00×10^{-6}	-333.85	-58.87
Benzo(a)pyrene	9.15×10^{-4}	50	25	5.60×10^{-5}	-333.85	-58.87
Benzo(b)fluoranthene	1.37×10^{-4}	50	25	8.00×10^{-6}	-333.85	-58.87
Chrysene	9.10×10^{-5}	50	25	6.00×10^{-6}	-333.85	-58.87
Dibenzo(a,h)anthracene	5.90×10^{-5}	50	25	4.00×10^{-6}	-333.85	-58.87
Indeno(1,2,3,c,d)pyrene	1.03×10^{-4}	50	25	6.00×10^{-6}	-333.85	-58.87
Methylene chloride	4.00×10^{-6}	50	25	0.00	*	*
Toluene	5.00×10^{-6}	75	0	0.00	*	*
B. METAL ($\mu g/m^3$)						
Antimony	8.91×10^{-4}	50	125	4.30×10^{-5}	-350.00	-50.00
Arsenic	5.13×10^{-1}	50	125	2.45×10^{-2}	-350.00	-50.00
Barium	4.19×10^{-2}	50	125	2.00×10^{-3}	-350.00	-50.00
Beryllium	4.87×10^{-3}	50	125	2.37×10^{-4}	-350.00	-50.00
Cadmium	1.62×10^{-2}	50	125	7.97×10^{-4}	-350.00	-50.00
Chromium	6.71×10^{-2}	50	125	3.31×10^{-3}	-350.00	-50.00
Cobalt	4.65×10^{-1}	50	125	2.22×10^{-2}	-350.00	-50.00
Copper	5.41×10^{-1}	50	125	2.59×10^{-2}	-350.00	-50.00
Lead	3.85×10^{-1}	50	125	1.84×10^{-2}	-350.00	-50.00
Manganese	8.37×10^{-1}	50	125	4.00×10^{-2}	-350.00	-50.00
Mercury	1.12×10^{-4}	50	125	5.00×10^{-6}	-350.00	-50.00
Nickel	7.00×10^{-1}	50	125	3.36×10^{-2}	-350.00	-50.00
Selenium	3.72×10^{-2}	50	125	1.78×10^{-3}	-350.00	-50.00
Silver	2.99×10^{-3}	50	125	1.43×10^{-4}	-350.00	-50.00
Thallium	9.10×10^{-3}	50	125	4.35×10^{-4}	-350.00	-50.00

TABLE E.1-14
(Continued)

Contaminant	On-Site Receptors			Off-Site Receptors		
	Maximum Concentration	Location**		Maximum Concentration	Location**	
		X (m)	Y (m)		X (m)	Y (m)
Vanadium	5.65×10^{-1}	50	125	2.70×10^{-2}	-350.00	-50.00
Zinc	8.67×10^{-2}	50	125	4.14×10^{-3}	-350.00	-50.00
C. RADIONUCLIDES (pCi/m^3)						
Actinium-227	1.04×10^{-1}	50	125	4.96×10^{-3}	-350.00	-50.00
Protactinium-231	1.51×10^{-1}	50	125	7.21×10^{-3}	-350.00	-50.00
Lead-210	7.67×10^{-1}	50	125	3.67×10^{-2}	-350.00	-50.00
Polonium-210	1.29×10^{-4}	75	0	9.00×10^{-6}	-318.55	-115.94
Radium-224	5.95×10^{-2}	50	125	2.85×10^{-3}	-350.00	-50.00
Radium-226	6.28×10^{-1}	50	125	3.00×10^{-2}	-350.00	-50.00
Radium-228	6.59×10^{-2}	50	125	3.16×10^{-3}	-350.00	-50.00
Strontium-90	3.17×10^{-4}	50	25	1.90×10^{-5}	-333.85	-58.87
Technetium-99	1.63×10^{-4}	50	25	1.00×10^{-5}	-333.85	-58.87
Thorium-228	1.42×10^{-1}	50	125	6.78×10^{-3}	-350.00	-50.00
Thorium-230	9.76×10^{00}	50	125	4.66×10^{-1}	-350.00	-50.00
Thorium-232	1.41×10^{-1}	50	125	6.75×10^{-3}	-350.00	-50.00
Uranium-234	3.16×10^{-1}	50	125	1.51×10^{-2}	-350.00	-50.00
Uranium-235/236	1.90×10^{-2}	50	125	9.09×10^{-4}	-350.00	-50.00
Uranium-238	2.90×10^{-1}	50	125	1.39×10^{-2}	-350.00	-50.00
Radon	5.41×10^{3}	50	125	2.63×10^{2}	-350.00	-50.00

* This is not a chemical constituent of concern, the concentration is less than 1 picogram per cubic meter (pg/m^3
** The origin is at plant coordinates (S 42+79.89.E 19+68.45)

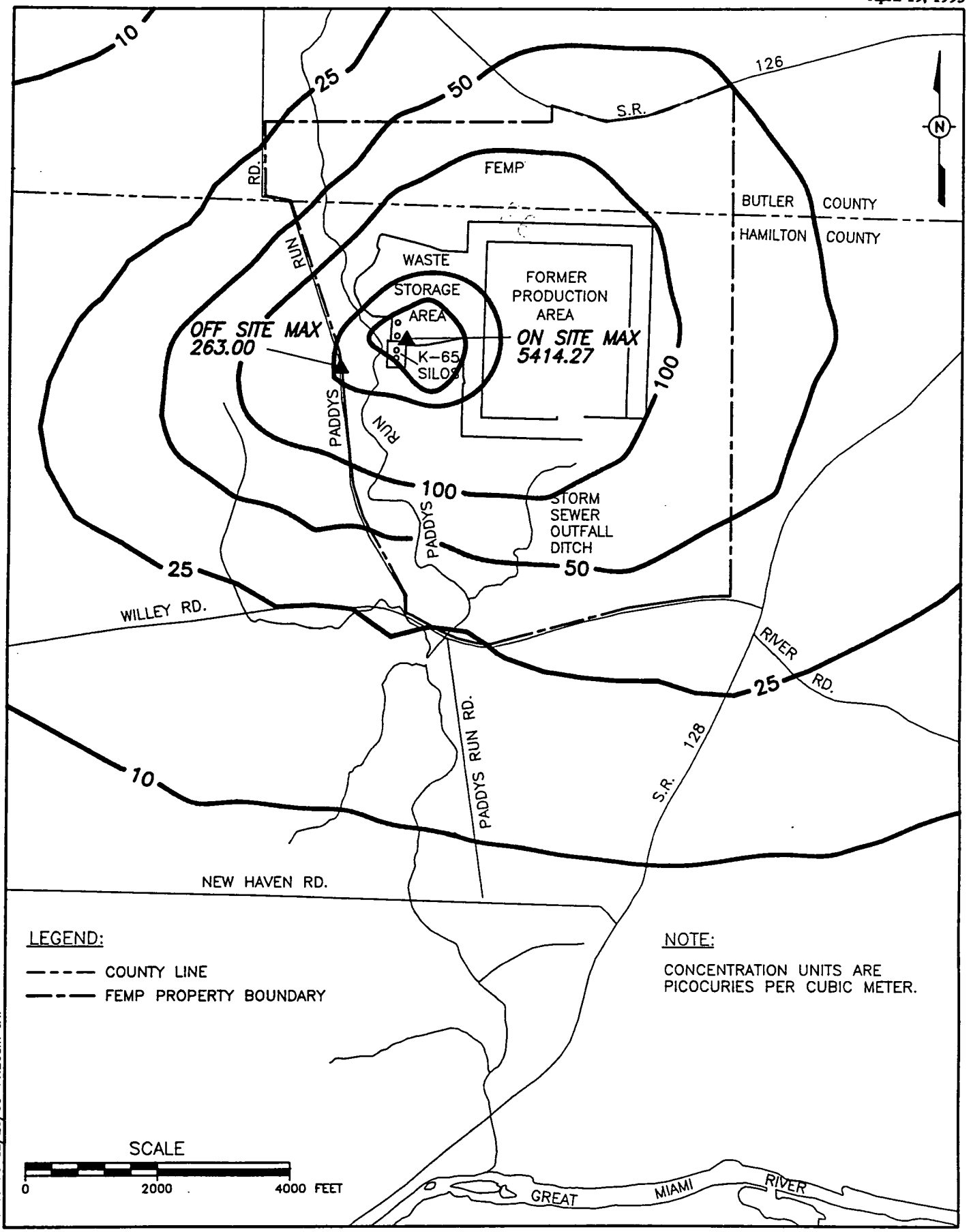

FIGURE E.1-17. ISOPLETH OF GROUND LEVEL CONCENTRATIONS OF RADON FUTURE SCENARIO

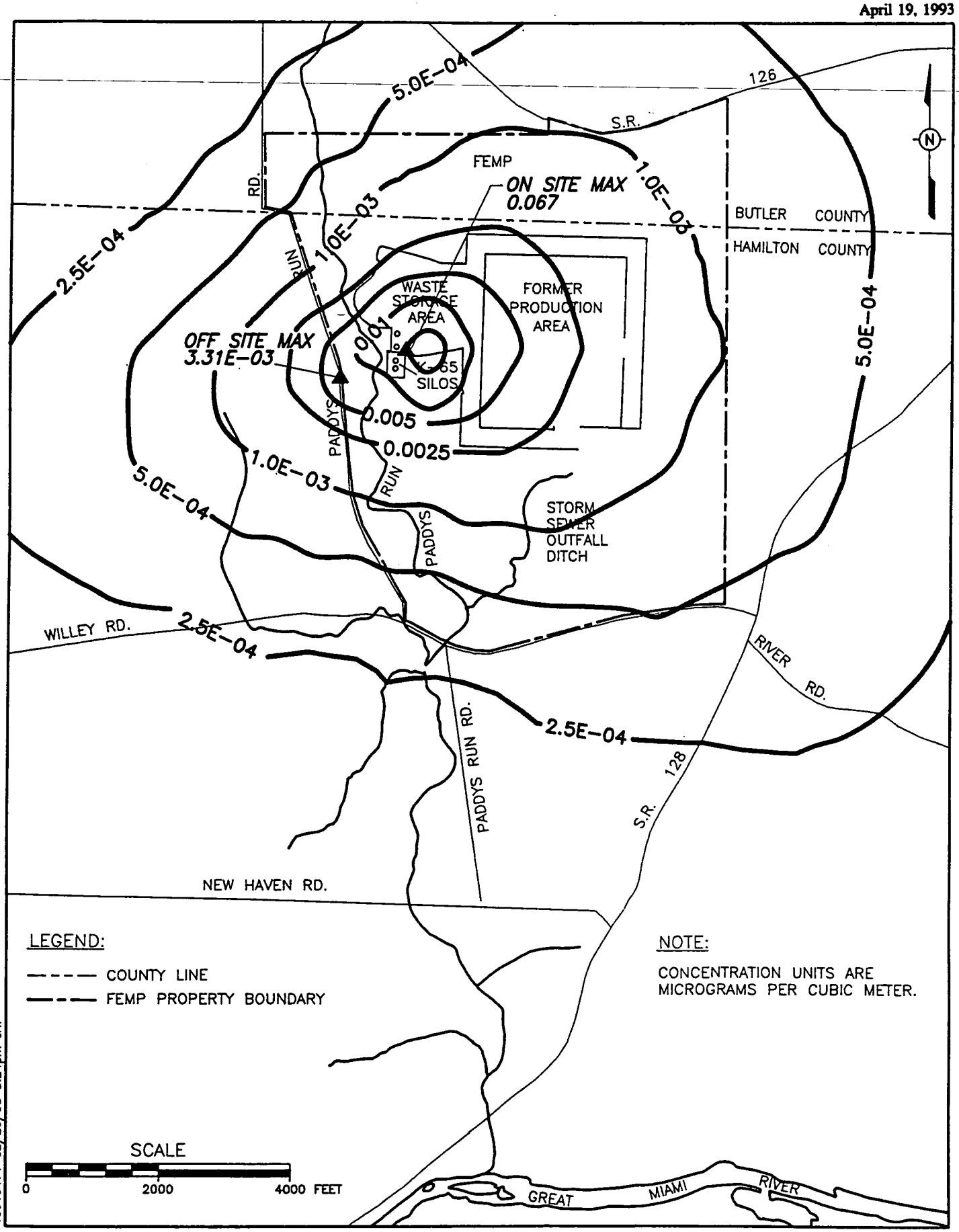

FIGURE E.1-18. ISOPLETH OF GROUND LEVEL CONCENTRATIONS OF CHROMIUM-FUTURE SCENARIO

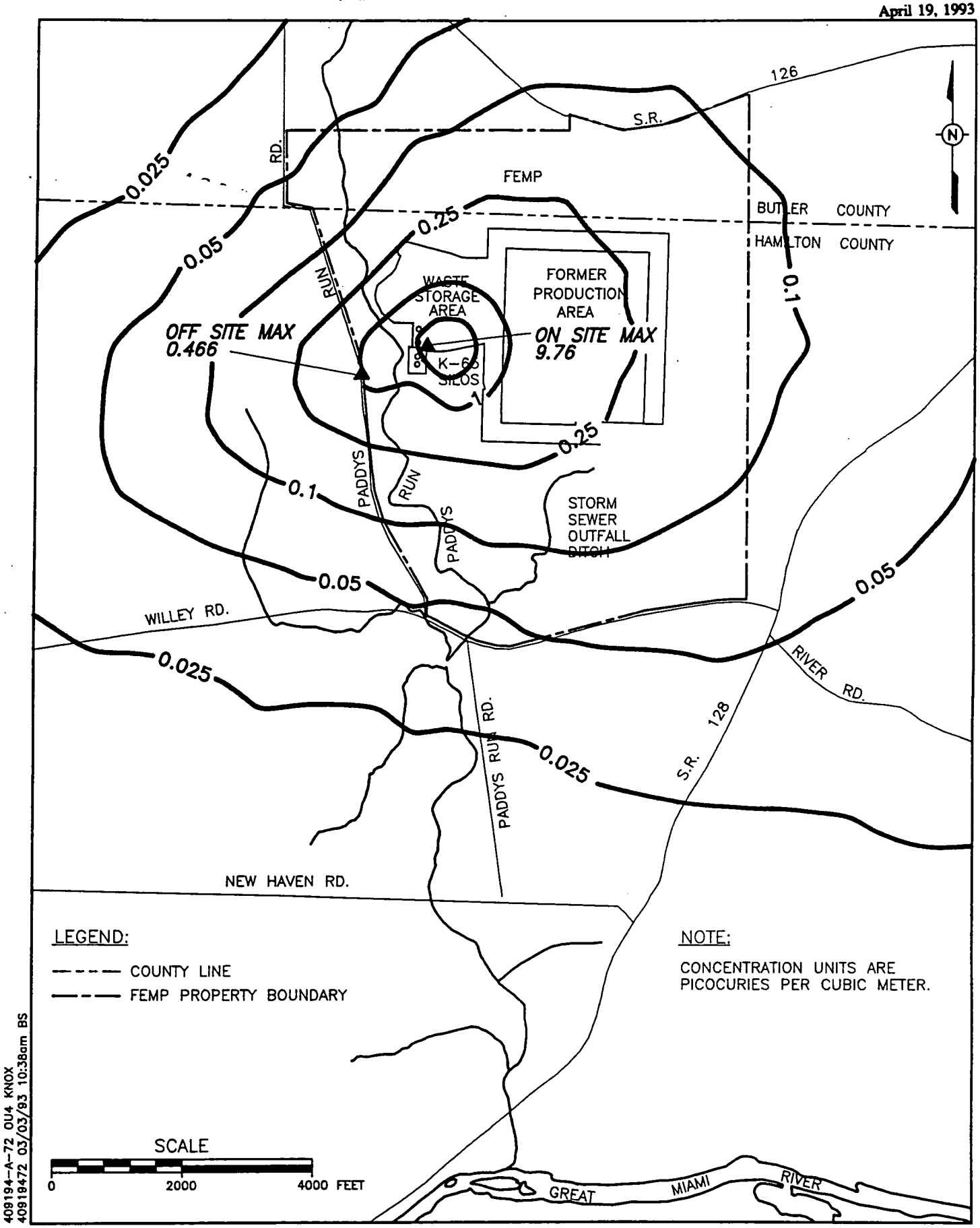

FIGURE E.1-19. ISOPLETH OF GROUND LEVEL CONCENTRATIONS OF THORIUM-230 FUTURE SCENARIO

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TABLE E.1-15

GROUND LEVEL CONCENTRATIONS OF CONTAMINANTS AT SENSITIVE RECEPTORS FUTURE SCENARIO

		Sensitive Receptor Identification						
Contaminant	Units	Crosby Elementary	Morgan Elementary	Elda Elementary	St. John Elementary	Ross Middle & High	Ross City Daycare	Venice Preschool
Benzo(a)pyrene	($\mu g/m^3$)	0.000001	0.000000	0.000001	0.000001	0.000001	0.000002	0.000003
Antimony	($\mu g/m^3$)	0.000000	0.000000	0.000001	0.000000	0.000001	0.000001	0.000002
Arsenic	($\mu g/m^3$)	0.000202	0.000149	0.000424	0.000199	0.000296	0.000789	0.001075
Barium	($\mu g/m^3$)	0.000016	0.000012	0.000035	0.000016	0.000024	0.000064	0.000088
Beryllium	($\mu g/m^3$)	0.000002	0.000001	0.000004	0.000002	0.000003	0.000008	0.000010
Cadmium	($\mu g/m^3$)	0.000007	0.000005	0.000014	0.000007	0.000010	0.000026	0.000035
Chromium	($\mu g/m^3$)	0.000027	0.000020	0.000058	0.000027	0.000040	0.000107	0.000146
Cobalt	($\mu g/m^3$)	0.000183	0.000135	0.000385	0.000180	0.000269	0.000716	0.000975
Copper	($\mu g/m^3$)	0.000213	0.000157	0.000447	0.000210	0.000312	0.000832	0.001133
Lead	($\mu g/m^3$)	0.000151	0.000112	0.000319	0.000149	0.000223	0.000593	0.000807
Manganese	($\mu g/m^3$)	0.000329	0.000243	0.000692	0.000324	0.000483	0.001287	0.001753
Nickel	($\mu g/m^3$)	0.000277	0.000205	0.000582	0.000273	0.000407	0.001083	0.001475
Selenium	($\mu g/m^3$)	0.000015	0.000011	0.000031	0.000014	0.000021	0.000057	0.000078
Silver	($\mu g/m^3$)	0.000001	0.000001	0.000002	0.000001	0.000002	0.000005	0.000006
Thallium	($\mu g/m^3$)	0.000004	0.000003	0.000008	0.000004	0.000005	0.000014	0.000019
Vanadium	($\mu g/m^3$)	0.000222	0.000164	0.000467	0.000219	0.000327	0.000870	0.001185
Zinc	($\mu g/m^3$)	0.000034	0.000025	0.000072	0.000034	0.000050	0.000133	0.000182
Ac-227	(pCi/m^3)	0.000041	0.000030	0.000086	0.000040	0.000060	0.000160	0.000217
Pa-231	(pCi/m^3)	0.000059	0.000044	0.000125	0.000058	0.000087	0.000232	0.000316
Lead-210	(pCi/m^3)	0.000301	0.000223	0.000634	0.000297	0.000443	0.001179	0.001606
Radium-224	(pCi/m^3)	0.000023	0.000017	0.000049	0.000023	0.000034	0.000092	0.000125

TABLE E.1-15
(Continued)

Contaminant	Units	Sensitive Receptor Identification						
		Crosby Elementary	Morgan Elementary	Elda Elementary	St. John Elementary	Ross Middle & High	Ross City Daycare	Venice Preschool
Radium-226	(pCi/m^3)	0.000247	0.000183	0.000519	0.000244	0.000363	0.000966	0.001316
Radium-228	(pCi/m^3)	0.000026	0.000019	0.000055	0.000026	0.000038	0.000102	0.000138
Strontium-90	(pCi/m^3)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000001
Thorium-228	(pCi/m^3)	0.000056	0.000041	0.000117	0.000055	0.000082	0.000218	0.000297
Thorium-230	(pCi/m^3)	0.003835	0.002838	0.008067	0.003782	0.005637	0.015008	0.020446
Thorium-232	(pCi/m^3)	0.000056	0.000041	0.000117	0.000055	0.000082	0.000217	0.000296
Uranium-234	(pCi/m^3)	0.000124	0.000092	0.000261	0.000123	0.000183	0.000486	0.000662
Uranium-235/236	(pCi/m^3)	0.000007	0.000006	0.000016	0.000007	0.000011	0.000029	0.000040
Uranium-238	(pCi/m^3)	0.000114	0.000085	0.000241	0.000113	0.000168	0.000447	0.000610
Radon	(pCi/m^3)	2.161627	1.596546	4.542175	2.130697	3.173295	8.447251	11.507347

Note: The contaminants that do not appear in this table either have no emissions in this scenario or the following applies:

(a) for organic and metals, the concentration is less than 1 picogram per cubic meter (pg/m^3)
(b) for radionuclides, the concentration is less than 1 attocurie per cubic meter (aCi/m^3)

available data. Thus, while steps are taken to counter these uncertainties with conservative assumptions, the results of the analysis should be viewed in this perspective.

A number of studies have been conducted to examine model accuracy. The results of these studies confirm that: a) models are more reliable for estimating longer-time averaged concentrations than for estimating short-term concentrations at specific locations; and b) the models are reasonably reliable in estimating the magnitude of highest concentrations occurring somewhere, sometime within an area (EPA, 1986b). Errors in the highest concentrations of 10 percent to 40 percent are considered to be typical. However, estimates of concentrations that occur at specific time and site are poorly correlated with actually observed concentrations at these locations.

Input data to the air dispersion model and the air dispersion model itself are major sources of uncertainties. The input to air dispersion models include: a) emission rates; b) meteorological data; c) source configurations; and d) site topography, all of which can lead to uncertainties.

In many cases, predictive models and default values are used for predicting the emission rates. For Operable Unit 4, a predictive model (Gillette's Unlimited Erosion Model) was used to determine the emission rate of particulates due to wind erosion. This model was developed based on tests at controlled conditions. Though this is recommended by the EPA for applications in hazardous waste sites (EPA 1985), the controlled condition could not be replicated in Operable Unit 4 in entirety. The concentrations of the contaminants in the particulate emissions were based on the analyses conducted at only selected locations of the Operable Unit 4. Further, it was assumed that these analyses accurately represent the concentrations of the contaminants in the suspended particulate emissions.

Both of these assumptions can lead to uncertainties in calculating emission rates. A number of steps were taken to reduce these uncertainties. Conservative values of threshold friction velocities, vegetative cover, and mean annual wind speeds were used in the wind erosion model to yield higher emission rates. The UCL concentrations (not the mean concentrations) of the contaminants in the soil were considered.

In the future scenario, the radon flux from the silos and other sources were determined using the "RAECOM" model recommended by the EPA. As with any predictive model, assumptions had to be made on various inputs to this model, such as a radon emanation coefficient, a radon diffusion coefficient, and a radon distribution coefficient. Conservative values were used for the coefficients in this analysis. However, the possibility exists for uncertainties in the emission rate estimations for radon in this scenario. In some cases, limited available site data had to be used in the emission rate calculations. Thus, for the Operable Unit 4, the radon release rates for the current scenario were determined from the limited site data on headspace radon concentrations and the breathing rates were estimated based on averages of limited temperature data over the annual time period. Such a method

of annualization of limited time data was warranted due to unavailability of the data for large time periods, yet the annualization could have introduced uncertainties in the emission rates.

Large uncertainties are also associated with the air dispersion models. Dispersion models generally attempt to estimate concentrations at specific sites that really represent an average of numerous repetitions of the same event. The event is characterized by the measures or "known" conditions that are input to the models (e.g., wind speed, wind direction, mixing layer height, surface heat flux, etc). However, in addition to these "known" conditions, there are unmeasured or unknown variations in the conditions of the event, (e.g., unresolved details of the atmospheric flow such as turbulent velocity field). These unknown conditions may vary among repetitions of the events. As a result, deviations in the observed concentrations from their average, and from the concentrations estimated by the model are likely to occur, even though the known conditions are fixed. Even with a perfect model that predicts the correct average, there are likely to be deviations from the observed concentrations from in individual repetitions of the event, due to variations in the unknown conditions. This is termed the "inherent uncertainty" of the models.

The "known" conditions can also introduce uncertainties in the results, because of the manner in which these data are collected. The wind direction and wind speeds are usually collected as 15 minute averages and then averaged to hourly values. This averaging procedure, though necessary for the model, does not truly represent the dispersion and dilution of contaminants at specific points in time.

The site topography may also introduce uncertainties in the results of the model, especially around elevated terrain and structures. The aerodynamics of the flow around structures are not fully developed, nor can these be appropriately included in models such as ISCLT2. This analysis, however was not affected by this factor since the modeling region was approximately flat and the sources were considered as ground level area sources.

It may be concluded that uncertainties were inevitable in the air transport analysis. However, measures were taken to reduce the uncertainties by making conservative assumptions and using site specific data as much as is practicable.

For this analysis, the ISCLT2 model was used. This model was developed by the EPA from years of studies in atmospheric dispersion. The model is recommended by the EPA for applications at superfund sites and was the most appropriate model based on the site characteristics and objectives of the analysis. To reduce the uncertainties in the analysis, six consecutive years of on-property meteorological data was used, and the maximum concentrations for all the contaminants were determined from the results from all these years. Regulatory default values were used to yield conservative estimates of the concentrations. Rural dispersion coefficients were used which would

result in higher ground level concentration for the area sources. The deposition of the suspended particulate was neglected in estimating the ground level air concentration.

E.1.13 COMPARISON OF MODEL PREDICTIONS WITH AMBIENT AIR MONITORING DATA

This section deals with the comparison of concentrations predicted by the ISCLT2 model with the on-property ambient air monitoring data. The purpose of this comparison study was to create a perspective of the contribution of the emissions from Operable Unit 4 on the ambient air quality. In view of the uncertainties inherent both in the air dispersion modeling and ambient monitoring data, the results of this comparison should be viewed qualitatively.

Currently radon, total suspended particulate, and gross beta activity concentrations are measured at the on-property ambient air monitoring stations. The radon was considered as the "fingerprint" chemical for this study for the following reasons :

- The source of radon was clearly identifiable for the Operable Unit 4, and the emission rates could be calculated based on site specific data such as head space concentrations and breathing rates.
- There were more numbers of monitors measuring radon at various distances from the Operable Unit 4 than for either TSP or the gross beta activity concentrations.
- Due to the presence of agricultural farming land around the FEMP boundary, there could be many other sources of TSP other than the Operable Unit 4.
- Background data for radon were available from off-property monitors.

Two modeling scenarios were considered in this study, i.e., pre-bentonite conditions in the year 1991, and post-bentonite conditions in 1992. These two years were selected because: a) the production area of the facility was closed during these years, thus eliminating other major sources of radon emissions, and b) useable meteorological and ambient air monitoring data were available in these years.

The sources of radon emissions from the Operable Unit 4 considered in this study were:

- The Silos 1, 2, and 3
- The berm fill material around the K-65 silos
- The surface soil around the silos

The emission flux of radon from the silos were estimated from the headspace concentrations and breathing rates as described earlier. The emission flux of radon from the berm fill and the surface soil were estimated using the previously described "RAECOM" model. The on-property meteorological data for the years 1991 and 1992 were used. The radon monitoring stations were considered as discrete receptors in the modeling. The ISCLT2 model was used to determine the annual average ground level concentrations of radon at these monitoring stations.

Two types of monitors were used at the FEMP for measuring the ambient radon concentration. The hourly radon concentrations were measured by "Pylon" Model 110 and 300A Lucas cells, which were then reported as monthly averages. These are scintillation cells and are considered as passive monitors. The sensitivity of the Pylon AB-5 monitors is 1.0 pCi/L (1000 pCi/m^3) as per the manufacturer. The other type of radon monitor used was alpha-track radon detectors called "Terradex" cups in weatherproof housings. The alpha-track radon detectors are devices for measuring radon concentrations in the air for long time periods. The "Terradex cups" were changed each calendar quarter and thus yielded quarterly radon concentrations. Details of the radon monitoring network and the operation of the monitors are described in the report "Draft-K-65 Removal Action-Bentonite Effectiveness Evaluation" prepared by DOE (1992).

The radon detectors measured ambient radon concentrations both at on-property and off-property locations. The on-property locations and the off-property locations are shown in Figures E.1-20 and E.1-21, respectively. Three levels of monitors based on the distance from the K-65 silos (which was the major source in the operable unit) was considered in this analysis. The first level was the on-property monitors "K-65 A" through "K-65 P" shown in Figure E.1-20. The next level were the four radon monitors on the K-65 silo exclusion fence are identified as "K-65 NE," "K-65 NW," "K-65 SE," and "K-65 SW." The third level was the air monitoring stations both at the FEMP boundary and outside the FEMP boundary as shown in Figure E.1-21. The background radon concentrations were determined from the measurements at the monitoring stations at Brookville, Indiana (34 km from FEMP), Westwood, Ohio (25 km from FEMP), and the monitoring stations AMS 15 and AMS 16.

The time period used for this study for the pre-bentonite monitoring data was from January 1 to September 30, 1991, while the post-bentonite monitoring data was from January 1, 1992 to September 30, 1992. The time period between October 1991 to December 1991 was not included in this analysis because the preparation and installation of bentonite on the K-65 silos were conducted during this period. These activities resulted in acute short term radon releases as observed in the ambient monitoring data.

Table E.1-16 summarizes the results of this study. This table shows the annual average radon concentrations at these monitoring stations determined from the air dispersion modeling and the annual average radon concentrations determined from the measurements at the ambient radon monitoring stations. The background concentrations were subtracted from the actual measurements at the radon monitoring stations to determine the incremental radon concentrations due to emission sources within the FEMP boundary. The background concentration was determined from an arithmetic average of the measurements at the four background stations mentioned earlier. This table also reports the ratio of the model prediction and the monitoring station measurements for all the stations.

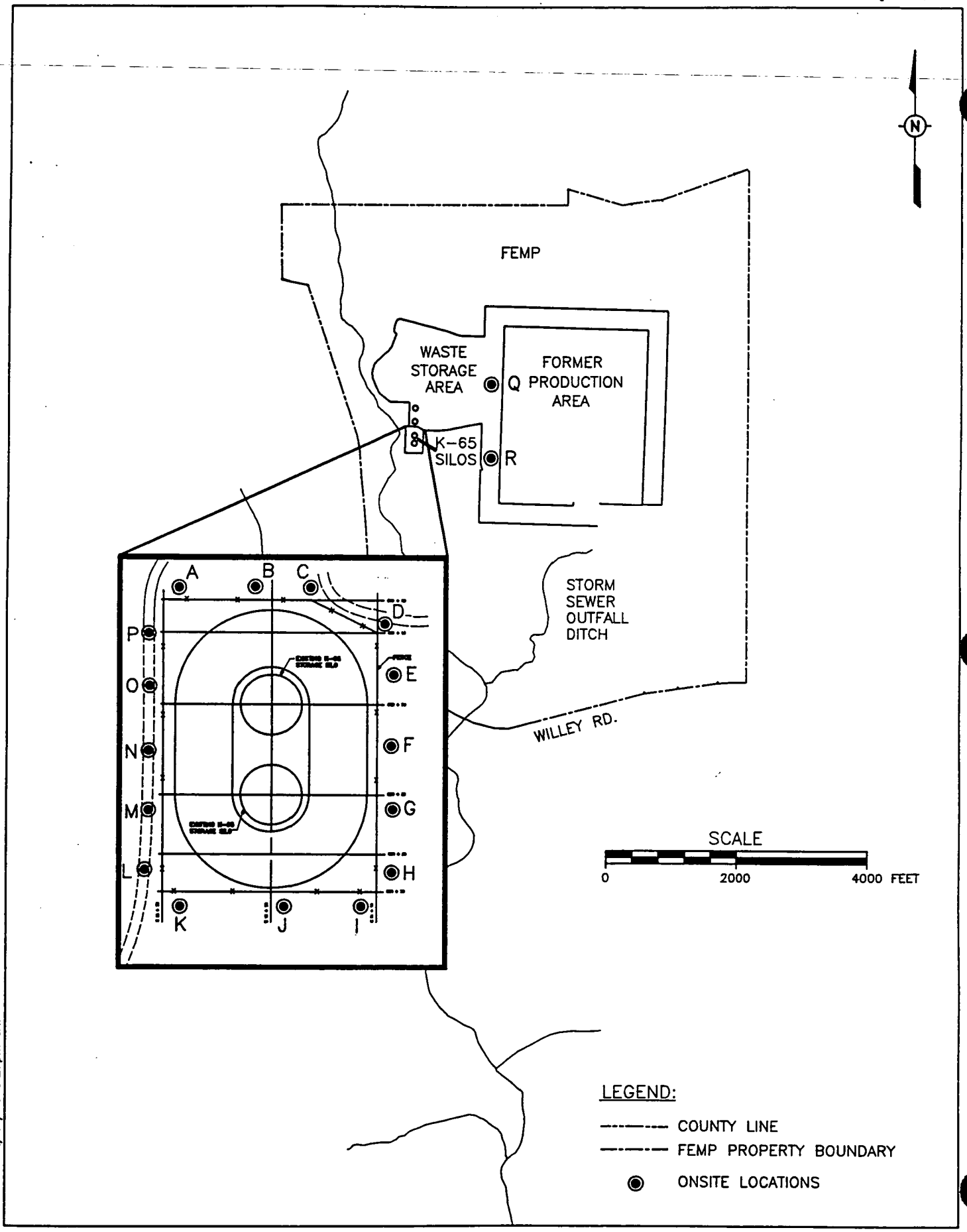

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FIGURE E.1-20. ON-SITE RADON AIR MONITORING LOCATIONS

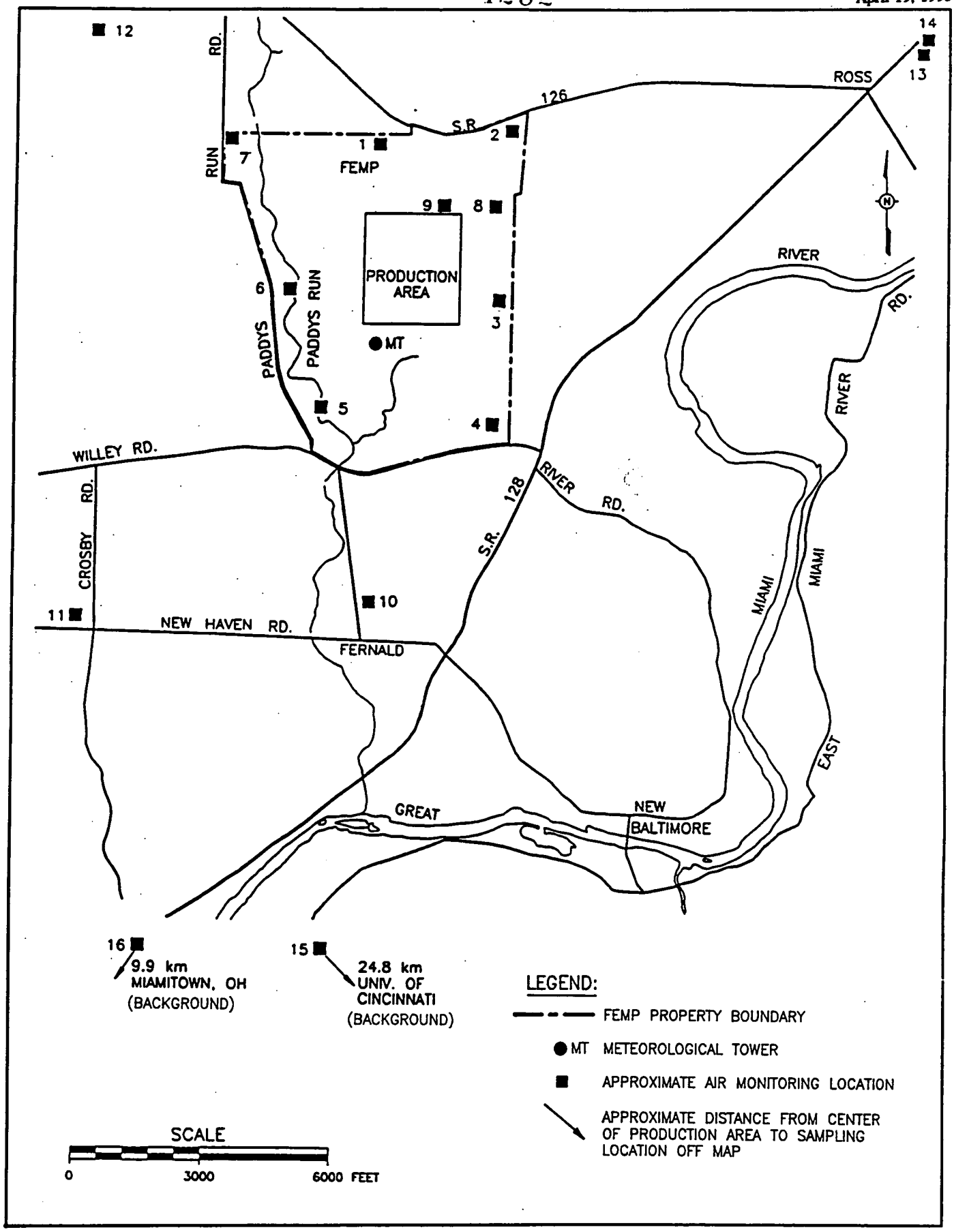

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FIGURE E.1-21. AIR MONITORING LOCATIONS

TABLE E.1-16

COMPARISON OF MODEL PREDICTIONS WITH AMBIENT AIR MONITORING DATA
CONTAMINANT: RADON

Monitoring Station ID	Location	X (M)	Y (M)	1991 Avg. Conc. (Terradex) (pCi/m^3)	1991 Model Prediction (pCi/m^3)	1991 Ratio of Model and Monitoring Data	1992 Avg. Conc. (Terradex) (pCi/m^3)	1992 Model Prediction (pCi/m^3)	1992 Ratio of Model and Monitoring Data
A1. OU-4 AREA									
K-65 A	K-65 Silos	0	59.4	2573	4280	1.66	0	86	
K-65 B	K-65 Silos	22.3	59.4	1540	5240	3.40	200	98	0.49
K-65 C	K-65 Silos	42.4	44.5	3740	5570	1.49	200	59	0.29
K-65 D	K-65 Silos	47.7	21.2	3807	6110	1.60	300	43	0.14
K-65 E	K-65 Silos	47.7	0	3307	5400	1.63	1100	31	0.03
K-65 F	K-65 Silos	47.7	-19.1	3607	4020	1.11	300	26	0.09
K-65 G	K-65 Silos	47.7	-44.5	1473	2350	1.59	400	19	0.05
K-65 H	K-65 Silos	25.4	-61.5	1140	1670	1.46	300	13	0.04
K-65 I	K-65 Silos	0	-61.5	1773	1340	0.76	100	12	0.11
K-65 J	K-65 Silos	-25.4	-61.5	973	875	0.90	0	9	
K-65 K	K-65 Silos	-38.2	-39.2	1440	1400	0.97	100	13	0.13
K-65 L	K-65 Silos	-38.2	-19	2040	2170	1.06	300	15	0.05
K-65 M	K-65 Silos	-38.2	0	2807	2980	1.06	200	19	0.10
K-65 N	K-65 Silos	-38.2	16.5	1673	3190	1.91	100	22	0.22
K-65 O	K-65 Silos	-38.2	35	2340	2340	1.00	-100	25	-0.25
K-65 P	K-65 Silos	-24.4	59.4	2773	1650	0.60	700	49	0.07

TABLE E.1-16
(Continued)

Monitoring Station ID	Location	X (M)	Y (M)	1991 Avg. Conc. (Terradex) (pCi/m^3)	1991 Model Prediction (pCi/m^3)	1991 Ratio of Model and Monitoring Data	1992 Avg. Conc. (Terradex) (pCi/m^3)	1992 Model Prediction (pCi/m^3)	1992 Ratio of Model and Monitoring Data
Average Ratio of Model Prediction and Monitoring Data						1.39			0.14
A2. EXCLUSION FENCE				(PYLON)			(PYLON)		
K-65 NE	Excl. Fence	47	19	8642	6420	0.74	746	43	0.06
K-65 NW	Excl. Fence	-47	19	3809	2370	0.62	436	20	0.04
K-65 SE	Excl. Fence	47	-19	6298	4110	0.65	262	26	0.10
K-65 SW	Excl. Fence	-47	-19	4534	1780	0.39	532	14	0.03
Average Ratio of Model Prediction and Monitoring Data						0.60			0.06

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TABLE E.1-16
(Continued)

Monitoring Station ID	Location	X (M)	Y (M)	1991 Avg. Conc. (Terradex) (pCi/m^3)	1991 Model Prediction (pCi/m^3)	1991 Ratio of Model and Monitoring Data	1992 Avg. Conc. (Terradex) (pCi/m^3)	1992 Model Prediction (pCi/m^3)	1992 Ratio of Model and Monitoring Data
AMS 1	On & off site	714	1017	240	23	0.09	-100	0.43	--
AMS 2	On & off site	1514	1200	6.7	12	1.79	-200	0.22	--
AMS 3	On & off site	1463	69	NA	18	--	0	0.32	--
AMS 4	On & off site	1320	-1109	773	12	0.02	200	0.21	1.03×10^{-3}
AMS 5	On & off site	6	-926	NA	12	--	0	0.23	--
AMS 6	On & off site	-320	-97	6.7	107	16.00	-100	1.80	--
AMS 7	On & off site	-589	1000	573	6	0.01	1200	0.15	1.22×10^{-4}
AMS 8	On & off site	1160	634	173	23	0.13	100	0.40	3.89×10^{-3}
AMS 9	On & off site	1217	749	-60	20	--	100	0.35	3.44×10^{-3}
AMS 10	On & off site	600	-2050	223	4	0.02	200	0.10	3.75×10^{-4}
AMS 11	On & off site	-2100	-2250	490	1.4	0.00	0	0.03	--
AMS 12	On & off site	-3650	3750	6.7	0.5	0.07	0	0.01	--
AMS 13	On & off site	4400	2000	-60	3	--	-100	0.05	-4.90×10^{-4}
AMS 14	On & off site	4500	2150	NA	3	--	0	0.05	--
Average Ratio of Model Prediction and Monitoring Data (Neglecting the outlier values of AMS 2 & 6)						0.05			1.77×10^{-3}

NOTES:
1. The radon monitoring data is from FEMP Environmental Monitoring Program.
2. The modeling results are based on 1991 meteorological data and pre-bentonite radon release rates from the silos. Other sources of radon considered were the surface soil and the berm fill material.
3. The background was determined from an arithmetic average of the radon monitoring data of the four background radon monitoring stations.
4. The background concentrations for 1991 were 660 pCi/m3 for TERRADEX cups and 572 pCi/m3 for PYLONs
5. The background concentrations for 1992 were 600 pCi/m3 for TERRADEX cups and 589 pCi/m3 for PYLONs.
6. A negative concentration in monitoring data indicates that the measured concentration was lower than the average background concentration.

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The model predictions are comparable to the ambient radon monitoring data for the year 1991 at the closest monitoring stations, i.e., K-65 A through P. Though the ratio of model prediction to monitoring data ranged from 0.60 to 3.4, the average ratio was 1.39. The ratio was reduced as the distance of the monitoring station from the K-65 silos increased. For example, at the exclusion fence- line receptors, the average ratio was 0.6, and at the farther located air monitoring stations, the ratio was reduced to 0.05. Thus, the effect of the radon emissions from the Operable Unit on the ambient radon concentration decreased with increasing distance.

As mentioned earlier, large uncertainties are inherent in modeling the atmospheric dispersion and dilution of pollutants. Uncertainties are also inherent in the monitoring data due to poor knowledge of all the local effects that might be affecting the monitors. The assumption that the background radon concentration was correctly represented by the average of radon concentration at the four background stations may also have introduced errors in the results, since the natural background radon levels may vary depending on the physical surroundings. This is clearly indicated by the fact that the background radon concentration varied between 100 pCi/m^3 to 1400 pCi/m^3 within this year.

In spite of these uncertainties, this comparison showed a clear trend. At the monitoring stations where the sources within Operable Unit 4 had the dominant effect, the model predicted the annual average concentrations very well, within the oft quoted "factor of two." For the fenceline monitors also, the predictions of the model were within a factor of two of the monitoring data. These results indicate that the model was appropriate for this application and the input parameters were appropriately selected.

The loss in the predictability of the ambient air monitoring data at greater distances is anticipated to be due to: a) the effect of other sources of radon from the FEMP site which overshadowed the emissions from the Operable Unit 4, and b) the large variation in the background concentration. For example, the Pit 5, when not covered, is potentially capable of producing radon flux within the same order of magnitude as the silos (DOE 1992). Likewise, there are evidence of radium concentrations in the Southfield and in the Active and Inactive Flyash pile (DOE 1992). Although the actual radon contribution from these sources may be small, these sources may be dominantly affecting the readings of some of the monitors on local scale. The large variation in the background radon concentrations also affected the results of the comparison study. The background radon concentration varied between 100 pCi/m^3 to 1400 pCi/m^3 between the study period. Thus, the temporal effect of the "true" background could not be determined in this study. Further, at the monitoring stations, the model predicted radon concentrations in the range of 0.5 pCi/m^3 (AMS 12) to 107 pCi/m^3 (AMS 6). Thus, these concentrations were not significantly above the background concentrations and might not have been precisely detected by the radon monitors, which resulted in the poor correlations.

After the contents of the K-65 silos were covered with the bentonite layer, the predicted radon emissions from the silos reduced drastically, by approximately two orders of magnitude. Since the emission from other radon sources in the vicinity of FEMP were unchanged, the radon emission from the Operable Unit 4 was probably no longer the dominant source affecting any of the monitors. This was one of the reasons for the concentrations predicted by the model being an order of magnitude lower than the monitoring data in the year 1992. However, the trend of lower correlation with increasing distance is still evident for the data in this year also.

Further, even at the closest monitors, the radon concentrations predicted by the model was 9 pCi/m^3 to 98 pCi/m^3, which were within the statistical uncertainty in the background concentration of approximately 600 pCi/m^3 in this year. The monitors did not have the sensitivity to accurately measure such a small change in the concentration. As mentioned earlier, the background concentration of radon varied by an order of magnitude during this period, which further adds uncertainty to the interpretation of the results.

Some general conclusions can be drawn from the results of this study. When the Operable Unit 4 was the dominant source of emission, the ISCLT2 model predicted the observed ambient radon concentrations extremely well, indicating the appropriateness of the model and the input data. As the emissions from the Operable Unit 4 became less dominant, either at larger distances and/or due to the placement of the bentonite cover, the effect of other uncontrolled sources at the FEMP site and the background concentrations dominated the ambient monitoring data. In such conditions, efforts to correlate the predictions of the model for emissions from Operable Unit 4 only were not appropriate.

Attachment E.1-I

Estimation of Radon Emission Flux

Attachment E.1-I

Estimation of Radon Emission Flux

A1. **Silos - Current Scenario**

$$ER_{radon} = C_{radon} * BR_{silo} \quad \text{..... E.1-I.1}$$

where:

ER_{radon} = Average annual emission rate of radon (pCi/yr)
C_{radon} = Annual average concentration of radon in silo headspace (pCi/m^3)
BR_{silo} = Breathing rate of silo (m^3/yr)

a) From Table E1-2, the UCL radon concentrations (C_{radon}) are:

Silo 1 = 45502 pCi/L
Silo 2 = 138628 pCi/L
Silo 3 = 239280 pCi/L

b) From Table E1-3, the annual average breathing rates (BR_{silo}) are:

Silo 1 = 2764.2 m^3/yr
Silo 2 = 4439.2 m^3/yr
Silo 3 = 6720.4 m^3/yr

Therefore, the emission rates of Radon are:

Silo 1 - 45502(pCi/L) * 1000 (L/m^3) * 2764.2 (m^3/yr) = 1.25E+11 pCi/yr
Silo 2 - 138628 (pCi/L) * 1000 (L/m^3) * 4439.2 (m^3/yr) = 6.12E+11 pCi/yr
Silo 3 - 239280 (pCi/L) * 1000 (L/m^3) * 6720.4 (m^3/yr) = 1.6E+12 pCi/yr

A2. **Silos - Future Scenario**

In this scenario, the following equation was used to determine the annual emission rate of radon :

$$ER = EF \times S_a \quad \text{..... E.1-I.2}$$

Where,

ER = Annual emission rate of radon (pCi/yr)
EF = Annual average emission flux of radon (pCi/m^2-yr)
S_a = Surface area of release (m^2)

a) The "RAECOM" model was used for this scenario.

RAECOM calculates the radon flux exiting the surface of the upper layer of cover material.

The code is based on a one-dimensional, multilayer solution of Fick's law using the boundary conditions set forth in NUREG/CR-3533 (NRC 1984). For a bare source, this solution becomes:

$$J_t = (10^4)(R)(\rho_t)(E)[(\lambda)(DC_t)]^{1/2} (\tanh [(x_t)(\lambda/DC_t)^{1/2}]) \quad \text{.....E1-I.3}$$

and for a covered source, the solution is:

$$J_c = \frac{(2)\ (J_t)\ (e^{-b_c x_c})}{[1 + ((a_t/a_c)^{1/2})\ (\tanh (b_t x_t))] + [1 - ((a_t/a_c)^{1/2}\ (\tanh (b_t x_t))]\ e^{-2 b_c x_c}} \quad \text{(6-33)}$$

where

J_t	=	Radon flux from the source materials surface (pCi/m^2-sec)
R	=	Specific activity of radium in the source materials (pCi/g)
ρ_t	=	Dry bulk density of source material (g/cm^3)
E	=	Radon emanation coefficient (unitless)
DC_t	=	Radon diffusion coefficient in the total tailings pore space (cm^2/sec)
λ	=	Radiological decay constant of radon (2.1 x 10^{-6} sec^{-1})
J_c	=	Radon flux from the surface of cover material (pCi/m^2/sec)
b_c	=	$(\lambda/DC_c)^{1/2}$ (cm^{-1})
x_c	=	Thickness of cover material (cm)
a_t	=	$(\rho_t)^2(DC_t)\ [1 - (1-k)\ m_t]^2$ (cm$_2$/sec)
a_c	=	$(\rho_c)^2(DC_c)\ [1 - (1-k)\ m_c]^2$ (cm$_2$/sec)
b_t	=	$(\lambda/DC_t)^{1/2}$ (cm^{-1})
x_t	=	Thickness of tailings (cm)
DC_c	=	Radon diffusion coefficient in the total cover pore space (cm^2/sec)
m	=	Fractional moisture saturation (unitless)
k	=	Radon distribution coefficient, C/C (unitless)
ρ_c	=	Dry bulk density of cover (g/cm^3)

b) The silos 1 and 2 were considered a covered source due to the presence of bentonite layer and the Silo No. 3 material was considered a bare source.
The relevant values used for the model variables were as follows:

Variable	Units	K65 Silos	Silo 3
R	pCi/g	8.90E x 10^5	3872
ρ_t	g/cc	1.60	2.40
E	--	0.35	0.22
DC_t	(cm^2/s)	1.72E-03	2.4E-02
λ	sec^{-1}	2.10E-06	2.10E-06
bc	cm^{-1}	1.29E-01	--
xc	cm	3.05E+01	--
A_t	cm^2/sec	6.08E-05	--
A_e	cm^2/sec	3.58E-06	--
b_t	cm^{-1}	2.49E-02	--
X_t	cm	7.32E+02	83
DC_c	cm^2/sec	1.26E-04	--
M_t	--	0.785	--
M_c	--	1.0	--
K_t	--	0.260	--
K_c	--	1.01	--
ρ_c	g/cc	0.880	--

c) The calculated values of the emission flux are:
K65 Silos - J_c = 2590 pCi/m^2-sec
Silo 3 materials - J_t = 2981 pCi/m^2-sec

d) Surface areas of Silos are:
Silo 1&2 = 467 * 2 = 934m^2, based on diameter of 80 ft.
Silo 3 materials = 10 * (Area of Silo 3)
= 10 * 467 = 4670m^2

e) The emission rates using equation E.1-I.2 are:

Silo 1&2 = 2.877E+02(pCi/m^2-sec) * 934(m^2) * 3.15E+07(secs/yr)
= 8.46E+12 pCi/yr

Silo 3 materials = 2.980E+03(pCi/m^2-sec) * 4670(m^2) * 3.15E+07 secs/yr
= 4.39E+14 pCi/yr

B1. Berm Fill Material and Surface Soils - Current & Future Scenarios

a) "RAECOM" model was used with the bare source option using using E.1-I.3. The values of the model variables used in this case were as follows:

Variable	Unit	Surface Soil	Berm Fill
R	pCi/g	2.18	6.68
ρ_t	g/cc	1.6	1.6
E		0.22	0.22
D_t	cm^2/sec	2.4E-02	2.4E-02
λ	sec^{-1}	2.1E-06	2.1E-06
X_t	cm	100	100

b) From the "RAECOM" model, the emission fluxes were:
Surface Soil = 1.26 pCi/m^2-sec
Berm Fill = 3.861 pCi/m^2-sec

c) The surface areas of these sources are:

Current Scenario

Soil around K65 Silos: 3600m^2
Soil around Silo 3: 10400m^2
Berm Fill: 7700m^2

Future Scenario

Soil around K65 Silos: 3600m^2

Soil around Silo 3: $5730m^2$
Berm Fill: $7700m^2$

d) The emission rates for these sources using equation E.1-I.2 are:

Current Scenario

Soil around K65 Silos: 1.43E+11 pCi/yr
Soil around Silo 3: 4.13E+11 pCi/yr
Berm Fill: 9.36E+11 pCi/yr

Future Scenario

As a conservative estimate, the total emission from soils in this scenario was considered the same as the Current Scenario (i.e., 1.43E+11 + 4.13E+11 = 5.56E+11 pCi/yr), this amount was distributed in the soil around K65 Silo and soil around Silo 3 in proportional to the area.

Soil around K65 Silos: 2.15E+11 pCi/yr
Soil around Silo 3: 3.45E+11 pCi/yr
Berm Fill: 9.36E+11 pCi/yr

Attachment E.1-II

Estimation of TSP Emission Rate from Operable Unit 4 Soil Surfaces Due to Wind Erosion

Attachment E.1-II

Objective

To estimate the total suspended particulate (TSP) emission rate from Operable Unit 4 soil surfaces, due to wind erosion.

Methodology:

The "Threshold friction velocity" approach is used for determining the wind erosion rate. The steps in this method are as follows:

a) Determine the modal diameter of the sample of soils, materials.
b) Determine the threshold friction velocity of the material based on the modal diameter.
c) Determine the mean annual wind speed from the meteorological data.
d) Correct the threshold friction velocity at the anemometer height.
e) Estimate flux of PM_{10} due to wind erosion.
f) Estimate flux of total suspended particulate based on a particle size multiplier.

Assumptions

1. No continuous vegetation at site.
2. No crust present at this site.
3. No nonerodible elements present at this site.
4. The sieve analysis for Operable Unit 4 is the same as the sieve analysis of Operable Unit 5 soil.

Solution:

Modal Diameters of Soils

The modal diameters determined form the sieve analyses of the soils and Silo 3 materials are:

Area	Berm Fill	Surface Soil	Silo 3 Material
Modal Diameter (mm)	0.036	0.0115	0.0156

Threshold Friction Velocity

Figure 3-4 of reference 1 (USEPA, 1985) shows the relationship between the threshold friction velocity and the modal diameter of the materials. The analytical equation represented by this log plot is given by:

$$\ln(u_t) = 4.174 \quad 0.415\ln(dp)$$

Where,

u_t = Threshold friction velocity (cm/s)
dp = Modal particle diameter of the sample (mm)

This equation has to be extrapolated beyond the ranges of the figure since all model diameters are below 0.1 mm - the minimum model diameter on the graph. Extrapolating, the threshold friction velocities are found as:

Area	Berm Fill	Surface Soil	Silo 3 Material
Modal Diameter (mm)	0.036	0.0115	0.0156
Threshold Friction Velocity u_t (cm/s)	16.3	10.2	11.55

Greeley & Iversen (1985) give another method to estimate the threshold friction velocity based on wind tunnel experiments on a number of different materials. The results of the experiment generated a plot of a threshold parameter

$$TF = \frac{\sqrt{Pp * g * Dp}}{P}$$

versus the threshold friction velocity u_t (cm/s). In this equation Dp = particle diameter "cm," g is acceleration due to gravity = 981 cm/sec^{2}m, Pp is the particle density (g/cc) and P is the density of air (g/cc). The threshold friction velocity is estimated from this threshold parameter from correlations based on the specific gravity of the sample. The correlation is presented in Figure 3-5 of this reference.

Using the modal diameters as Dp, an average air density of $1.2 * 10^{-3}$ g/cc, the threshold friction velocities by this method are estimated as:

	Berm Fill	Surface Soil	Silo 3
Particle dia. (cm)	0.0036	0.00115	0.00156
Particle density (g/cc)	2.7	2.7	2.4
Threshold friction Velocity	21	35	30

A summary of the threshold friction velocities determined from both methods is as follows:

	Berm (cm/s)	Surface Soil (cm/s)	Silo 3 Material (cm/s)
U.S. EPA Method	16.3	10.2	11.55
Greeley & Iversen	21	35	30

Lower the threshold friction velocity higher is the potential for emission due to wind erosion. Therefore, to be conservative, the lower threshold friction velocities as obtained by U.S. EPA method are considered.

Since the threshold friction velocities for all the materials are below 75 cm/s, Gillette's "Unlimited Erosion Potential" model will be applicable for all the three materials.

These friction velocities are determined at the ground surface and will have to be corrected at the anemometer height of 10m. The following equation is used for this purpose (U.S. EPA).

$$U^{*(10)} = U^{*(s)} \frac{1}{0.4} * \ln(10/Zo)$$

where Zo is the roughness of the surface in meters. From site visit on January 13, 1993, the Operable Unit 4 area was found to be mostly covered with grass. The roughness heights for grassland usually varies between 2.0 cm to 4.0 cm (USEPA, 1985). Considering an average roughness value of 3.0 cm, the threshold friction velocities for the three materials at anemometer height of 10m are:

	Berm	Surface Soil	Silo 3 Material
U^{ts} (m/s)	0.163	0.102	0.115
u_{t10} (m/s)	2.37	1.48	1.68

Application of Gillett's "Unlimited Erosion Potential" model

As mentioned earlier, the Gillette's model is as follows:

$$E_{10} = 0.036 * (1-V) \left[\left(\frac{U}{U}\right)^3\right] * F(x)$$

where

E_{10} = Emission rate of PM_{10} particulate (g/m^2-hr)
V = Fraction of vegetative cover
U_{10} = Annual mean wind speed at anemometer height of 10 meters (m/s)
U_{t10} = Threshold friction velocity measured at the same height as U (m/s)
X = $0.886 * [Ut_{10}/U_{10}]$
F(x) = A function of 'x'
= 1.91 if x <0.5
= $0.18\ (8x^3 + 12x)EXP\ (-X2)$ for x > 2
= Figure 4-3 of Reference 1 for 0.5 < x <2

At present 80-85% of the Operable Unit 4 area is covered by grass. However, in order to be conservative, a vegetative fraction of 0.5 is considered for the Berm fill and the Operable Unit 4 surface. For the Silo 3 waste in the suture scenario, the vegetative cover is considered to be nil.

The mean annual wind speed obtained form the on-site data collection between 1987 - 1992 are as follows:

Year	1987	1988	1989	1990	1991	1992
Mean Annual Wind Speed	5.1	5.0	4.4	4.5	4.1	4.0
mph (m/s)	(2.28)	(2.235)	(1.967)	(2.011)	(1.833)	(1.788)

Again, to be conservative in predicting the emission rates, the highest of these mean annual wind speed, i.e., 2.28 m/s was selected for the Gillette model. Also, a particle size factor of 0.5 was used as per recommendations at USEPA (1985, 1990).

Based on these input values, the emission flux for the various materials calculated are as follows:

Area	Berm Fill	Surface Soil	Silo 3 Material
Emission Flux (g/m^2-s)	1.42E-05	6.76E-05	9.0E-05

An example calculation is shown below:

Material = Silo 3 waste

U_{t10} = 1.68 m/s
U_{10} = 2.28 m/s
X = 0.886 *(U_{t10}) = 0.6529

Since "x" is greater than 0.5 but less than 2.0, use Figure 4.3 for F(x).

F(x) = 1.8
V = 0.0 (assumed that no vegetative cover on material)
E_{10} = 0.036 * (1 - 0.0) * [$(2.28/1.68)^3$] * 1.8
= 0.036 * 1 * 2.5 * 1.8
= 0.162 g/m^2-hr
= 0.162 * g/m^2-hr * 1/3600 hr/sec
= 4.5 e^{-05} g/m^2-sec

The emission flux for TSP is determined by dividing the emission flux of PM_{10} by a particle size factor (K), where 'K' is the fraction of PM_{10} particulate in the suspended particulate. From data available in the literature, (USEPA, 1985, USEPA 1990) K = 0.5, therefore, emission flux of TSP from Silo 3 material is

$$ER_{TSP} = 4.5E^{-05}/0.5 = 9.\text{-}E^{-05}\ g/m^2\text{-sec}$$

Reference:

1. "Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites," Office of Health and Environmental Assessment, USEPA, NTIS PB85-192291, 1985.

2. "Air/Superfund National Technical Guidance Study Series. Volume II - Estimation of Baseline Air Emissions at Superfund Sites," Office of Air Quality Planning and Standards, USEPA, EPA-450/1-89-002a, 1990.

3. "Wind as Geological Process," Greeley, R., and Iversen, J.D., Cambridge University Press, p. 77, 1985.

Attachment E.1-III

Joint Frequency Distribution of the On-Site Wind Data

1987-1992

Joint Frequency Distribution of the On-Site Wind Data

1987

STATION: FEMP YEAR: 87 RUN ID: #409194.04.03.02 FERNALD OU-4

FREQUENCY DISTRIBUTION 4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000000	.000000	.000000	.000000	.000000	.000000	.000000
NNE	.000138	.000000	.000138	.000138	.000000	.000000	.000414
NE	.000138	.000000	.000138	.000138	.000000	.000000	.000414
ENE	.000138	.000276	.000827	.000000	.000000	.000000	.001241
E	.000000	.000551	.000689	.000138	.000000	.000000	.001379
ESE	.000138	.000276	.000276	.000000	.000000	.000000	.000689
SE	.000000	.000000	.000000	.000000	.000000	.000000	.000000
SSE	.000000	.000000	.000000	.000000	.000000	.000000	.000000
S	.000000	.000000	.000138	.000000	.000000	.000000	.000138
SSW	.000000	.000414	.001517	.000000	.000000	.000000	.001930
SW	.000000	.001241	.003447	.000414	.000000	.000000	.005101
WSW	.000000	.000965	.002344	.000000	.000000	.000000	.003309
W	.000000	.000827	.001379	.000000	.000000	.000000	.002206
WNW	.000000	.000276	.000689	.000414	.000000	.000000	.001379
NW	.000138	.000138	.000276	.000551	.000000	.000000	.001103
NNW	.000000	.000000	.000414	.000414	.000138	.000000	.000965
TOTAL	.000689	.004963	.012271	.002206	.000138	.000000	

FREQUENCY OF OCCURENCE OF A STABILITY = .020267

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000000	.000414	.000138	.000000	.000000	.000000	.000551
NNE	.000000	.000276	.000551	.000000	.000000	.000000	.000827
NE	.000000	.000827	.002344	.000138	.000000	.000000	.003309
ENE	.000276	.000827	.000276	.000689	.000000	.000000	.002068
E	.000276	.000689	.000276	.000138	.000000	.000000	.001379
ESE	.000000	.000827	.000000	.000000	.000000	.000000	.000827
SE	.000000	.000138	.000000	.000000	.000000	.000000	.000138
SSE	.000138	.000276	.000138	.000138	.000000	.000000	.000689
S	.000138	.000138	.000138	.000000	.000000	.000000	.000414
SSW	.000138	.000965	.002068	.000276	.000000	.000000	.003447
SW	.000276	.001241	.002757	.000138	.000000	.000000	.004412
WSW	.000551	.001103	.002068	.000000	.000000	.000000	.003723
W	.000138	.000965	.001379	.000138	.000000	.000000	.002620
WNW	.000000	.000689	.000827	.000276	.000000	.000000	.001792
NW	.000276	.001103	.000827	.000551	.000000	.000000	.002757
NNW	.000000	.000138	.000414	.000000	.000000	.000000	.000551
TOTAL	.002206	.010616	.014201	.002482	.000000	.000000	

FREQUENCY OF OCCURENCE OF B STABILITY = .029505

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = .000000

FREQUENCY DISTRIBUTION 4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000276	.000689	.000827	.000000	.000000	.000000	.001792
NNE	.000138	.000689	.000965	.000000	.000000	.000000	.001792
NE	.000276	.001241	.001379	.000414	.000000	.000000	.003309
ENE	.000689	.002068	.000551	.001241	.000000	.000000	.004550
E	.000414	.001241	.000276	.000138	.000000	.000000	.002068
ESE	.000551	.000689	.000000	.000000	.000000	.000000	.001241
SE	.000276	.000276	.000000	.000000	.000000	.000000	.000551
SSE	.000138	.000276	.000138	.000000	.000000	.000000	.000551
S	.000414	.000827	.000414	.000000	.000000	.000000	.001654
SSW	.000414	.001517	.000827	.000138	.000000	.000000	.002895
SW	.001379	.003860	.001930	.000276	.000000	.000000	.007445
WSW	.001103	.003723	.001379	.000414	.000000	.000000	.006618
W	.000414	.001241	.001103	.000414	.000000	.000000	.003171
WNW	.000414	.001241	.001241	.000276	.000000	.000000	.003171
NW	.000276	.000965	.000827	.000276	.000138	.000000	.002482
NNW	.000276	.001379	.001103	.000000	.000000	.000000	.002757
TOTAL	.007445	.021922	.012960	.003585	.000138	.000000	

FREQUENCY OF OCCURENCE OF C STABILITY = .046050

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.002925	.005653	.009789	.000827	.000000	.000000	.019194
NNE	.002386	.009789	.010892	.004136	.000000	.000000	.027203
NE	.004759	.015856	.010892	.001930	.000000	.000000	.033436
ENE	.008523	.024266	.017648	.005239	.000000	.000000	.055676
E	.006661	.005791	.001517	.000138	.000000	.000000	.014106
ESE	.003883	.002620	.000000	.000000	.000000	.000000	.006502
SE	.003052	.002482	.000551	.000000	.000000	.000000	.006085
SSE	.002777	.002895	.001517	.000551	.000000	.000000	.007740
S	.004306	.005101	.002068	.000276	.000000	.000000	.011752
SSW	.005161	.012271	.004136	.001654	.000000	.000000	.023223
SW	.006154	.019440	.009238	.000827	.000551	.000000	.036211
WSW	.007241	.013650	.006756	.003860	.000276	.000000	.031783
W	.005719	.013512	.014477	.003723	.000000	.000000	.037430
WNW	.004335	.013374	.007997	.001517	.000000	.000000	.027222
NW	.002940	.009927	.007997	.001654	.000414	.000000	.022931
NNW	.004596	.008824	.006066	.002482	.000276	.000000	.022244
TOTAL	.075417	.165449	.111540	.028816	.001517	.000000	

FREQUENCY OF OCCURENCE OF D STABILITY = .382738

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = .000827

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.003486	.005239	.000689	.000138	.000000	.000000	.009552
NNE	.002507	.003171	.001792	.000276	.000000	.000000	.007746
NE	.003202	.003723	.000827	.000000	.000000	.000000	.007752
ENE	.012519	.011995	.001930	.000000	.000000	.000000	.026444
E	.011648	.003171	.000276	.000000	.000000	.000000	.015095
ESE	.006380	.002068	.000138	.000000	.000000	.000000	.008586
SE	.004859	.002620	.000965	.000000	.000000	.000000	.008444
SSE	.006661	.002895	.001241	.000551	.000000	.000000	.011349
S	.006945	.004412	.002620	.000138	.000000	.000000	.014114
SSW	.009055	.011581	.004412	.000414	.000000	.000000	.025462
SW	.014227	.022336	.006204	.001103	.000138	.000000	.044008
WSW	.021366	.008410	.004136	.001103	.000000	.000000	.035016
W	.013201	.009651	.003998	.000276	.000000	.000000	.027126
WNW	.007369	.006342	.002344	.000138	.000000	.000000	.016193
NW	.009712	.003723	.001930	.000276	.000000	.000000	.015640
NNW	.008184	.002895	.001379	.000138	.000000	.000000	.012596
TOTAL	.141321	.104233	.034882	.004550	.000138	.000000	

FREQUENCY OF OCCURENCE OF E STABILITY = .285123

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = .001103

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.006570	.000138	.000000	.000000	.000138	.000138	.006983
NNE	.005994	.000000	.000138	.000000	.000000	.000000	.006132
NE	.006279	.000000	.000000	.000000	.000000	.000000	.006279
ENE	.012646	.002482	.000000	.000000	.000000	.000000	.015127
E	.017287	.000551	.000000	.000000	.000000	.000000	.017839
ESE	.013558	.000000	.000000	.000000	.000000	.000000	.013558
SE	.006860	.000276	.000000	.000000	.000000	.000000	.007136
SSE	.004286	.000138	.000000	.000000	.000000	.000000	.004424
S	.005708	.000000	.000000	.000000	.000000	.000000	.005708
SSW	.010019	.000827	.000000	.000000	.000000	.000000	.010846
SW	.020475	.001930	.000000	.000000	.000000	.000000	.022406
WSW	.026873	.001241	.000000	.000000	.000000	.000000	.028114
W	.028414	.000414	.000000	.000000	.000000	.000000	.028828
WNW	.025412	.000276	.000000	.000000	.000000	.000000	.025688
NW	.022553	.000138	.000000	.000000	.000000	.000000	.022691
NNW	.014281	.000276	.000000	.000000	.000000	.000000	.014557
TOTAL	.227216	.008686	.000138	.000000	.000138	.000138	

FREQUENCY OF OCCURENCE OF F STABILITY = .236316

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = .007997

FEMP-04RI-4 DRAFT
April 19, 1993

Joint Frequency Distribution of the On-Site Wind Data

1988

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000137	.000775	.000645	.000258	.000000	.000000	.001815
NNE	.000657	.000775	.002453	.001162	.000000	.000000	.005046
NE	.000789	.001033	.001420	.000775	.000000	.000000	.004017
ENE	.000001	.000129	.000387	.000000	.000000	.000000	.000517
E	.000000	.000000	.000000	.000000	.000000	.000129	.000129
ESE	.000000	.000000	.000000	.000000	.000000	.000000	.000000
SE	.000000	.000000	.000000	.000000	.000000	.000129	.000129
SSE	.000000	.000000	.000258	.000129	.000000	.000000	.000387
S	.000522	.000129	.000000	.000000	.000000	.000000	.000651
SSW	.001044	.000387	.001162	.000129	.000000	.000000	.002723
SW	.000531	.001291	.003615	.000258	.000000	.000000	.005695
WSW	.000145	.001807	.002711	.000000	.000000	.000000	.004663
W	.000535	.001807	.003615	.000516	.000000	.000000	.006474
WNW	.000786	.000645	.002066	.000645	.000000	.000000	.004143
NW	.000395	.000516	.001033	.000000	.000000	.000000	.001944
NNW	.000396	.000645	.000645	.000000	.000000	.000000	.001687
TOTAL	.005939	.009941	.020010	.003873	.000000	.000258	

FREQUENCY OF OCCURENCE OF A STABILITY = .040021

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = .000129

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000129	.001033	.000387	.000000	.000000	.000000	.001549
NNE	.000129	.000258	.001162	.000516	.000000	.000000	.002066
NE	.000129	.001033	.000775	.000000	.000000	.000000	.001936
ENE	.000000	.000516	.000516	.000000	.000000	.000000	.001033
E	.000387	.000258	.000387	.000000	.000000	.000000	.001033
ESE	.000129	.000000	.000000	.000000	.000000	.000000	.000129
SE	.000000	.000000	.000000	.000000	.000000	.000000	.000000
SSE	.000258	.000000	.000000	.000000	.000000	.000000	.000258
S	.000129	.000000	.000129	.000000	.000000	.000000	.000258
SSW	.000387	.001033	.001549	.000258	.000000	.000000	.003227
SW	.000775	.001549	.002066	.000129	.000000	.000000	.004518
WSW	.000516	.001549	.001549	.000258	.000000	.000000	.003873
W	.000129	.000904	.002324	.000258	.000000	.000000	.003615
WNW	.000516	.000904	.002324	.000387	.000000	.000000	.004131
NW	.000516	.000387	.001162	.000129	.000000	.000000	.002195
NNW	.000645	.000904	.001033	.000000	.000000	.000000	.002582
TOTAL	.004777	.010328	.015363	.001936	.000000	.000000	

FREQUENCY OF OCCURENCE OF B STABILITY = .032404

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000387	.001033	.000775	.000516	.000000	.000000	.002711
NNE	.000387	.001162	.001420	.000258	.000000	.000000	.003227
NE	.000000	.001936	.000645	.000258	.000000	.000000	.002840
ENE	.000258	.001420	.000645	.000000	.000000	.000000	.002324
E	.000387	.000645	.000387	.000000	.000000	.000000	.001420
ESE	.000645	.000258	.000129	.000000	.000000	.000000	.001033
SE	.000129	.000387	.000000	.000000	.000000	.000000	.000516
SSE	.000258	.000516	.000387	.000000	.000000	.000000	.001162
S	.000387	.000775	.000387	.000000	.000000	.000000	.001549
SSW	.000516	.001549	.000904	.000258	.000129	.000000	.003357
SW	.000516	.003227	.001678	.000258	.000000	.000000	.005680
WSW	.001162	.003227	.001678	.000258	.000000	.000000	.006326
W	.000258	.001549	.001936	.000258	.000000	.000000	.004002
WNW	.000645	.001420	.002711	.000516	.000000	.000000	.005293
NW	.000516	.001162	.001549	.000129	.000000	.000000	.003357
NNW	.000129	.001033	.000904	.000000	.000000	.000000	.002066
TOTAL	.006584	.021301	.016137	.002711	.000129	.000000	

FREQUENCY OF OCCURENCE OF C STABILITY = .046863

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.001813	.008133	.004131	.000516	.000000	.000000	.014594
NNE	.002717	.007359	.006842	.000516	.000000	.000000	.017434
NE	.003624	.011748	.005809	.000387	.000000	.000000	.021569
ENE	.005952	.016654	.004906	.000129	.000000	.000000	.027641
E	.005687	.004906	.001162	.000129	.000000	.000000	.011883
ESE	.004264	.002195	.000129	.000129	.000000	.000000	.006717
SE	.002714	.002840	.000387	.000000	.000000	.000000	.005942
SSE	.004265	.004131	.002324	.000000	.000000	.000000	.010720
S	.004136	.004002	.002324	.000000	.000000	.000000	.010462
SSW	.006981	.008908	.007617	.004389	.000000	.000000	.027895
SW	.009309	.013943	.009812	.002840	.000258	.000000	.036161
WSW	.011634	.014459	.006584	.001033	.000000	.000000	.033710
W	.008404	.012135	.011490	.001807	.000000	.000000	.033836
WNW	.004398	.009812	.012781	.002066	.000000	.000000	.029056
NW	.004783	.005680	.006197	.000516	.000000	.000000	.017176
NNW	.003363	.007359	.005164	.000387	.000000	.000000	.016273
TOTAL	.084043	.134263	.087658	.014846	.000258	.000000	

FREQUENCY OF OCCURENCE OF D STABILITY = .321069

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = .000129

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.003497	.003357	.001291	.000129	.000000	.000000	.008274
NNE	.003366	.002066	.001291	.000129	.000000	.000000	.006852
NE	.002852	.003873	.000516	.000000	.000000	.000000	.007241
ENE	.008552	.009682	.002582	.000000	.000000	.000000	.020816
E	.006340	.002195	.000258	.000000	.000000	.000000	.008793
ESE	.004012	.001678	.000000	.000000	.000000	.000000	.005690
SE	.004528	.001033	.000000	.000000	.000000	.000000	.005561
SSE	.005695	.002711	.001420	.000000	.000000	.000000	.009826
S	.005054	.006068	.006197	.001936	.000000	.000000	.019255
SSW	.010624	.011490	.013168	.003615	.000000	.000000	.038897
SW	.014386	.018074	.009295	.001291	.000000	.000000	.043046
WSW	.015540	.012523	.006455	.001420	.000000	.000000	.035938
W	.013606	.016008	.005035	.000258	.000000	.000000	.034907
WNW	.008809	.008650	.002969	.000387	.000000	.000000	.020815
NW	.006862	.004389	.001549	.000129	.000000	.000000	.012929
NNW	.004920	.003486	.001162	.000258	.000000	.000000	.009826
TOTAL	.118642	.107281	.053189	.009553	.000000	.000000	

FREQUENCY OF OCCURENCE OF E STABILITY = .288665

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = .000387

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.006108	.000000	.000000	.000000	.000000	.000129	.006238
NNE	.005849	.000129	.000000	.000000	.000000	.000000	.005979
NE	.005719	.000000	.000000	.000000	.000000	.000000	.005719
ENE	.008846	.001162	.000000	.000000	.000000	.000000	.010008
E	.015468	.000258	.000000	.000000	.000000	.000000	.015726
ESE	.008968	.000000	.000000	.000000	.000129	.000000	.009097
SE	.007409	.000129	.000000	.000000	.000000	.000000	.007538
SSE	.005850	.000258	.000000	.000000	.000000	.000000	.006108
S	.010140	.000387	.000000	.000000	.000000	.000000	.010527
SSW	.016905	.001420	.000000	.000129	.000000	.000000	.018455
SW	.028615	.003227	.000000	.000000	.000000	.000000	.031842
WSW	.034336	.003615	.000000	.000000	.000000	.000000	.037951
W	.034318	.000904	.000000	.000000	.000000	.000000	.035221
WNW	.035741	.000000	.000129	.000000	.000000	.000000	.035870
NW	.021965	.000129	.000129	.000000	.000000	.000000	.022224
NNW	.011831	.000645	.000000	.000000	.000000	.000000	.012477
TOTAL	.258069	.012264	.000258	.000129	.000129	.000129	

FREQUENCY OF OCCURENCE OF F STABILITY = .270979

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = .001807

FEMP-04RI-4 DRAFT
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Joint Frequency Distribution of the On-Site Wind Data

1989

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000000	.000478	.000598	.000239	.000000	.000000	.001315
NNE	.000000	.000359	.000000	.000000	.000000	.000000	.000359
NE	.000000	.000837	.000239	.000000	.000000	.000000	.001076
ENE	.000120	.001435	.001076	.000000	.000000	.000000	.002630
E	.000000	.001076	.000000	.000000	.000000	.000000	.001076
ESE	.000120	.000000	.000000	.000000	.000000	.000000	.000120
SE	.000000	.000000	.000000	.000000	.000000	.000000	.000000
SSE	.000000	.000000	.000000	.000000	.000000	.000000	.000000
S	.000000	.000000	.000000	.000000	.000000	.000000	.000000
SSW	.000000	.000837	.001793	.000120	.000000	.000000	.002750
SW	.000000	.002630	.002272	.000239	.000000	.000000	.005141
WSW	.000000	.002989	.002391	.000000	.000000	.000000	.005380
W	.000120	.001435	.002511	.000120	.000000	.000000	.004185
WNW	.000239	.000837	.000359	.000359	.000000	.000000	.001793
NW	.000478	.000956	.000120	.000000	.000000	.000000	.001554
NNW	.000120	.000239	.001196	.000000	.000000	.000000	.001554
TOTAL	.001196	.014108	.012554	.001076	.000000	.000000	

FREQUENCY OF OCCURENCE OF A STABILITY = .028934

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000120	.000598	.001076	.000359	.000000	.000000	.002152
NNE	.000000	.000478	.000120	.000000	.000000	.000000	.000598
NE	.000359	.000598	.000000	.000000	.000000	.000000	.000956
ENE	.000239	.002152	.000598	.000000	.000000	.000000	.002989
E	.000717	.000239	.000000	.000000	.000000	.000000	.000956
ESE	.000120	.000000	.000000	.000000	.000000	.000000	.000120
SE	.000000	.000000	.000120	.000000	.000000	.000000	.000120
SSE	.000239	.000000	.000000	.000000	.000000	.000000	.000239
S	.000000	.000359	.000120	.000000	.000000	.000000	.000478
SSW	.000359	.001435	.001076	.000000	.000000	.000000	.002869
SW	.000717	.001674	.001913	.000120	.000000	.000000	.004424
WSW	.000120	.003109	.001196	.000120	.000000	.000000	.004543
W	.000598	.001196	.000717	.000000	.000000	.000000	.002511
WNW	.000359	.000717	.000000	.000000	.000000	.000000	.001076
NW	.000239	.000598	.000239	.000000	.000000	.000000	.001076
NNW	.000239	.000478	.000717	.000120	.000000	.000000	.001554
TOTAL	.004424	.013630	.007891	.000717	.000000	.000000	

FREQUENCY OF OCCURENCE OF B STABILITY = .026662

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000000	.001076	.001196	.000359	.000000	.000000	.002630
NNE	.000478	.000837	.000478	.000120	.000000	.000000	.001913
NE	.000359	.001674	.001315	.000000	.000000	.000000	.003348
ENE	.001315	.002152	.000120	.000000	.000000	.000000	.003587
E	.001315	.000956	.000000	.000000	.000000	.000000	.002272
ESE	.000478	.000598	.000000	.000000	.000000	.000000	.001076
SE	.000359	.000717	.000239	.000000	.000000	.000000	.001315
SSE	.000000	.000359	.000000	.000000	.000000	.000000	.000359
S	.000000	.001076	.000359	.000120	.000000	.000000	.001554
SSW	.000478	.001674	.001196	.000000	.000000	.000000	.003348
SW	.000837	.003228	.002033	.000120	.000000	.000000	.006217
WSW	.001076	.002750	.001315	.000000	.000000	.000000	.005141
W	.000598	.001435	.000837	.000120	.000000	.000000	.002989
WNW	.000239	.001315	.000717	.000000	.000000	.000000	.002272
NW	.000359	.001196	.000717	.000000	.000000	.000000	.002272
NNW	.000239	.001196	.000717	.000000	.000000	.000000	.002152
TOTAL	.008130	.022238	.011239	.000837	.000000	.000000	

FREQUENCY OF OCCURENCE OF C STABILITY = .042444

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.003467	.012673	.011358	.001793	.000000	.000000	.029292
NNE	.006217	.014586	.011956	.000598	.000000	.000000	.033357
NE	.007771	.016858	.009206	.000000	.000000	.000000	.033835
ENE	.009326	.021879	.006695	.000120	.000000	.000000	.038020
E	.006815	.006337	.000478	.000000	.000000	.000000	.013630
ESE	.005619	.002391	.000000	.000000	.000000	.000000	.008011
SE	.004065	.002391	.000120	.000000	.000000	.000000	.006576
SSE	.003706	.001674	.000478	.000120	.000000	.000000	.005978
S	.004304	.007293	.002391	.000239	.000000	.000000	.014228
SSW	.007771	.014347	.006337	.000478	.000000	.000000	.028934
SW	.011119	.015065	.006217	.000717	.000000	.000000	.033118
WSW	.010760	.008608	.005380	.000239	.000000	.000000	.024988
W	.008608	.007293	.005500	.000478	.000000	.000000	.021879
WNW	.004065	.009206	.007293	.001076	.000000	.000000	.021640
NW	.005739	.008847	.007771	.000837	.000000	.000000	.023195
NNW	.004185	.008967	.003826	.000478	.000000	.000000	.017456
TOTAL	.103539	.158417	.085007	.007174	.000000	.000000	

FREQUENCY OF OCCURENCE OF D STABILITY = .354137

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = .000000

STATION: FEMP YEAR: 89 RUN ID: #409194.04.03.02 FERNALD OU-4

FREQUENCY DISTRIBUTION 4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.004916	.005022	.000837	.000000	.000000	.000000	.010774
NNE	.004076	.003826	.000359	.000239	.000000	.000000	.008500
NE	.004674	.003228	.000239	.000000	.000000	.000000	.008141
ENE	.011263	.006815	.000598	.000000	.000000	.000000	.018676
E	.008024	.001913	.000120	.000000	.000000	.000000	.010057
ESE	.003233	.000120	.000000	.000000	.000000	.000000	.003352
SE	.004551	.000956	.000000	.000000	.000000	.000000	.005507
SSE	.006350	.003348	.000359	.000000	.000000	.000000	.010056
S	.007789	.005380	.002152	.000239	.000000	.000000	.015561
SSW	.015101	.011478	.007054	.001674	.000000	.000000	.035307
SW	.025648	.019608	.006695	.000359	.000000	.000000	.052310
WSW	.023478	.009087	.001793	.000000	.000000	.000000	.034358
W	.015099	.010043	.004663	.000000	.000000	.000000	.029805
WNW	.011508	.010163	.005858	.000956	.000000	.000000	.028485
NW	.009466	.005380	.001674	.000120	.000000	.000000	.016639
NNW	.006589	.003228	.000717	.000359	.000000	.000000	.010893
TOTAL	.161765	.099593	.033118	.003945	.000000	.000000	

FREQUENCY OF OCCURENCE OF E STABILITY = .298422

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = .000359

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.001871	.000000	.000000	.000000	.000000	.000000	.001871
NNE	.002868	.000000	.000000	.000000	.000000	.000000	.002868
NE	.003616	.000000	.000000	.000000	.000000	.000000	.003616
ENE	.005268	.000717	.000000	.000000	.000000	.000000	.005986
E	.010225	.000000	.000000	.000000	.000000	.000000	.010225
ESE	.008355	.000000	.000000	.000000	.000000	.000000	.008355
SE	.005487	.000000	.000000	.000000	.000000	.000000	.005487
SSE	.006360	.000000	.000000	.000000	.000000	.000000	.006360
S	.007487	.000120	.000000	.000000	.000000	.000000	.007607
SSW	.013114	.000478	.000000	.000000	.000000	.000000	.013592
SW	.025979	.000956	.000000	.000000	.000000	.000000	.026935
WSW	.040429	.000598	.000000	.000000	.000000	.000000	.041027
W	.044154	.000239	.000000	.000000	.000000	.000000	.044394
WNW	.038912	.000120	.000000	.000000	.000000	.000000	.039031
NW	.022955	.000239	.000000	.000000	.000000	.000000	.023194
NNW	.008734	.000120	.000000	.000000	.000000	.000000	.008854
TOTAL	.245815	.003587	.000000	.000000	.000000	.000000	

FREQUENCY OF OCCURENCE OF F STABILITY = .249402

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = .010282

FEMP-04RI-4 DRAFT
April 19, 1993

Joint Frequency Distribution of the On-Site Wind Data

1990

FER/OU4RI/JK.1112E1.CVR/04-15-93 12:07pm

FREQUENCY DISTRIBUTION 4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000150	.000599	.000150	.000449	.000000	.000000	.001347
NNE	.000449	.000000	.000000	.000000	.000000	.000000	.000449
NE	.000449	.000898	.000000	.000000	.000000	.000000	.001347
ENE	.001646	.001945	.000299	.000000	.000000	.000000	.003890
E	.000599	.000748	.000000	.000000	.000000	.000000	.001347
ESE	.000748	.000150	.000000	.000000	.000000	.000000	.000898
SE	.000299	.000000	.000000	.000000	.000000	.000000	.000299
SSE	.000150	.000299	.000000	.000000	.000000	.000000	.000449
S	.000000	.000299	.000150	.000000	.000000	.000000	.000449
SSW	.000150	.002095	.002993	.000150	.000000	.000000	.005387
SW	.000599	.002095	.001347	.000000	.000000	.000000	.004040
WSW	.001047	.001796	.001197	.000150	.000000	.000000	.004190
W	.000599	.001347	.002245	.000150	.000000	.000000	.004339
WNW	.000449	.000599	.000299	.000000	.000000	.000000	.001347
NW	.000000	.000748	.000599	.000000	.000000	.000000	.001347
NNW	.000599	.000449	.000449	.000150	.000000	.000000	.001646
TOTAL	.007931	.014066	.009726	.001047	.000000	.000000	

FREQUENCY OF OCCURENCE OF A STABILITY = .032770

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000005	.000449	.000000	.000150	.000000	.000000	.000604
NNE	.000000	.000000	.000000	.000000	.000000	.000000	.000000
NE	.000304	.000150	.000000	.000000	.000000	.000000	.000454
ENE	.000007	.000599	.000000	.000000	.000000	.000000	.000605
E	.000308	.000449	.000299	.000000	.000000	.000000	.001056
ESE	.000005	.000449	.000000	.000000	.000000	.000000	.000454
SE	.000454	.000000	.000000	.000000	.000000	.000000	.000454
SSE	.000000	.000000	.000000	.000000	.000000	.000000	.000000
S	.000151	.000000	.000150	.000000	.000000	.000000	.000301
SSW	.000169	.001496	.001347	.000000	.000000	.000000	.003012
SW	.000320	.001496	.000748	.000000	.000000	.000000	.002565
WSW	.000470	.001347	.000449	.000000	.000000	.000000	.002265
W	.000461	.000599	.001197	.000299	.000000	.000000	.002556
WNW	.000158	.000599	.000449	.000150	.000000	.000000	.001355
NW	.000016	.001347	.001347	.000000	.000000	.000000	.002709
NNW	.000164	.001047	.000898	.000150	.000000	.000000	.002258
TOTAL	.002993	.010025	.006883	.000748	.000000	.000000	

FREQUENCY OF OCCURENCE OF B STABILITY = .020649

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = .000150

4292

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000150	.000748	.000299	.000000	.000000	.000000	.001197
NNE	.000150	.000299	.000449	.000299	.000000	.000000	.001197
NE	.000150	.000898	.000449	.000000	.000000	.000000	.001496
ENE	.000898	.001646	.000299	.000000	.000000	.000000	.002843
E	.000449	.000449	.000000	.000000	.000000	.000000	.000898
ESE	.000000	.000150	.000000	.000000	.000000	.000000	.000150
SE	.000748	.000000	.000000	.000000	.000000	.000000	.000748
SSE	.000449	.000449	.000000	.000000	.000000	.000000	.000898
S	.000150	.000748	.000299	.000000	.000000	.000000	.001197
SSW	.000000	.002095	.002245	.000150	.000000	.000000	.004489
SW	.000449	.002245	.002544	.000299	.000000	.000000	.005536
WSW	.000748	.002095	.001197	.000150	.000000	.000000	.004190
W	.000449	.000898	.001496	.000748	.000000	.000000	.003591
WNW	.000748	.000748	.000150	.000150	.000000	.000000	.001796
NW	.000599	.001945	.001945	.000000	.000000	.000000	.004489
NNW	.000599	.001496	.001047	.000150	.000000	.000000	.003292
TOTAL	.006734	.016909	.012420	.001945	.000000	.000000	

FREQUENCY OF OCCURENCE OF C STABILITY = .038007

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.001231	.011671	.005985	.000299	.000000	.000000	.019187
NNE	.003624	.008978	.002394	.000150	.000000	.000000	.015146
NE	.006323	.008080	.003591	.000000	.000000	.000000	.017994
ENE	.006787	.013467	.007332	.000000	.000000	.000000	.027586
E	.005565	.005088	.000599	.000000	.000000	.000000	.011251
ESE	.005704	.001197	.000000	.000000	.000000	.000000	.006901
SE	.003606	.001945	.000299	.000000	.000000	.000000	.005850
SSE	.003016	.005836	.000748	.000000	.000000	.000000	.009600
S	.004371	.007781	.007033	.001646	.000000	.000000	.020831
SSW	.006492	.015263	.016011	.001646	.000000	.000000	.039411
SW	.008739	.014066	.007182	.001047	.000000	.000000	.031034
WSW	.009318	.006135	.003890	.003292	.000150	.000000	.022785
W	.007525	.008828	.010923	.002843	.000000	.000000	.030119
WNW	.004677	.009876	.009577	.001496	.000000	.000000	.025626
NW	.005126	.009427	.009427	.000000	.000000	.000000	.023980
NNW	.003787	.013617	.007482	.000599	.000000	.000000	.025484
TOTAL	.085890	.141254	.092473	.013018	.000150	.000000	

FREQUENCY OF OCCURENCE OF D STABILITY = .332785

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = .000599

FREQUENCY DISTRIBUTION

4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.007111	.006285	.000599	.000000	.000000	.000000	.013994
NNE	.004223	.003591	.000748	.000150	.000000	.000000	.008712
NE	.005081	.002095	.000748	.000000	.000000	.000000	.007924
ENE	.010190	.007033	.000000	.000000	.000000	.000000	.017223
E	.012228	.001646	.000000	.000000	.000000	.000000	.013874
ESE	.006219	.000000	.000000	.000000	.000000	.000000	.006219
SE	.006887	.000449	.000150	.000000	.000000	.000000	.007485
SSE	.007741	.003741	.001197	.000000	.000000	.000000	.012679
S	.009848	.011522	.005536	.000748	.000000	.000000	.027654
SSW	.016128	.022146	.009726	.001047	.000000	.000000	.049047
SW	.036086	.017657	.006734	.000299	.000000	.000000	.060775
WSW	.026366	.008080	.003442	.000599	.000000	.000000	.038486
W	.022151	.007033	.006883	.001945	.000000	.000000	.038012
WNW	.017585	.007931	.005237	.000299	.000000	.000000	.031052
NW	.011238	.005985	.001945	.000150	.000000	.000000	.019318
NNW	.009954	.003442	.001197	.000000	.000000	.000000	.014593
TOTAL	.209038	.108634	.044142	.005237	.000000	.000000	

FREQUENCY OF OCCURENCE OF - E STABILITY = .367051

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = .019602

FREQUENCY DISTRIBUTION

4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.002872	.000449	.000000	.000000	.000000	.000000	.003321
NNE	.003795	.000000	.000000	.000000	.000000	.000000	.003795
NE	.003163	.000000	.000000	.000000	.000000	.000000	.003163
ENE	.007275	.000000	.000000	.000000	.000000	.000000	.007275
E	.012177	.000000	.000000	.000000	.000000	.000000	.012177
ESE	.006009	.000000	.000000	.000000	.000000	.000000	.006009
SE	.003488	.000150	.000000	.000000	.000000	.000000	.003637
SSE	.004436	.000150	.000000	.000000	.000000	.000000	.004586
S	.006984	.000449	.000000	.000000	.000000	.000000	.007433
SSW	.011621	.001347	.000000	.000000	.000000	.000000	.012968
SW	.018447	.001796	.000150	.000000	.000000	.000000	.020392
WSW	.030282	.001347	.000000	.000000	.000000	.000000	.031628
W	.026893	.000150	.000000	.000000	.000000	.000000	.027042
WNW	.031154	.000000	.000000	.000000	.000000	.000000	.031154
NW	.025145	.000000	.000000	.000000	.000000	.000000	.025145
NNW	.008416	.000599	.000000	.000000	.000000	.000000	.009014
TOTAL	.202155	.006434	.000150	.000000	.000000	.000000	

FREQUENCY OF OCCURENCE OF F STABILITY = .208739

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = .011223

FEMP-04RI-4 DRAFT
April 19, 1993

Joint Frequency Distribution of the On-Site Wind Data

1991

FREQUENCY DISTRIBUTION 4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000987	.002837	.001850	.000000	.000000	.000000	.005674
NNE	.000740	.003824	.000740	.000000	.000000	.000000	.005304
NE	.002837	.007401	.002220	.000000	.000000	.000000	.012458
ENE	.008141	.010855	.004071	.000247	.000000	.000000	.023313
E	.004811	.003824	.000370	.000123	.000000	.000000	.009128
ESE	.003207	.001850	.000000	.000000	.000000	.000000	.005057
SE	.001850	.000863	.000000	.000000	.000000	.000000	.002714
SSE	.002590	.001110	.000000	.000000	.000000	.000000	.003701
S	.002960	.003084	.002344	.000000	.000000	.000000	.008388
SSW	.004811	.011595	.006291	.000123	.000000	.000000	.022820
SW	.006784	.011595	.005181	.000370	.000000	.000000	.023930
WSW	.007894	.009128	.004811	.000123	.000000	.000000	.021956
W	.004071	.010978	.004934	.000617	.000000	.000000	.020599
WNW	.002714	.004687	.005797	.000493	.000000	.000000	.013692
NW	.002590	.002590	.001850	.000000	.000000	.000000	.007031
NNW	.001480	.003207	.001480	.000123	.000000	.000000	.006291
TOTAL	.058468	.089429	.041939	.002220	.000000	.000000	

FREQUENCY OF OCCURENCE OF A STABILITY = .192056

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000247	.001110	.000987	.000000	.000000	.000000	.002344
NNE	.000370	.000370	.000617	.000123	.000000	.000000	.001480
NE	.000493	.000863	.000493	.000000	.000000	.000000	.001850
ENE	.000987	.001234	.000493	.000000	.000000	.000000	.002714
E	.000863	.000740	.000000	.000000	.000000	.000000	.001604
ESE	.000740	.000370	.000000	.000000	.000000	.000000	.001110
SE	.000247	.000247	.000000	.000000	.000000	.000000	.000493
SSE	.000740	.000123	.000247	.000000	.000000	.000000	.001110
S	.001727	.001480	.000370	.000000	.000000	.000000	.003577
SSW	.001480	.002097	.000863	.000000	.000000	.000000	.004441
SW	.001604	.002590	.001234	.000000	.000000	.000000	.005427
WSW	.001604	.000987	.001480	.000000	.000000	.000000	.004071
W	.001850	.001727	.000863	.000247	.000000	.000000	.004687
WNW	.000740	.000617	.000493	.000123	.000000	.000000	.001974
NW	.000617	.000863	.000740	.000000	.000000	.000000	.002220
NNW	.000493	.000863	.000987	.000000	.000000	.000000	.002344
TOTAL	.014802	.016282	.009868	.000493	.000000	.000000	

FREQUENCY OF OCCURENCE OF B STABILITY = .041446

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000740	.000987	.000987	.000123	.000000	.000000	.002837
NNE	.000247	.001604	.000370	.000000	.000000	.000000	.002220
NE	.000370	.001357	.000493	.000000	.000000	.000000	.002220
ENE	.001357	.000987	.000123	.000000	.000000	.000000	.002467
E	.001727	.000863	.000000	.000123	.000000	.000000	.002714
ESE	.001480	.000617	.000000	.000000	.000000	.000000	.002097
SE	.000863	.000247	.000000	.000000	.000000	.000000	.001110
SSE	.000370	.000247	.000000	.000123	.000000	.000000	.000740
S	.000493	.001234	.000370	.000000	.000000	.000000	.002097
SSW	.000493	.001974	.001974	.000000	.000000	.000000	.004441
SW	.001974	.002714	.000987	.000000	.000000	.000000	.005674
WSW	.000863	.001604	.000740	.000123	.000000	.000000	.003330
W	.002097	.001234	.000740	.000123	.000000	.000000	.004194
WNW	.000617	.001974	.000370	.000123	.000000	.000000	.003084
NW	.000493	.001480	.000493	.000000	.000000	.000000	.002467
NNW	.000617	.000123	.001110	.000000	.000000	.000000	.001850
TOTAL	.014802	.019243	.008758	.000740	.000000	.000000	

FREQUENCY OF OCCURENCE OF C STABILITY = .043543

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = .000000

FREQUENCY DISTRIBUTION

4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.002677	.009868	.007154	.000247	.000000	.000000	.019946
NNE	.004652	.008141	.002714	.000247	.000000	.000000	.015754
NE	.006751	.006291	.002344	.000123	.000000	.000000	.015509
ENE	.007986	.005181	.007031	.001357	.000000	.000000	.021554
E	.004735	.002097	.000493	.000000	.000000	.000000	.007325
ESE	.002735	.000370	.000000	.000000	.000000	.000000	.003105
SE	.002246	.001480	.000000	.000000	.000000	.000000	.003726
SSE	.002996	.002097	.000863	.000000	.000000	.000000	.005956
S	.003520	.006044	.002837	.000247	.000000	.000000	.012648
SSW	.010789	.015295	.007771	.000493	.000000	.000000	.034349
SW	.014496	.012582	.003947	.000000	.000000	.000000	.031025
WSW	.011601	.007154	.004934	.000740	.000000	.000000	.024430
W	.007673	.013815	.008881	.000987	.000000	.000000	.031356
WNW	.008996	.007524	.005797	.000987	.000000	.000000	.023304
NW	.005014	.006538	.001974	.000123	.000000	.000000	.013648
NNW	.004404	.008141	.003577	.000247	.000000	.000000	.016369
TOTAL	.101271	.112619	.060318	.005797	.000000	.000000	

FREQUENCY OF OCCURENCE OF D STABILITY = .280005

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = .001480

FREQUENCY DISTRIBUTION

4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.004311	.001110	.000247	.000000	.000000	.000000	.005667
NNE	.002417	.000987	.000123	.000000	.000000	.000000	.003527
NE	.003187	.001604	.000000	.000000	.000000	.000000	.004790
ENE	.009925	.004194	.000123	.000000	.000000	.000000	.014242
E	.007585	.000987	.000000	.000000	.000000	.000000	.008572
ESE	.004289	.000123	.000000	.000000	.000000	.000000	.004412
SE	.005314	.000863	.000000	.000000	.000000	.000000	.006177
SSE	.004461	.002220	.000863	.000000	.000000	.000000	.007545
S	.010341	.005921	.002467	.000123	.000000	.000000	.018852
SSW	.013744	.011595	.004317	.000987	.000000	.000000	.030643
SW	.026035	.008758	.002344	.000123	.000000	.000000	.037260
WSW	.024452	.005551	.001110	.000247	.000000	.000000	.031360
W	.015464	.003824	.001357	.000000	.000000	.000000	.020644
WNW	.010153	.003084	.000740	.000123	.000000	.000000	.014100
NW	.009731	.001110	.000370	.000000	.000000	.000000	.011211
NNW	.007961	.000863	.000617	.000000	.000000	.000000	.009441
TOTAL	.159368	.052794	.014679	.001604	.000000	.000000	

FREQUENCY OF OCCURENCE OF E STABILITY = .228445

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = .004564

FREQUENCY DISTRIBUTION

4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.005192	.000000	.000000	.000000	.000000	.000000	.005192
NNE	.004919	.000000	.000000	.000000	.000000	.000000	.004919
NE	.004372	.000000	.000000	.000000	.000000	.000000	.004372
ENE	.007718	.000617	.000000	.000000	.000000	.000000	.008334
E	.011203	.000000	.000000	.000000	.000000	.000000	.011203
ESE	.007105	.000000	.000000	.000000	.000000	.000000	.007105
SE	.004099	.000000	.000000	.000000	.000000	.000000	.004099
SSE	.006012	.000000	.000000	.000000	.000000	.000000	.006012
S	.007118	.000123	.000000	.000000	.000000	.000000	.007241
SSW	.013689	.000247	.000000	.000000	.000000	.000000	.013936
SW	.018048	.000123	.000000	.000000	.000000	.000000	.018172
WSW	.023773	.000000	.000000	.000000	.000000	.000000	.023773
W	.025699	.000123	.000000	.000000	.000000	.000000	.025823
WNW	.028692	.000000	.000000	.000000	.000000	.000000	.028692
NW	.030208	.000123	.000000	.000000	.000000	.000000	.030331
NNW	.015056	.000247	.000000	.000000	.000000	.000000	.015302
TOTAL	.212902	.001604	.000000	.000000	.000000	.000000	

FREQUENCY OF OCCURENCE OF F STABILITY = .214506

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = .020846

FEMP-04RI-4 DRAFT
April 19, 1993

Joint Frequency Distribution of the On-Site Wind Data

1992

FREQUENCY DISTRIBUTION 4292

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000252	.000827	.000709	.000000	.000000	.000000	.001788
NNE	.000995	.002481	.001300	.000000	.000000	.000000	.004776
NE	.002099	.004253	.000591	.000000	.000000	.000000	.006943
ENE	.001142	.004371	.001772	.000000	.000000	.000000	.007286
E	.001462	.001654	.000236	.000118	.000000	.000000	.003471
ESE	.000962	.000236	.000000	.000000	.000000	.000000	.001199
SE	.000370	.000709	.000000	.000000	.000000	.000000	.001079
SSE	.000724	.000354	.000000	.000000	.000000	.000000	.001079
S	.001478	.002717	.001890	.000000	.000000	.000000	.006085
SSW	.001882	.005789	.003544	.000000	.000000	.000000	.011215
SW	.002848	.006262	.004017	.000000	.000000	.000000	.013126
WSW	.002128	.006262	.001890	.000000	.000000	.000000	.010281
W	.001485	.003190	.002481	.000236	.000000	.000000	.007392
WNW	.000868	.002009	.001418	.000354	.000000	.000000	.004649
NW	.000875	.002481	.002717	.000118	.000000	.000000	.006192
NNW	.000515	.002481	.001063	.000000	.000000	.000000	.004060
TOTAL	.020085	.046078	.023629	.000827	.000000	.000000	

FREQUENCY OF OCCURENCE OF A STABILITY = .090619

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = .000945

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000118	.000945	.000591	.000000	.000000	.000000	.001654
NNE	.000236	.001063	.000473	.000000	.000000	.000000	.001772
NE	.001063	.001536	.000000	.000000	.000000	.000000	.002599
ENE	.000709	.001890	.000591	.000000	.000000	.000000	.003190
E	.001181	.000591	.000000	.000000	.000000	.000000	.001772
ESE	.000473	.000236	.000000	.000000	.000000	.000000	.000709
SE	.000945	.000236	.000000	.000000	.000000	.000000	.001181
SSE	.000827	.000709	.000000	.000000	.000000	.000000	.001536
S	.000709	.002481	.000354	.000000	.000000	.000000	.003544
SSW	.001418	.002127	.000473	.000000	.000000	.000000	.004017
SW	.001536	.002481	.001418	.000118	.000000	.000000	.005553
WSW	.001181	.001181	.000118	.000000	.000000	.000000	.002481
W	.001181	.001063	.000473	.000000	.000000	.000000	.002717
WNW	.000591	.001181	.000236	.000000	.000000	.000000	.002009
NW	.000591	.001418	.001300	.000000	.000000	.000000	.003308
NNW	.000591	.000591	.000709	.000000	.000000	.000000	.001890
TOTAL	.013351	.019731	.006734	.000118	.000000	.000000	

FREQUENCY OF OCCURENCE OF B STABILITY = .039934

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = .000000

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FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.000473	.000591	.000709	.000000	.000000	.000000	.001772
NNE	.000709	.001063	.000354	.000000	.000000	.000000	.002127
NE	.001418	.001536	.000236	.000000	.000000	.000000	.003190
ENE	.000945	.001536	.000354	.000000	.000000	.000000	.002836
E	.001418	.000236	.000118	.000000	.000000	.000000	.001772
ESE	.000827	.000236	.000000	.000000	.000000	.000000	.001063
SE	.000591	.000236	.000000	.000000	.000000	.000000	.000827
SSE	.000473	.000827	.000236	.000000	.000000	.000000	.001536
S	.001181	.001772	.000827	.000000	.000000	.000000	.003781
SSW	.002009	.002717	.000591	.000000	.000000	.000000	.005317
SW	.002127	.001063	.000945	.000118	.000000	.000000	.004253
WSW	.001772	.001063	.000118	.000000	.000000	.000000	.002954
W	.001063	.001063	.000709	.000118	.000000	.000000	.002954
WNW	.000709	.001536	.000591	.000118	.000000	.000000	.002954
NW	.000945	.001063	.001654	.000236	.000000	.000000	.003899
NNW	.000709	.000945	.000709	.000000	.000000	.000000	.002363
TOTAL	.017368	.017486	.008152	.000591	.000000	.000000	

FREQUENCY OF OCCURENCE OF C STABILITY = .043596

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = .000000

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.003960	.009097	.005435	.000000	.000000	.000000	.018492
NNE	.005160	.011933	.003544	.000000	.000000	.000000	.020637
NE	.008606	.012760	.000709	.000000	.000000	.000000	.022075
ENE	.014432	.014887	.003544	.000000	.000000	.000000	.032864
E	.005604	.005435	.000591	.000000	.000000	.000000	.011630
ESE	.004523	.002599	.000000	.000000	.000000	.000000	.007122
SE	.004401	.002009	.000000	.000000	.000000	.000000	.006410
SSE	.006190	.003663	.000236	.000118	.000000	.000000	.010207
S	.006560	.006616	.002599	.000000	.000000	.000000	.015775
SSW	.009921	.014650	.003663	.000000	.000000	.000000	.028234
SW	.009913	.012996	.003663	.000354	.000000	.000000	.026926
WSW	.011920	.010751	.002954	.000118	.000000	.000000	.025744
W	.014056	.010633	.005671	.000118	.000000	.000000	.030479
WNW	.007910	.016186	.008507	.000000	.000000	.000000	.032603
NW	.007527	.010397	.006971	.000709	.000000	.000000	.025603
NNW	.005262	.008270	.004135	.000236	.000000	.000000	.017903
TOTAL	.125945	.152883	.052221	.001654	.000000	.000000	

FREQUENCY OF OCCURENCE OF D STABILITY = .332703

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = .001300

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.004908	.001772	.000000	.000118	.000000	.000945	.007744
NNE	.003228	.002481	.000709	.000000	.000000	.000000	.006418
NE	.004537	.001536	.000000	.000000	.000000	.000000	.006073
ENE	.011159	.003781	.000236	.000000	.000000	.000000	.015176
E	.008791	.001654	.000000	.000000	.000000	.000000	.010446
ESE	.006329	.000473	.000000	.000000	.000000	.000000	.006802
SE	.007196	.001063	.000591	.000000	.000000	.000000	.008850
SSE	.007994	.003544	.001181	.000354	.000000	.000000	.013075
S	.011243	.011106	.001654	.000000	.000000	.000000	.024003
SSW	.020583	.015005	.001772	.000000	.000000	.000000	.037360
SW	.028202	.013823	.002127	.000118	.000000	.000000	.044270
WSW	.020311	.005317	.000709	.000118	.000000	.000000	.026455
W	.015105	.005907	.001181	.000118	.000000	.000000	.022312
WNW	.013523	.005789	.001063	.000236	.000000	.000000	.020612
NW	.010279	.002717	.000118	.000118	.000000	.000000	.013233
NNW	.008204	.002363	.000945	.000000	.000000	.000000	.011512
TOTAL	.181593	.078332	.012287	.001181	.000000	.000945	

FREQUENCY OF OCCURENCE OF E STABILITY = .274338

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = .007089

FREQUENCY DISTRIBUTION

SPEED(MPH)

DIRECTION	1 - 3	4 - 7	8 - 12	13 - 18	19 - 24	GREATER THAN 24	TOTAL
N	.006912	.000118	.000000	.000000	.000000	.000000	.007030
NNE	.005376	.000000	.000000	.000000	.000000	.000000	.005376
NE	.004411	.000000	.000000	.000000	.000000	.000000	.004411
ENE	.009315	.000473	.000236	.000000	.000000	.000000	.010024
E	.009984	.000354	.000000	.000000	.000000	.000000	.010339
ESE	.006774	.000118	.000000	.000000	.000000	.000000	.006893
SE	.006597	.000709	.000000	.000000	.000000	.000000	.007306
SSE	.003761	.000236	.000000	.000000	.000000	.000000	.003998
S	.007050	.000945	.000000	.000000	.000000	.000000	.007995
SSW	.013175	.002127	.000591	.000000	.000000	.000000	.015892
SW	.019260	.001418	.000000	.000000	.000000	.000000	.020678
WSW	.024045	.000354	.000000	.000000	.000000	.000000	.024400
W	.026645	.000236	.000118	.000000	.000000	.000000	.026999
WNW	.026605	.000000	.000000	.000000	.000000	.000000	.026605
NW	.026546	.000473	.000236	.000000	.000000	.000000	.027255
NNW	.013135	.000236	.000236	.000000	.000000	.000000	.013608
TOTAL	.209594	.007798	.001418	.000000	.000000	.000000	

FREQUENCY OF OCCURENCE OF F STABILITY = .218809

FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = .031073

Attachment E.1-IV

Typical Runstream Input and Output Files from Air Dispersion Model Run (ISCLT2)

Notes:

1. The following input runstream file is for "Current Conditions" only. Separate files were prepared for "Future Conditions."

2. The ISCLT2 version 92273 can account for 5 sources at a time. Therefore, a separate run was done for each scenario for source No. 6 i.e., Silo 3 - Soil. The input file for these runs is not included in this appendix. These output from two separate runs were then merged.

3. Source Silo 0 indicates the origin of the receptor grid system.

4. The ISCLT2 version 92273 can account for 1200 receptors at a time. Three separate runs had to be done for each scenario to account for all receptors. The outputs from these runs were then merged.

```
CO STARTING
CO TITLEONE FERNALD OU-4  ISCLT2 - Max Annual Conc  CURRENT SCENARIO  1989 MET
CO TITLETWO IT Project No. 409194.04.03.02  M. Claggett & A. Pakrasi  02/08/93
CO MODELOPT DFAULT CONC RURAL
CO AVERTIME ANNUAL
CO POLLUTID OTHER
CO TERRHGTS FLAT
CO RUNORNOT RUN
CO FINISHED

SO STARTING
**            SRCID  SRCTYP   XS     YS     ZS
**          -------- ------ ------ ------ ------
SO LOCATION SILO0     AREA     0.     0.     0.
SO LOCATION SILO1     AREA   -11.   -30.     0.
SO LOCATION SILO2     AREA   -11.     8.     0.
SO LOCATION SILO3     AREA   -11.    70.     0.
SO LOCATION BERMFILL  AREA   -44.   -44.     0.
SO LOCATION K65_SOIL  AREA   -30.   -30.     0.
SO LOCATION S3_SOIL   AREA   -51.    71.     0.

** Area Source   SRCID  EMISS HGT LENGTH
** Parameters: -------- ----- --- ------
SO SRCPARAM    SILO0     0.0   0.    1.
SO SRCPARAM    SILO1     0.1   0.   22.
SO SRCPARAM    SILO2     0.1   0.   22.
SO SRCPARAM    SILO3     0.1   0.   22.
SO SRCPARAM    BERMFILL  0.1   0.   88.
SO SRCPARAM    K65_SOIL  0.1   0.   60.
SO SRCPARAM    S3_SOIL   0.1   0.  102.
SO SRCGROUP SOURCE1 SILO1
SO SRCGROUP SOURCE2 SILO2
SO SRCGROUP SOURCE3 SILO3
SO SRCGROUP SOURCE4 BERMFILL
SO SRCGROUP SOURCE5 K65_SOIL
SO FINISHED

RE STARTING
** 100 m x 100 m COARSE GRID
RE GRIDCART COARSE1 STA
RE GRIDCART COARSE1 XYINC -1500 31 100 -1500 31 100
RE GRIDCART COARSE1 END

**                                      DEGREES
** Boundary          10    20    30    40    50    60    70    80    90
** Distances:      ----- ----- ----- ----- ----- ----- ----- ----- -----
RE BOUNDARY SILO0  1077. 1130. 1230. 1456. 1984. 1741. 1551. 1486. 1469.
**
** Boundary         100   110   120   130   140   150   160   170   180
** Distances:      ----- ----- ----- ----- ----- ----- ----- ----- -----
RE BOUNDARY SILO0  1498. 1572. 1718. 1753. 1562. 1470. 1433. 1322.  960.
**
** Boundary         190   200   210   220   230   240   250   260   270
** Distances:      ----- ----- ----- ----- ----- ----- ----- ----- -----
RE BOUNDARY SILO0   767.  660.  558.  441.  397.  416.  339.  339.  350.
**
** Boundary         280   290   300   310   320   330   340   350   360
** Distances:      ----- ----- ----- ----- ----- ----- ----- ----- -----
RE BOUNDARY SILO0   380.  418.  488.  565.  797. 1195. 1133. 1076. 1060.

** Sensitive Receptors
RE DISCCART -2800. -3400.
RE DISCCART -3925.  3400.
RE DISCCART  6510.  2450.
RE DISCCART  4260. -5440.
```

```
RE DISCCART  6260.  5660.
RE DISCCART  3430.  2830.
RE DISCCART  2860.  2260.
RE FINISHED

ME STARTING
ME INPUTFIL FEMPMET\FEMP89.STR (7X,6F7.6)
ME ANEMHGHT 10.
ME SURFDATA 93814 1989 FERNALD
ME UAIRDATA 13840 1989 DAYTON

** Stability Class:  A    B    C    D    E    F
**                 ---- ---- ---- ---- ---- ----
ME AVETEMPS ANNUAL 290. 290. 290. 284. 280. 280.

** Wind Speed Class:   1     2     3     4     5     6
**                  ----- ----- ----- ----- ----- -----
ME AVEMIXHT ANNUAL A 1854. 1995. 1698. 1524. 1730. 2313.
ME AVEMIXHT ANNUAL B 1236. 1330. 1132. 1016. 1153. 1542.
ME AVEMIXHT ANNUAL C 1236. 1330. 1132. 1016. 1153. 1542.
ME AVEMIXHT ANNUAL D 1236. 1330. 1132. 1016. 1153. 1542.
ME AVEMIXHT ANNUAL E 5000. 5000. 5000. 5000. 5000. 5000.
ME AVEMIXHT ANNUAL F 5000. 5000. 5000. 5000. 5000. 5000.
ME FINISHED

OU STARTING
OU RECTABLE SRCGRP
OU MAXTABLE 10 SRCGRP
OU PLOTFILE ANNUAL SOURCE1 CURR1A89.PLT
OU PLOTFILE ANNUAL SOURCE2 CURR2A89.PLT
OU PLOTFILE ANNUAL SOURCE3 CURR3A89.PLT
OU PLOTFILE ANNUAL SOURCE4 CURR4A89.PLT
OU PLOTFILE ANNUAL SOURCE5 CURR5A89.PLT
OU FINISHED


 *** Message Summary For ISC2 Model Setup ***

 --------- Summary of Total Messages --------

A Total of           0 Fatal Error Message(s)
A Total of           1 Warning Message(s)
A Total of           0 Informational Message(s)


   ******** FATAL ERROR MESSAGES ********
             ***  NONE  ***


   ********   WARNING MESSAGES   ********
SO W320   24 APARM : Source Parameter May Be Out-of-Range for Parameter     QS

************************************
*** SETUP Finishes Successfully ***
************************************
```

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** MODEL SETUP OPTIONS SUMMARY ***

**Model Is Setup For Calculation of Average CONCentration Values.

**Model Uses RURAL Dispersion.

**Model Uses Regulatory DEFAULT Options:
1. Final Plume Rise.
2. Stack-tip Downwash.
3. Buoyancy-induced Dispersion.
4. Default Wind Profile Exponents.
5. Default Vertical Potential Temperature Gradients.
6. "Upper Bound" Values For Supersquat Buildings.
7. No Exponential Decay for RURAL Mode

**Model Assumes Receptors on FLAT Terrain.

**Model Assumes No FLAGPOLE Receptor Heights.

**Model Calculates 1 STAR Average(s) for the Following Months: 0 0 0 0 0 0 0 0 0 0 0 0
Seasons/Quarters: 0 0 0 0
and Annual: 1

**Model Assumes 1 STAR Summaries In Data File for the Averaging Periods Identified Above

**This Run Includes: 7 Source(s); 5 Source Group(s); and 1004 Receptor(s)

**The Model Assumes A Pollutant Type of: OTHER

**Model Set To Continue RUNning After the Setup Testing.

**Output Options Selected:
Model Outputs Tables of Long Term Values by Receptor (RECTABLE Keyword)
Model Outputs Tables of Maximum Long Term Values (MAXTABLE Keyword)
Model Outputs External File(s) of Long Term Values for Plotting (PLOTFILE Keyword)

**Misc. Inputs: Anem. Hgt. (m) = 10.00 ; Decay Coef. = 0.0000 ; Rot. Angle = 0.0
Emission Units = GRAMS/SEC ; Emission Rate Unit Factor = 0.10000E+07
Output Units = MICROGRAMS/M**3

**Input Runstream File: CURR89A1.DAT ; **Output Print File: CURR89A1.OUT

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** AREA SOURCE DATA ***

SOURCE ID	NUMBER PART. CATS.	EMISSION RATE (GRAMS/SEC /METER**2)	COORD (SW CORNER) X (METERS)	Y (METERS)	BASE ELEV. (METERS)	RELEASE HEIGHT (METERS)	WIDTH OF AREA (METERS)	EMISSION RATE SCALAR VARY BY
SILO0	0	0.00000E+00	0.0	0.0	0.0	0.00	1.00	
SILO1	0	0.10000E+00	-11.0	-30.0	0.0	0.00	22.00	
SILO2	0	0.10000E+00	-11.0	8.0	0.0	0.00	22.00	
SILO3	0	0.10000E+00	-11.0	70.0	0.0	0.00	22.00	
BERMFILL	0	0.10000E+00	-44.0	-44.0	0.0	0.00	88.00	
K65_SOIL	0	0.10000E+00	-30.0	-30.0	0.0	0.00	60.00	
S3_SOIL	0	0.10000E+00	-51.0	71.0	0.0	0.00	102.00	

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** SOURCE IDs DEFINING SOURCE GROUPS ***

GROUP ID	SOURCE IDs
SOURCE1	SILO1 ,
SOURCE2	SILO2 ,
SOURCE3	SILO3 ,
SOURCE4	BERMFILL,
SOURCE5	K65_SOIL,

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** GRIDDED RECEPTOR NETWORK SUMMARY ***

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

*** X-COORDINATES OF GRID ***
(METERS)

-1500.0,	-1400.0,	-1300.0,	-1200.0,	-1100.0,	-1000.0,	-900.0,	-800.0,	-700.0,	-600.0,
-500.0,	-400.0,	-300.0,	-200.0,	-100.0,	0.0,	100.0,	200.0,	300.0,	400.0,
500.0,	600.0,	700.0,	800.0,	900.0,	1000.0,	1100.0,	1200.0,	1300.0,	1400.0,
1500.0,									

*** Y-COORDINATES OF GRID ***
(METERS)

-1500.0,	-1400.0,	-1300.0,	-1200.0,	-1100.0,	-1000.0,	-900.0,	-800.0,	-700.0,	-600.0,
-500.0,	-400.0,	-300.0,	-200.0,	-100.0,	0.0,	100.0,	200.0,	300.0,	400.0,
500.0,	600.0,	700.0,	800.0,	900.0,	1000.0,	1100.0,	1200.0,	1300.0,	1400.0,
1500.0,									

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** DISCRETE CARTESIAN RECEPTORS ***
(X-COORD, Y-COORD, ZELEV, ZFLAG)
(METERS)

(-2800.0,	-3400.0,	0.0,	0.0);	(-3925.0,	3400.0,	0.0,	0.0);
(6510.0,	2450.0,	0.0,	0.0);	(6260.0,	-5660.0,	0.0,	0.0);
(6260.0,	5660.0,	0.0,	0.0);	(3430.0,	2830.0,	0.0,	0.0);
(2860.0,	2260.0,	0.0,	0.0);				

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** BOUNDARY RECEPTOR LOCATIONS ***
(DISCRETE RECEPTORS AT 10 DEGREE SECTORS)

BOUNDARY RECEPTORS FOR SOURCE ID: SILOO
OF SOURCE TYPE: AREA ; WITH ORIGIN AT (0.00, 0.00, 0.00)

SEC.	XCOORD	YCOORD	ZELEV	ZFLAG	SEC.	XCOORD	YCOORD	ZELEV	ZFLAG	SEC.	XCOORD	YCOORD	ZELEV	ZFLAG
1	187.02,	1060.64,	0.00,	0.0	2	386.48,	1061.85,	0.00,	0.0	3	615.00,	1065.21,	0.00,	0.0
4	935.90,	1115.36,	0.00,	0.0	5	1519.83,	1275.29,	0.00,	0.0	6	1507.75,	870.50,	0.00,	0.0
7	1457.46,	530.47,	0.00,	0.0	8	1463.42,	258.04,	0.00,	0.0	9	1469.00,	0.00,	0.00,	0.0
10	1475.24,	-260.12,	0.00,	0.0	11	1477.20,	-537.66,	0.00,	0.0	12	1487.83,	-859.00,	0.00,	0.0
13	1342.88,	-1126.81,	0.00,	0.0	14	1004.03,	-1196.56,	0.00,	0.0	15	735.00,	-1273.06,	0.00,	0.0
16	490.11,	-1346.58,	0.00,	0.0	17	229.56,	-1301.92,	0.00,	0.0	18	0.00,	-960.00,	0.00,	0.0
19	-133.19,	-755.35,	0.00,	0.0	20	-225.73,	-620.20,	0.00,	0.0	21	-279.00,	-483.24,	0.00,	0.0
22	-283.47,	-337.83,	0.00,	0.0	23	-304.12,	-255.19,	0.00,	0.0	24	-360.27,	-208.00,	0.00,	0.0
25	-318.56,	-115.94,	0.00,	0.0	26	-333.85,	-58.87,	0.00,	0.0	27	-350.00,	0.00,	0.00,	0.0
28	-374.23,	65.99,	0.00,	0.0	29	-392.79,	142.96,	0.00,	0.0	30	-422.62,	244.00,	0.00,	0.0
31	-432.82,	363.17,	0.00,	0.0	32	-512.30,	610.54,	0.00,	0.0	33	-597.50,	1034.90,	0.00,	0.0
34	-387.51,	1064.67,	0.00,	0.0	35	-186.85,	1059.65,	0.00,	0.0	36	0.00,	1060.00,	0.00,	0.0

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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* SOURCE-RECEPTOR COMBINATIONS LESS THAN 1.0 METER OR 3*ZLB *
IN DISTANCE. CALCULATIONS MAY NOT BE PERFORMED.

SOURCE ID	- - RECEPTOR LOCATION - - XR (METERS)	YR (METERS)	DISTANCE (METERS)
SILOO	0.0	0.0	0.14
BERMFILL	0.0	0.0	-49.65
K65_SOIL	0.0	0.0	-33.85
S3_SOIL	0.0	100.0	-35.55

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** AVERAGE SPEED FOR EACH WIND SPEED CATEGORY ***
(METERS/SEC)

1.50, 2.50, 4.30, 6.80, 9.50, 12.50,

*** WIND PROFILE EXPONENTS ***

STABILITY CATEGORY	WIND SPEED CATEGORY 1	2	3	4	5	6
A	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01
B	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01
C	.10000E+00	.10000E+00	.10000E+00	.10000E+00	.10000E+00	.10000E+00
D	.15000E+00	.15000E+00	.15000E+00	.15000E+00	.15000E+00	.15000E+00
E	.35000E+00	.35000E+00	.35000E+00	.35000E+00	.35000E+00	.35000E+00
F	.55000E+00	.55000E+00	.55000E+00	.55000E+00	.55000E+00	.55000E+00

*** VERTICAL POTENTIAL TEMPERATURE GRADIENTS ***
(DEGREES KELVIN PER METER)

STABILITY CATEGORY	WIND SPEED CATEGORY 1	2	3	4	5	6
A	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
B	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
C	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
D	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
E	.20000E-01	.20000E-01	.20000E-01	.20000E-01	.20000E-01	.20000E-01
F	.35000E-01	.35000E-01	.35000E-01	.35000E-01	.35000E-01	.35000E-01

*** AVERAGE AMBIENT AIR TEMPERATURE (KELVIN) ***

	STABILITY CATEGORY A	STABILITY CATEGORY B	STABILITY CATEGORY C	STABILITY CATEGORY D	STABILITY CATEGORY E	STABILITY CATEGORY F
ANNUAL	290.0000	290.0000	290.0000	284.0000	280.0000	280.0000

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** AVERAGE MIXING LAYER HEIGHT (METERS) ***

	WIND SPEED CATEGORY 1	WIND SPEED CATEGORY 2	ANNUAL WIND SPEED CATEGORY 3	WIND SPEED CATEGORY 4	WIND SPEED CATEGORY 5	WIND SPEED CATEGORY 6
STABILITY CATEGORY A	1854.0000	1995.0000	1698.0000	1524.0000	1730.0000	2313.0000
STABILITY CATEGORY B	1236.0000	1330.0000	1132.0000	1016.0000	1153.0000	1542.0000
STABILITY CATEGORY C	1236.0000	1330.0000	1132.0000	1016.0000	1153.0000	1542.0000
STABILITY CATEGORY D	1236.0000	1330.0000	1132.0000	1016.0000	1153.0000	1542.0000
STABILITY CATEGORY E	5000.0000	5000.0000	5000.0000	5000.0000	5000.0000	5000.0000
STABILITY CATEGORY F	5000.0000	5000.0000	5000.0000	5000.0000	5000.0000	5000.0000

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** FREQUENCY OF OCCURRENCE OF WIND SPEED, DIRECTION AND STABILITY ***

4292

FILE: FEMPMET\FEMP89.STR FORMAT: (7X,6F7.6)
SURFACE STATION NO.: 93814 UPPER AIR STATION NO.: 13840
NAME: FERNALD NAME: DAYTON
YEAR: 1989 YEAR: 1989

ANNUAL: STABILITY CATEGORY A

DIRECTION (DEGREES)	WIND SPEED CATEGORY 1 (1.500 M/S)	WIND SPEED CATEGORY 2 (2.500 M/S)	WIND SPEED CATEGORY 3 (4.300 M/S)	WIND SPEED CATEGORY 4 (6.800 M/S)	WIND SPEED CATEGORY 5 (9.500 M/S)	WIND SPEED CATEGORY 6 (12.500 M/S)
0.000	0.00000000	0.00047900	0.00059800	0.00024000	0.00000000	0.00000000
22.500	0.00000000	0.00035900	0.00000000	0.00000000	0.00000000	0.00000000
45.000	0.00000000	0.00083700	0.00024000	0.00000000	0.00000000	0.00000000
67.500	0.00012000	0.00143500	0.00107700	0.00000000	0.00000000	0.00000000
90.000	0.00000000	0.00107700	0.00000000	0.00000000	0.00000000	0.00000000
112.500	0.00012000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
135.000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
157.500	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
180.000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
202.500	0.00000000	0.00083700	0.00179400	0.00012000	0.00000000	0.00000000
225.000	0.00000000	0.00263100	0.00227200	0.00024000	0.00000000	0.00000000
247.500	0.00000000	0.00299000	0.00239200	0.00000000	0.00000000	0.00000000
270.000	0.00012000	0.00143500	0.00251100	0.00012000	0.00000000	0.00000000
292.500	0.00024000	0.00083700	0.00035900	0.00035900	0.00000000	0.00000000
315.000	0.00047900	0.00095700	0.00012000	0.00000000	0.00000000	0.00000000
337.500	0.00012000	0.00024000	0.00119600	0.00000000	0.00000000	0.00000000

ANNUAL: STABILITY CATEGORY B

DIRECTION (DEGREES)	WIND SPEED CATEGORY 1 (1.500 M/S)	WIND SPEED CATEGORY 2 (2.500 M/S)	WIND SPEED CATEGORY 3 (4.300 M/S)	WIND SPEED CATEGORY 4 (6.800 M/S)	WIND SPEED CATEGORY 5 (9.500 M/S)	WIND SPEED CATEGORY 6 (12.500 M/S)
0.000	0.00012000	0.00059800	0.00107700	0.00035900	0.00000000	0.00000000
22.500	0.00000000	0.00047900	0.00012000	0.00000000	0.00000000	0.00000000
45.000	0.00035900	0.00059800	0.00000000	0.00000000	0.00000000	0.00000000
67.500	0.00024000	0.00215300	0.00059800	0.00000000	0.00000000	0.00000000
90.000	0.00071800	0.00024000	0.00000000	0.00000000	0.00000000	0.00000000
112.500	0.00012000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
135.000	0.00000000	0.00000000	0.00012000	0.00000000	0.00000000	0.00000000
157.500	0.00024000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
180.000	0.00000000	0.00035900	0.00012000	0.00000000	0.00000000	0.00000000
202.500	0.00035900	0.00143500	0.00107700	0.00000000	0.00000000	0.00000000
225.000	0.00071800	0.00167400	0.00191300	0.00012000	0.00000000	0.00000000
247.500	0.00012000	0.00310900	0.00119600	0.00012000	0.00000000	0.00000000
270.000	0.00059800	0.00119600	0.00071800	0.00000000	0.00000000	0.00000000
292.500	0.00035900	0.00071800	0.00000000	0.00000000	0.00000000	0.00000000
315.000	0.00024000	0.00059800	0.00024000	0.00000000	0.00000000	0.00000000
337.500	0.00024000	0.00047900	0.00071800	0.00012000	0.00000000	0.00000000

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** FREQUENCY OF OCCURRENCE OF WIND SPEED, DIRECTION AND STABILITY ***

FILE: FEMPMET\FEMP89.STR FORMAT: (7X,6F7.6)
SURFACE STATION NO.: 93814 UPPER AIR STATION NO.: 13840
NAME: FERNALD NAME: DAYTON
YEAR: 1989 YEAR: 1989

ANNUAL: STABILITY CATEGORY C

DIRECTION (DEGREES)	WIND SPEED CATEGORY 1 (1.500 M/S)	WIND SPEED CATEGORY 2 (2.500 M/S)	WIND SPEED CATEGORY 3 (4.300 M/S)	WIND SPEED CATEGORY 4 (6.800 M/S)	WIND SPEED CATEGORY 5 (9.500 M/S)	WIND SPEED CATEGORY 6 (12.500 M/S)
0.000	0.00000000	0.00107700	0.00119600	0.00035900	0.00000000	0.00000000
22.500	0.00047900	0.00083700	0.00047900	0.00012000	0.00000000	0.00000000
45.000	0.00035900	0.00167400	0.00131600	0.00000000	0.00000000	0.00000000
67.500	0.00131600	0.00215300	0.00012000	0.00000000	0.00000000	0.00000000
90.000	0.00131600	0.00095700	0.00000000	0.00000000	0.00000000	0.00000000
112.500	0.00047900	0.00059800	0.00000000	0.00000000	0.00000000	0.00000000
135.000	0.00035900	0.00071800	0.00024000	0.00000000	0.00000000	0.00000000
157.500	0.00000000	0.00035900	0.00000000	0.00000000	0.00000000	0.00000000
180.000	0.00000000	0.00107700	0.00035900	0.00012000	0.00000000	0.00000000
202.500	0.00047900	0.00167400	0.00119600	0.00000000	0.00000000	0.00000000
225.000	0.00083700	0.00322900	0.00203300	0.00012000	0.00000000	0.00000000
247.500	0.00107700	0.00275000	0.00131600	0.00000000	0.00000000	0.00000000
270.000	0.00059800	0.00143500	0.00083700	0.00012000	0.00000000	0.00000000
292.500	0.00024000	0.00131600	0.00071800	0.00000000	0.00000000	0.00000000
315.000	0.00035900	0.00119600	0.00071800	0.00000000	0.00000000	0.00000000
337.500	0.00024000	0.00119600	0.00071800	0.00000000	0.00000000	0.00000000

ANNUAL: STABILITY CATEGORY D

DIRECTION (DEGREES)	WIND SPEED CATEGORY 1 (1.500 M/S)	WIND SPEED CATEGORY 2 (2.500 M/S)	WIND SPEED CATEGORY 3 (4.300 M/S)	WIND SPEED CATEGORY 4 (6.800 M/S)	WIND SPEED CATEGORY 5 (9.500 M/S)	WIND SPEED CATEGORY 6 (12.500 M/S)
0.000	0.00346800	0.01267400	0.01135900	0.00179400	0.00000000	0.00000000
22.500	0.00621800	0.01458700	0.01195700	0.00059800	0.00000000	0.00000000
45.000	0.00777200	0.01685800	0.00920700	0.00000000	0.00000000	0.00000000
67.500	0.00932600	0.02188000	0.00669600	0.00012000	0.00000000	0.00000000
90.000	0.00681500	0.00633700	0.00047900	0.00000000	0.00000000	0.00000000
112.500	0.00562000	0.00239200	0.00000000	0.00000000	0.00000000	0.00000000
135.000	0.00406600	0.00239200	0.00012000	0.00000000	0.00000000	0.00000000
157.500	0.00370700	0.00167400	0.00047900	0.00012000	0.00000000	0.00000000
180.000	0.00430500	0.00729400	0.00239200	0.00024000	0.00000000	0.00000000
202.500	0.00777200	0.01434800	0.00633700	0.00047900	0.00000000	0.00000000
225.000	0.01112000	0.01506500	0.00621800	0.00071800	0.00000000	0.00000000
247.500	0.01076100	0.00860900	0.00538100	0.00024000	0.00000000	0.00000000
270.000	0.00860900	0.00729400	0.00550000	0.00047900	0.00000000	0.00000000
292.500	0.00406600	0.00920700	0.00729400	0.00107700	0.00000000	0.00000000
315.000	0.00573900	0.00884800	0.00777200	0.00083700	0.00000000	0.00000000
337.500	0.00418500	0.00896800	0.00382600	0.00047900	0.00000000	0.00000000

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** FREQUENCY OF OCCURRENCE OF WIND SPEED, DIRECTION AND STABILITY ***

FILE: FEMPMET\FEMP89.STR FORMAT: (7X,6F7.6)
SURFACE STATION NO.: 93814 UPPER AIR STATION NO.: 13840
NAME: FERNALD NAME: DAYTON
YEAR: 1989 YEAR: 1989

ANNUAL: STABILITY CATEGORY E

DIRECTION (DEGREES)	WIND SPEED CATEGORY 1 (1.500 M/S)	WIND SPEED CATEGORY 2 (2.500 M/S)	WIND SPEED CATEGORY 3 (4.300 M/S)	WIND SPEED CATEGORY 4 (6.800 M/S)	WIND SPEED CATEGORY 5 (9.500 M/S)	WIND SPEED CATEGORY 6 (12.500 M/S)
0.000	0.00491600	0.00502200	0.00083700	0.00000000	0.00000000	0.00000000
22.500	0.00407600	0.00382600	0.00035900	0.00024000	0.00000000	0.00000000
45.000	0.00467400	0.00322900	0.00024000	0.00000000	0.00000000	0.00000000
67.500	0.01126400	0.00681500	0.00059800	0.00000000	0.00000000	0.00000000
90.000	0.00802500	0.00191300	0.00012000	0.00000000	0.00000000	0.00000000
112.500	0.00323300	0.00012000	0.00000000	0.00000000	0.00000000	0.00000000
135.000	0.00455100	0.00095700	0.00000000	0.00000000	0.00000000	0.00000000
157.500	0.00635000	0.00334800	0.00035900	0.00000000	0.00000000	0.00000000
180.000	0.00779000	0.00538100	0.00215300	0.00024000	0.00000000	0.00000000
202.500	0.01510200	0.01147800	0.00705500	0.00167400	0.00000000	0.00000000
225.000	0.02564800	0.01960800	0.00669600	0.00035900	0.00000000	0.00000000
247.500	0.02347900	0.00908700	0.00179400	0.00000000	0.00000000	0.00000000
270.000	0.01510000	0.01004400	0.00466300	0.00000000	0.00000000	0.00000000
292.500	0.01150800	0.01016300	0.00585900	0.00095700	0.00000000	0.00000000
315.000	0.00946600	0.00538100	0.00167400	0.00012000	0.00000000	0.00000000
337.500	0.00659000	0.00322900	0.00071800	0.00035900	0.00000000	0.00000000

ANNUAL: STABILITY CATEGORY F

DIRECTION (DEGREES)	WIND SPEED CATEGORY 1 (1.500 M/S)	WIND SPEED CATEGORY 2 (2.500 M/S)	WIND SPEED CATEGORY 3 (4.300 M/S)	WIND SPEED CATEGORY 4 (6.800 M/S)	WIND SPEED CATEGORY 5 (9.500 M/S)	WIND SPEED CATEGORY 6 (12.500 M/S)
0.000	0.00187100	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
22.500	0.00286900	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
45.000	0.00361700	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
67.500	0.00526900	0.00071800	0.00000000	0.00000000	0.00000000	0.00000000
90.000	0.01022600	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
112.500	0.00835500	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
135.000	0.00548700	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
157.500	0.00636000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
180.000	0.00748800	0.00012000	0.00000000	0.00000000	0.00000000	0.00000000
202.500	0.01311500	0.00047900	0.00000000	0.00000000	0.00000000	0.00000000
225.000	0.02597900	0.00095700	0.00000000	0.00000000	0.00000000	0.00000000
247.500	0.04042900	0.00059800	0.00000000	0.00000000	0.00000000	0.00000000
270.000	0.04415500	0.00024000	0.00000000	0.00000000	0.00000000	0.00000000
292.500	0.03891200	0.00012000	0.00000000	0.00000000	0.00000000	0.00000000
315.000	0.02295600	0.00024000	0.00000000	0.00000000	0.00000000	0.00000000
337.500	0.00873500	0.00012000	0.00000000	0.00000000	0.00000000	0.00000000

SUM OF FREQUENCIES, FTOTAL = 1.00014

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE1 ***
INCLUDING SOURCE(S): SILO1 ,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -1500.00	-1400.00	-1300.00	-1200.00	-1100.00	-1000.00	-900.00	-800.00	-700.00
1500.00	15.833163	16.818312	18.124271	19.541155	21.047007	22.626797	24.266146	25.944113	27.632072
1400.00	16.643419	17.669180	18.880621	20.488041	22.206350	24.028036	25.938967	27.916599	29.928192
1300.00	17.914532	18.671755	19.951548	21.433937	23.395826	25.500193	27.734671	30.076294	32.488602
1200.00	19.295553	20.240232	21.183439	22.759483	24.590799	27.024076	29.643423	32.427776	35.338490
1100.00	20.764355	21.917955	23.100389	24.286392	26.262049	28.566261	31.641499	34.964039	38.496593
1000.00	22.306086	23.698027	25.158699	26.667877	28.190710	30.720018	33.683052	37.657352	41.966446
900.00	23.906910	25.567078	27.347092	29.235596	31.206705	33.211555	36.532883	40.444592	45.720726
800.00	25.546459	27.503437	29.643900	31.970440	34.473026	37.119537	39.840458	44.339745	49.673740
700.00	27.196665	29.475243	32.014088	34.836006	37.955959	41.371597	45.046474	48.881058	55.253792
600.00	30.442602	31.438717	34.406227	37.773491	41.591599	45.905140	50.736870	56.061146	62.066486
500.00	33.286175	35.762695	38.755768	41.132927	45.276985	50.602146	56.788223	64.187912	72.941154
400.00	36.938080	40.134319	43.726753	47.755100	52.242352	59.043587	63.006863	72.846489	84.903397
300.00	40.518074	44.442448	48.974655	54.235714	60.369167	67.537262	76.178375	88.957451	97.267235
200.00	43.941910	48.574116	54.027122	60.508503	68.293800	77.752525	89.994995	105.611641	125.465721
100.00	47.122410	52.410416	58.718834	66.338524	75.674080	87.317955	102.913033	123.567352	151.458908
0.00	50.505432	56.468193	63.651596	72.428757	83.331360	97.179054	116.016014	141.657562	177.546402
-100.00	53.782242	60.361324	68.332275	78.133453	90.394531	106.136574	127.810493	157.578827	199.754059
-200.00	55.696735	62.570972	70.897591	81.128151	93.906181	110.173882	132.538986	163.113708	205.931732
-300.00	56.966663	63.957493	72.394234	82.709053	95.506866	111.652870	133.148026	162.514847	209.094849
-400.00	57.618362	64.562271	72.888466	82.984726	95.379417	110.802383	132.280624	146.917480	169.214737
-500.00	57.698303	64.454765	72.486191	83.044914	91.118034	100.533455	111.223091	124.006744	138.384506
-600.00	57.267944	65.209579	68.626709	74.509857	80.993843	88.053780	95.570686	103.364418	111.687294
-700.00	53.911663	57.835613	62.094658	66.675621	71.528343	76.537971	81.478310	85.934822	91.270309
-800.00	49.404007	52.561550	55.889988	59.337994	62.810562	66.143478	69.063416	72.510864	74.440994
-900.00	45.093136	47.570595	50.090050	52.576916	54.912350	56.911781	59.315777	60.671719	65.689697
-1000.00	41.021049	42.906593	44.736897	46.425400	47.844391	49.586899	50.577526	54.358276	58.107780
-1100.00	37.213142	38.591972	39.845184	40.882359	42.185646	42.932491	45.858372	48.780350	51.582142
-1200.00	33.681316	34.632530	35.409676	36.409996	36.987675	39.302826	41.625462	43.883427	45.977585
-1300.00	30.427113	31.021980	31.806694	32.263199	34.129688	36.007896	37.851170	39.596371	41.161106
-1400.00	27.465685	28.071653	28.439089	29.968163	31.509918	33.033146	34.496151	35.845051	37.012367
-1500.00	25.042006	25.316874	26.565014	27.847412	29.120489	30.355875	31.517210	32.559200	33.426960

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE1 ***
INCLUDING SOURCE(S): SIL01 ,

4292

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -600.00	-500.00	-400.00	-300.00	-200.00	-100.00	0.00	100.00	200.00
1500.00	30.274841	33.177437	36.018181	38.730846	41.245522	43.493000	48.909283	54.713936	60.962566
1400.00	32.842373	35.943592	39.361179	42.638439	45.680889	48.393761	54.853905	61.723846	69.040871
1300.00	34.918835	39.026760	43.185215	47.195057	50.926445	54.246937	62.050018	70.273499	78.921768
1200.00	38.314461	43.665806	47.572327	52.549034	57.197102	61.327076	70.890610	80.862534	91.190002
1100.00	42.171345	45.881702	52.612007	58.889225	64.783798	70.017685	81.939941	94.213539	106.687225
1000.00	46.541107	51.256432	58.742771	66.454903	74.087471	80.868507	96.084526	111.403679	126.658546
900.00	51.458202	57.520840	64.999527	75.762871	86.175262	95.364784	115.322182	135.189713	153.915298
800.00	56.912472	65.024231	73.605606	87.598320	102.028183	114.845581	141.985794	168.280136	191.985794
700.00	63.158653	74.055267	85.916168	107.136169	122.708054	141.340958	179.727859	215.571243	245.961716
600.00	72.049019	84.242828	100.909843	118.875015	150.565704	179.413925	236.653549	287.470917	326.283661
500.00	82.672768	98.807999	119.032310	147.000320	194.862778	236.539825	327.921509	403.346619	485.331451
400.00	99.436150	116.740074	146.306091	183.757416	234.461197	327.006805	487.288544	605.335388	764.949951
300.00	117.839516	145.453217	180.494553	242.299011	322.654999	481.871613	805.476624	1000.204100	1244.580200
200.00	151.430298	191.145859	234.414703	319.157898	486.168579	833.167908	1610.458980	2487.595210	2327.501460
100.00	191.585266	250.844986	342.317810	533.713806	724.444580	1511.048220	4737.755370	6781.504880	3756.853520
0.00	231.421204	316.427216	462.195709	746.875122	1449.939450	4242.443850	84731.460900	15416.812500	4981.960940
-100.00	263.620087	365.506104	542.073792	887.339417	1923.170900	3587.982910	6406.804200	7037.712400	4189.274900
-200.00	269.097260	366.462006	520.046082	676.741028	962.031372	1180.996220	1658.751710	1842.414790	1952.973750
-300.00	243.962250	296.487885	360.651550	445.812531	502.200897	625.137695	740.497620	770.555176	872.966370
-400.00	195.093979	223.739731	258.808777	281.542633	332.548828	361.060974	423.465179	413.680389	503.591644
-500.00	152.972672	170.112747	181.273438	209.586731	251.645737	244.234924	275.290833	274.774109	328.678711
-600.00	121.307411	127.432785	144.330399	159.483704	168.592056	176.412308	194.040726	195.750366	199.791565
-700.00	95.049828	106.029625	116.393295	126.995071	130.178589	133.655945	144.626526	146.710403	151.840973
-800.00	81.429367	88.764580	95.121140	99.437759	103.636276	105.151100	112.456734	114.560844	119.516472
-900.00	70.611450	75.086258	78.795387	81.599106	84.482407	85.057137	90.194893	92.101646	96.498405
-1000.00	61.628746	64.640724	69.158447	68.787918	70.267937	70.358398	74.123444	75.785179	79.598427
-1100.00	54.101212	56.121681	57.413910	59.211407	60.099201	59.902142	62.788490	64.175842	67.488037
-1200.00	47.777336	50.290356	50.323223	51.545807	52.069588	51.784466	54.044098	55.214912	58.030926
-1300.00	42.441765	43.183807	44.478127	45.317375	45.612774	45.292923	47.098724	48.093426	50.499672
-1400.00	37.916275	38.662777	39.609680	40.188366	40.338341	40.012035	41.480553	42.331684	44.400005
-1500.00	34.545612	34.816479	35.515106	35.913731	35.970318	35.652348	36.864567	37.598019	39.386948

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE1 ***
INCLUDING SOURCE(S): SILO1 ,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 300.00	400.00	500.00	600.00	700.00	800.00	900.00	1000.00	1100.00
1500.00	66.301422	70.702415	74.173218	76.752670	83.527145	86.471413	88.229645	89.001854	88.969353
1400.00	75.189781	80.142097	83.920151	91.775497	95.212425	97.915337	99.254318	99.487679	98.843742
1300.00	86.044548	91.617569	95.689949	104.963181	109.148682	111.398392	112.088943	111.554176	110.080986
1200.00	99.486534	105.742386	116.797264	122.120949	125.868301	127.350121	127.069000	125.455917	122.868759
1100.00	116.396942	123.369690	136.882172	143.165955	146.041336	146.290359	144.584000	141.475204	139.945999
1000.00	138.055786	147.656662	163.783508	169.183746	170.505829	168.838943	165.074738	163.148605	153.737335
900.00	166.734665	189.364105	198.082947	201.589111	200.295517	195.715988	193.240601	180.870102	167.872208
800.00	206.848328	236.302979	243.263382	242.204712	236.651993	233.394043	216.617752	199.148697	182.861160
700.00	294.350769	302.503510	303.736023	294.921783	289.028137	265.247559	240.906784	218.569946	198.444046
600.00	384.456635	394.085602	383.588928	374.043518	335.944519	298.642059	266.743469	238.677277	214.201019
500.00	535.132813	523.472412	507.955841	446.128754	386.635651	335.430573	293.273804	258.723480	229.513077
400.00	768.016724	741.196472	627.215271	523.699158	440.233032	373.014282	319.298859	289.250397	243.745499
300.00	1201.355350	963.058716	758.904480	604.616028	492.404053	421.628387	343.137878	293.433868	254.554398
200.00	1685.121830	1206.432740	936.075867	681.021362	536.603149	435.207489	360.348022	304.233124	261.994415
100.00	2446.266850	1422.462770	990.625183	730.020325	562.144958	449.994446	369.256226	309.462708	265.251282
0.00	2506.966060	1526.196530	1033.220340	749.559448	571.821350	455.073456	372.064240	311.155548	266.166656
-100.00	2101.838620	1344.540410	936.376953	691.747437	534.233154	429.254181	353.439117	297.171722	255.342667
-200.00	1397.041750	1089.758300	811.125854	621.319702	491.930237	401.480469	334.299591	283.481659	245.199493
-300.00	917.637085	750.084778	614.380371	504.405060	449.463806	364.070343	308.354767	265.287628	231.616409
-400.00	515.218262	537.210693	467.927063	406.921478	353.874481	308.222076	282.502014	243.861786	215.483688
-500.00	344.591644	342.398834	355.498840	322.672607	292.014069	262.102386	235.306473	212.439102	192.440643
-600.00	237.597824	249.828949	247.025421	256.457214	238.022919	220.248840	203.218750	186.896484	171.679932
-700.00	171.779327	186.362732	191.264618	188.377258	194.868713	184.339203	174.177582	163.207687	152.239609
-800.00	121.292191	141.462280	149.744141	151.539047	149.838043	155.340546	148.476730	141.731354	134.257965
-900.00	97.761467	109.160400	118.769394	123.580009	124.709633	123.262215	127.364754	122.581696	117.904144
-1000.00	81.457855	88.105148	95.906876	101.692657	104.390305	104.786758	103.531334	106.682129	103.217690
-1100.00	69.328323	69.827118	78.295578	84.381721	87.920662	89.467857	89.504944	88.432228	90.911514
-1200.00	59.762321	60.483479	65.738121	70.584961	74.514809	76.748726	77.642143	77.503006	76.589279
-1300.00	52.089222	52.905350	53.023064	59.498547	63.544579	66.158119	67.601471	68.110054	67.888176
-1400.00	45.841625	46.681973	46.969040	50.515900	54.514343	57.306446	59.086533	60.034252	60.310272
-1500.00	40.686806	41.512650	41.895657	43.356731	47.035168	49.875984	51.845669	53.081490	53.709450

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE1 ***
INCLUDING SOURCE(S): SILO1 ,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

4292

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 1200.00	1300.00	1400.00	1500.00
1500.00	88.292366	87.144295	85.740730	85.206367
1400.00	97.519295	95.680199	94.880608	91.134048
1300.00	107.909325	106.896515	102.146782	97.092026
1200.00	121.633667	115.780052	109.527657	103.496262
1100.00	132.601669	124.790451	117.298897	110.203690
1000.00	143.780869	134.300339	125.397278	117.112770
900.00	155.608246	144.212143	133.724258	124.129906
800.00	167.927811	154.372162	142.137543	131.127975
700.00	180.490982	164.556900	150.442780	137.941193
600.00	192.933731	174.460281	158.386841	149.040756
500.00	206.105225	185.685074	165.667831	149.994476
400.00	215.209671	191.427795	171.431534	154.474533
300.00	223.079208	197.257233	175.815308	157.814835
200.00	228.314453	201.006119	178.538727	159.816376
100.00	230.389084	202.324249	179.362610	160.312012
0.00	230.885223	202.565811	179.447556	160.300247
-100.00	222.301285	195.629837	173.753281	155.560806
-200.00	214.520691	189.529861	168.880798	151.605515
-300.00	204.131042	181.415710	162.428574	146.393509
-400.00	191.720734	171.687973	154.676590	140.124985
-500.00	179.917358	160.778412	145.930725	133.020981
-600.00	157.774094	145.201263	139.736389	125.307014
-700.00	141.706787	131.821716	122.669380	114.262833
-800.00	126.594475	119.059921	111.834839	105.013046
-900.00	112.617409	107.086700	101.544724	96.135445
-1000.00	99.856995	95.998978	91.897392	87.722763
-1100.00	88.322220	85.835869	82.945992	79.832802
-1200.00	78.580086	76.593979	74.708542	72.495018
-1300.00	67.108284	68.734337	67.177071	65.716713
-1400.00	60.054405	59.385609	60.733059	59.582325
-1500.00	53.842136	53.577869	53.097870	54.341629

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE1 ***
INCLUDING SOURCE(S): SILO1 ,

*** DISCRETE CARTESIAN RECEPTOR POINTS ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

X-COORD (M)	Y-COORD (M)	CONC	X-COORD (M)	Y-COORD (M)	CONC
-2800.00	-3400.00	7.421734	-3925.00	3400.00	4.099218
6510.00	2450.00	15.510240	6260.00	-5660.00	7.022265
6260.00	5660.00	10.724207	3430.00	2830.00	28.273415
2860.00	2260.00	38.382168			

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE1 ***
INCLUDING SOURCE(S): SILO1 ,

** CONC OF OTHER IN MICROGRAMS/M**3 **

BOUNDARY RECEPTOR NETWORK OF SOURCE ID: SILOO
OF SOURCE TYPE: AREA ; WITH ORIGIN AT (0.00, 0.00, 0.00)

(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC
1	187.0,	1060.6,	112.353249	2	386.5,	1061.9,	130.448486	3	615.0,	1065.2,	152.161697
4	935.9,	1115.4,	140.825867	5	1519.8,	1275.3,	97.613312	6	1507.8,	870.5,	125.467255
7	1457.5,	530.5,	154.650940	8	1463.4,	258.0,	165.175034	9	1469.0,	0.0,	165.869858
10	1475.2,	-260.1,	152.457199	11	1477.2,	-537.7,	132.833252	12	1487.8,	-859.0,	100.434227
13	1342.9,	-1126.8,	82.195129	14	1004.0,	-1196.6,	77.827438	15	735.0,	-1273.1,	67.333420
16	490.1,	-1346.6,	50.071613	17	229.6,	-1301.9,	50.923111	18	0.0,	-960.0,	79.955795
19	-133.2,	-755.3,	116.377769	20	-225.7,	-620.2,	158.053223	21	-279.0,	-483.2,	226.071579
22	-283.5,	-337.8,	354.829376	23	-304.1,	-255.2,	523.956116	24	-360.3,	-208.0,	547.556885
25	-318.6,	-115.9,	799.933533	26	-333.8,	-58.9,	726.124512	27	-350.0,	0.0,	578.289063
28	-374.2,	66.0,	419.898804	29	-392.8,	143.0,	324.161591	30	-422.6,	244.0,	197.943344
31	-432.8,	363.2,	142.811310	32	-512.3,	610.5,	81.274155	33	-597.5,	1034.9,	45.062752
34	-387.5,	1064.7,	55.431351	35	-186.8,	1059.7,	69.114548	36	0.0,	1060.0,	87.152763

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE2 ***
INCLUDING SOURCE(S): SILO2 ,

4292

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -1500.00	-1400.00	-1300.00	-1200.00	-1100.00	-1000.00	-900.00	-800.00	-700.00
1500.00	16.143347	17.041569	18.409338	19.899754	21.482868	23.150129	24.887115	26.672197	28.475172
1400.00	17.116024	18.046686	19.165342	20.848852	22.655893	24.579893	26.607161	28.714804	30.868572
1300.00	18.425447	19.254688	20.420839	21.787802	23.850985	26.074612	28.447590	30.947317	33.536232
1200.00	19.844461	20.865149	21.894857	23.340885	25.038952	27.610357	30.394060	33.370716	36.501614
1100.00	21.342241	22.582890	23.866312	25.168781	26.995995	29.146601	32.415607	35.971447	39.778992
1000.00	22.908386	24.398758	25.975880	27.622385	29.306145	31.667492	34.454979	38.710449	43.362545
900.00	24.526720	26.296450	28.208677	30.256687	32.419685	34.653889	37.789558	41.505585	47.206867
800.00	26.174072	28.250641	30.538324	33.046597	35.773731	38.697151	41.757378	46.063263	51.193062
700.00	27.819195	30.225132	32.923889	35.947796	39.324142	43.066193	47.156448	51.516529	57.745998
600.00	31.019844	34.058174	35.307011	38.891674	42.993214	47.679295	53.003704	59.021938	66.046623
500.00	34.677288	37.424679	40.443192	44.326702	46.727894	52.393059	59.140434	67.448402	77.384735
400.00	38.311390	41.784786	45.733799	50.227978	55.334064	61.097019	69.453888	76.150940	89.609062
300.00	41.842247	46.039669	50.926453	56.656303	63.422264	71.463570	81.478577	93.863525	112.808052
200.00	45.183865	50.073147	55.861507	62.789066	71.181641	81.489082	95.058510	112.639145	135.607849
100.00	48.249451	53.766380	60.372807	68.388412	78.262558	90.676132	107.397858	129.798965	160.498138
0.00	52.536469	58.891876	66.580681	76.020653	87.811752	102.922752	123.625298	152.058762	192.322403
-100.00	54.586395	61.299213	69.435188	79.441879	91.961090	107.984329	130.124130	160.466766	203.350754
-200.00	56.254299	63.193275	71.589638	81.891068	94.731911	111.033981	133.224243	163.547913	205.664551
-300.00	57.285007	64.276169	72.695114	82.959618	95.649040	111.582298	132.434006	164.587982	189.978165
-400.00	57.713028	64.600830	72.834480	82.780304	94.931107	112.394867	121.636299	137.989655	157.056396
-500.00	57.591187	64.245247	72.616272	79.994019	87.173714	95.693787	105.105774	115.864601	127.727814
-600.00	58.223209	61.218155	66.112587	71.481789	77.316681	83.552650	90.021454	96.377213	102.682701
-700.00	52.179028	55.801960	59.693256	63.823311	68.122025	72.451607	76.562195	80.020485	83.696609
-800.00	47.740013	50.628735	53.635368	56.698189	59.711010	62.499046	64.782257	67.223709	70.972740
-900.00	43.515907	45.758133	48.001911	50.166969	52.129646	53.703045	55.429993	58.183861	62.676029
-1000.00	39.542015	41.225250	42.823597	44.248268	45.370911	46.637905	48.726059	52.154388	55.510784
-1100.00	35.838245	37.045662	38.106731	38.931068	39.888561	41.513409	44.193707	46.842976	49.351315
-1200.00	32.412205	33.220074	33.840218	34.581772	35.873436	38.011864	40.139187	42.186546	44.061340
-1300.00	29.267645	29.738607	30.324982	31.370522	33.106369	34.840885	36.529182	38.111691	39.511944
-1400.00	26.411171	26.858334	27.711576	29.141865	30.575449	31.982113	33.322205	34.545204	35.588688
-1500.00	24.032894	24.723267	25.892344	27.086485	28.270205	29.411118	30.474873	31.419168	32.193306

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE2 ***
INCLUDING SOURCE(S): SILO2 ,

4292

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -600.00	-500.00	-400.00	-300.00	-200.00	-100.00	0.00	100.00	200.00
1500.00	31.531363	34.193016	37.236652	40.147305	42.846756	45.257183	51.040646	57.221409	63.849403
1400.00	33.020878	37.076420	40.753422	44.286243	47.568489	50.492805	57.422649	64.768097	72.556015
1300.00	36.158363	40.286465	44.781242	49.126400	53.174736	56.774929	65.189705	74.023903	83.263702
1200.00	39.722767	44.548206	49.405598	54.830376	59.906136	64.414421	74.791222	85.561783	96.641968
1100.00	43.768990	47.827595	54.716747	61.605022	68.090675	73.849609	86.879616	100.219551	113.664192
1000.00	48.344292	53.525085	62.767509	69.711128	78.183311	85.780647	102.546143	119.454384	135.786926
900.00	53.470493	60.163147	67.135246	79.986862	91.728729	102.111862	124.452614	146.482117	166.930038
800.00	59.177151	68.308685	77.993073	93.184593	109.226059	123.922226	154.720612	184.193024	210.211319
700.00	65.646095	77.805206	91.278511	108.738785	132.221924	154.014389	198.378616	239.079178	272.487976
600.00	76.041885	88.329941	107.365326	128.622513	163.769135	198.337753	266.093781	324.799683	367.487793
500.00	88.792664	105.454109	126.722000	159.887115	222.768295	265.821686	377.489166	466.329559	610.032043
400.00	106.288536	127.194077	159.036316	200.084488	263.776672	375.678680	580.836426	722.872742	913.729309
300.00	125.034111	157.139633	200.199051	270.822937	366.516113	594.566345	1016.824040	1388.209230	1521.825680
200.00	167.034302	210.341202	275.308838	363.140015	574.262146	905.271667	2275.089110	3297.393310	2969.146480
100.00	205.570129	274.092529	385.206787	582.600464	1113.868530	2067.671630	8811.853520	10320.604500	5063.882810
0.00	253.449173	351.530914	523.578003	870.082764	1768.481810	5623.265140	62709.562500	14144.651400	4727.612790
-100.00	267.835480	369.729950	543.150391	938.721436	1358.636600	2271.432620	3449.159420	4128.552730	2780.222900
-200.00	266.828827	362.177826	444.554504	572.076294	733.990417	982.409119	1173.772460	1382.621950	1412.797730
-300.00	224.716034	267.279022	314.860535	367.954254	426.994324	481.132751	586.883179	559.374084	703.140930
-400.00	178.220062	199.792435	222.870087	251.115234	288.049622	308.350037	355.313721	350.616241	415.192749
-500.00	138.934921	150.601578	166.042236	188.394485	210.706863	214.416611	239.139572	239.862457	261.352661
-600.00	109.423759	118.772118	132.803085	144.680023	152.203415	157.979156	172.563873	174.526047	179.150925
-700.00	89.599792	99.018883	107.627220	120.678192	119.005272	121.552673	130.879333	133.009048	138.176743
-800.00	77.031532	83.139900	88.413879	91.661400	95.649536	96.727020	103.084358	105.124863	109.884865
-900.00	67.009369	70.857422	74.770927	76.215736	78.588089	78.946716	83.490189	85.306847	89.472801
-1000.00	58.611206	61.201294	63.132034	64.886139	66.105774	66.009560	69.448074	70.955406	74.624199
-1100.00	51.568851	53.300739	54.552193	56.102661	56.831436	56.592281	59.215263	60.515038	63.627602
-1200.00	45.643852	48.270321	47.971626	49.030457	49.454967	49.152058	51.222523	52.322102	54.973007
-1300.00	40.635185	41.377224	42.525299	43.253799	43.486191	43.161469	44.827652	45.764351	48.034485
-1400.00	37.042122	37.129013	37.971848	38.474331	38.583908	38.259525	39.622578	40.426243	42.382175
-1500.00	32.645866	33.505245	34.128735	34.474174	34.504742	34.192158	35.323120	36.017487	37.713173

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE2 ***
INCLUDING SOURCE(S): SILO2 ,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

-COORD (METERS)	X-COORD (METERS) 300.00	400.00	500.00	600.00	700.00	800.00	900.00	1000.00	1100.00
1500.00	69.478844	74.081184	77.668617	82.732933	87.731369	90.603836	92.224991	92.815201	92.572411
1400.00	79.053848	84.233971	88.127045	95.904663	100.216888	102.777260	103.901237	103.873627	102.943497
1300.00	90.806839	96.632912	100.806190	111.082870	115.141281	117.143204	117.508698	116.605904	114.747108
1200.00	105.445175	111.972000	124.700455	129.607635	133.085831	134.164063	133.403259	131.277756	128.175629
1100.00	123.981461	131.222839	146.362518	152.398315	154.780823	154.396851	151.994614	148.180084	146.943848
1000.00	147.900635	166.701111	175.826523	180.656296	181.135818	178.500366	173.740341	172.111069	158.996857
900.00	180.522217	204.451355	213.568146	215.942368	213.263672	207.228928	205.016754	187.662170	173.478485
800.00	228.266861	259.034454	264.310883	260.469238	252.480576	249.363068	225.629959	206.413406	188.731506
700.00	321.903412	333.784729	331.478851	318.669556	311.715393	277.613037	250.578033	226.163254	204.439987
600.00	434.335175	437.787415	420.305725	409.173645	354.692780	312.145508	276.806152	246.353516	220.112732
500.00	611.681641	586.194519	564.971008	474.815735	406.836639	349.817108	303.275848	266.107544	235.253296
400.00	887.912781	846.019226	675.945007	554.415710	460.552032	386.756439	341.245087	284.469025	248.193451
300.00	1425.573120	1054.078250	810.306641	634.696350	534.640747	419.860870	350.509918	298.123474	257.825439
200.00	1884.613890	1356.266720	936.931030	703.580811	548.729980	442.428772	364.829926	306.920288	263.763885
100.00	2347.197510	1470.914060	1010.037290	738.530029	565.878052	451.750854	370.039276	309.793396	265.254456
0.00	2407.774660	1476.748290	1004.934880	731.808044	559.911011	446.659241	365.882141	306.470703	262.506012
-100.00	2045.144900	1260.664310	894.827881	668.568054	520.282776	420.092133	347.113403	292.581146	251.945267
-200.00	1187.098630	918.399963	761.368591	588.007996	471.780670	388.174622	325.113434	277.039642	240.396912
-300.00	726.775513	657.738647	555.737427	465.914856	395.243561	356.019257	297.213898	257.448944	225.735977
-400.00	440.636292	447.503113	419.432526	373.263885	329.540283	290.292084	256.510223	240.569366	208.877350
-500.00	298.124512	303.007416	306.534180	294.418274	270.511078	245.627838	222.788696	202.550156	184.322769
-600.00	207.975845	223.034943	223.866470	226.165939	219.717850	205.917587	191.799698	177.650558	164.138306
-700.00	156.656418	167.490768	174.042770	173.281464	175.019226	172.083817	164.013672	154.775391	145.222214
-800.00	110.655998	127.953400	136.863174	140.041931	139.654556	141.332458	139.587875	134.180283	127.847244
-900.00	90.919365	100.474342	109.352226	114.643326	116.477615	115.830879	117.018936	115.908325	112.127960
-1000.00	76.492592	77.924744	88.680687	94.639412	97.724648	98.625755	97.922974	98.798355	98.066101
-1100.00	65.433090	66.036545	72.681114	78.773529	82.502785	84.355751	84.761681	84.083267	84.749275
-1200.00	56.652489	57.420952	61.451691	66.089470	70.088692	72.496384	73.629112	73.765099	73.140717
-1300.00	49.567654	50.399185	50.592251	55.864975	59.907719	62.608307	64.200653	64.897179	64.884476
-1400.00	43.768803	44.606991	44.937393	48.219082	51.507694	54.330605	56.197193	57.269585	57.694321
-1500.00	38.961987	39.776264	40.182564	40.218460	44.534054	47.369816	49.383144	50.698071	51.429493

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE2 ***
INCLUDING SOURCE(S): SIL02 ,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 1200.00	1300.00	1400.00	1500.00
1500.00	91.669952	90.256378	88.604584	88.271034
1400.00	101.323296	99.190132	98.574020	93.358749
1300.00	112.190369	111.427849	104.902733	99.468575
1200.00	127.214645	119.140907	112.437485	106.016632
1100.00	136.766663	128.349579	120.342232	112.809769
1000.00	148.205582	138.026428	128.541275	119.772636
900.00	160.242889	148.054169	136.920456	126.799522
800.00	172.690079	158.254120	145.318619	133.749069
700.00	185.257309	168.372818	153.519806	140.439957
600.00	197.531174	178.070084	167.088318	146.738403
500.00	212.585281	186.944534	168.001801	151.817673
400.00	218.473434	193.863098	173.275726	155.889404
300.00	225.409637	198.947449	177.059952	158.743027
200.00	229.500000	201.809692	179.086639	160.189789
100.00	230.261459	202.130554	179.138962	160.078705
0.00	227.951126	200.173538	177.468262	158.641769
-100.00	219.685913	193.572067	172.103775	154.217194
-200.00	210.849655	186.663208	166.600739	149.762817
-300.00	199.619446	177.886108	159.619629	144.124237
-400.00	186.604797	167.658096	151.453400	137.511597
-500.00	169.436050	157.478012	142.410919	130.149490
-600.00	151.572418	140.058670	129.595596	124.952110
-700.00	135.839371	126.888405	118.496552	110.711594
-800.00	121.143158	114.410484	107.854019	101.589844
-900.00	107.623322	102.765816	97.799263	92.880035
-1000.00	95.330734	92.027489	88.412231	84.660851
-1100.00	84.253098	82.216690	79.731598	76.978577
-1200.00	73.660950	73.317482	71.764496	69.853539
-1300.00	64.321953	64.737183	64.495270	63.309727
-1400.00	57.600231	57.098083	57.462967	57.400005
-1500.00	51.680950	51.566349	51.229507	51.622185

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE2 ***
INCLUDING SOURCE(S): SILO2 ,

*** DISCRETE CARTESIAN RECEPTOR POINTS ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

X-COORD (M)	Y-COORD (M)	CONC	X-COORD (M)	Y-COORD (M)	CONC
-2800.00	-3400.00	7.337234	-3925.00	3400.00	4.142123
6510.00	2450.00	15.555443	6260.00	-5660.00	6.960477
6260.00	5660.00	10.784451	3430.00	2830.00	28.559586
2860.00	2260.00	38.847530			

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE2 ***
INCLUDING SOURCE(S): SILO2 ,

** CONC OF OTHER IN MICROGRAMS/M**3 **

BOUNDARY RECEPTOR NETWORK OF SOURCE ID: SILOO
OF SOURCE TYPE: AREA ; WITH ORIGIN AT (0.00, 0.00, 0.00)

(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC
1	187.0,	1060.6,	119.971298	2	386.5,	1061.9,	139.049255	3	615.0,	1065.2,	162.033920
4	935.9,	1115.4,	147.818085	5	1519.8,	1275.3,	99.962708	6	1507.8,	870.5,	128.092102
7	1457.5,	530.5,	156.789001	8	1463.4,	258.0,	165.962875	9	1469.0,	0.0,	164.120056
10	1475.2,	-260.1,	150.236893	11	1477.2,	-537.7,	129.751450	12	1487.8,	-859.0,	97.047745
13	1342.9,	-1126.8,	78.838966	14	1004.0,	-1196.6,	74.081673	15	735.0,	-1273.1,	63.529613
16	490.1,	-1346.6,	47.830360	17	229.6,	-1301.9,	48.443039	18	0.0,	-960.0,	74.383408
19	-133.2,	-755.3,	106.653610	20	-225.7,	-620.2,	142.066879	21	-279.0,	-483.2,	202.036545
22	-283.5,	-337.8,	313.838348	23	-304.1,	-255.2,	443.704254	24	-360.3,	-208.0,	477.538818
25	-318.6,	-115.9,	836.992371	26	-333.8,	-58.9,	740.457336	27	-350.0,	0.0,	663.409607
28	-374.2,	66.0,	467.259979	29	-392.8,	143.0,	344.645111	30	-422.6,	244.0,	216.324173
31	-432.8,	363.2,	157.723709	32	-512.3,	610.5,	85.103905	33	-597.5,	1034.9,	46.802879
34	-387.5,	1064.7,	57.724289	35	-186.8,	1059.7,	72.797943	36	0.0,	1060.0,	92.636681

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE3 ***
INCLUDING SOURCE(S): SILO3 ,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -1500.00	-1400.00	-1300.00	-1200.00	-1100.00	-1000.00	-900.00	-800.00	-700.00
1500.00	16.643419	17.669180	18.880621	20.488041	22.206350	24.028036	25.938967	27.916599	29.928192
1400.00	17.914532	18.671755	19.951548	21.433937	23.395826	25.500193	27.734671	30.076294	32.488602
1300.00	19.295553	20.240232	21.183439	22.759483	24.590799	27.024076	29.643423	32.427776	35.338490
1200.00	20.764355	21.917955	23.100389	24.286392	26.262049	28.566261	31.641499	34.964039	38.496593
1100.00	22.306086	23.698027	25.158699	26.667877	28.190710	30.720018	33.683052	37.657352	41.966446
1000.00	23.906910	25.567078	27.347092	29.235596	31.206705	33.211555	36.532883	40.444592	45.720726
900.00	25.546459	27.503437	29.643900	31.970440	34.473026	37.119537	39.840458	44.339745	49.673740
800.00	27.196665	29.475243	32.014088	34.836006	37.955959	41.371597	45.046474	48.881058	55.253792
700.00	30.442602	31.438717	34.406227	37.773491	41.591599	45.905140	50.736870	56.061146	62.066486
600.00	33.286175	35.762695	38.755768	41.132927	45.276985	50.602146	56.788223	64.187912	72.941154
500.00	36.938080	40.134319	43.726753	47.755100	52.242352	59.043587	63.006863	72.846489	84.903397
400.00	40.518074	44.442448	48.974655	54.235714	60.369167	67.537262	76.178375	88.957451	97.267235
300.00	43.941910	48.574116	54.027122	60.508503	68.293800	77.752525	89.994995	105.611641	125.465721
200.00	47.122410	52.410416	58.718834	66.338524	75.674080	87.317955	102.913033	123.567352	151.458908
100.00	50.505432	56.468193	63.651596	72.428757	83.331360	97.179054	116.016014	141.657562	177.546402
0.00	53.782242	60.361324	68.332275	78.133453	90.394531	106.136574	127.810493	157.578827	199.754059
-100.00	55.696735	62.570972	70.897591	81.128151	93.906181	110.173882	132.538986	163.113708	205.931732
-200.00	56.966663	63.957493	72.394234	82.709053	95.506866	111.652870	133.148026	162.514847	209.094849
-300.00	57.618362	64.562271	72.888466	82.984726	95.379417	110.802383	132.280624	146.917480	169.214737
-400.00	57.698303	64.454765	72.486191	83.044914	91.118034	100.533455	111.223091	124.006744	138.384506
-500.00	57.267944	65.209579	68.626709	74.509857	80.993843	88.053780	95.570686	103.364418	111.687294
-600.00	53.911663	57.835613	62.094658	66.675621	71.528343	76.537971	81.478310	85.934822	91.270309
-700.00	49.404007	52.561550	55.889988	59.337994	62.810562	66.143478	69.063416	72.510864	74.440994
-800.00	45.093136	47.570595	50.090050	52.576916	54.912350	56.911781	59.315777	60.671719	65.689697
-900.00	41.021049	42.906593	44.736897	46.425400	47.844391	49.586899	50.577526	54.358276	58.107780
-1000.00	37.213142	38.591972	39.845184	40.882359	42.185646	42.932491	45.858372	48.780350	51.582142
-1100.00	33.681316	34.632530	35.409676	36.409996	36.987675	39.302826	41.625462	43.883427	45.977585
-1200.00	30.427113	31.021980	31.806694	32.263199	34.129688	36.007896	37.851170	39.596371	41.161106
-1300.00	27.465685	28.071653	28.439089	29.968163	31.509918	33.033146	34.496151	35.845051	37.012367
-1400.00	25.042006	25.316874	26.565014	27.847412	29.120489	30.355875	31.517210	32.559200	33.426960
-1500.00	22.741360	23.784555	24.839428	25.896658	26.947865	27.949949	28.871679	29.675312	30.316307

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE3 ***
INCLUDING SOURCE(S): SIL03 ,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -600.00	-500.00	-400.00	-300.00	-200.00	-100.00	0.00	100.00	200.00
1500.00	32.842373	35.943592	39.361179	42.638439	45.680889	48.393761	54.853905	61.723846	69.040871
1400.00	34.918835	39.026760	43.185215	47.195057	50.926445	54.246937	62.050018	70.273499	78.921768
1300.00	38.314461	43.665806	47.572327	52.549034	57.197102	61.327076	70.890610	80.862534	91.190002
1200.00	42.171345	45.881702	52.612007	58.889225	64.783798	70.017685	81.939941	94.213539	106.687225
1100.00	46.541107	51.256432	58.742771	66.454903	74.087471	80.868507	96.084526	111.403679	126.658546
1000.00	51.458202	57.520840	64.999527	75.762871	86.175262	95.364784	115.322182	135.189713	153.915298
900.00	56.912472	65.024231	73.605606	87.598320	102.028183	114.845581	141.985794	168.280136	191.985794
800.00	63.158653	74.055267	85.916168	107.136169	122.708054	141.340958	179.727859	215.571243	245.961716
700.00	72.049019	84.242828	100.909843	118.875015	150.565704	179.413925	236.653549	287.470917	326.283661
600.00	82.672768	98.807999	119.032310	147.000320	194.862778	236.539825	327.921509	403.346619	485.331451
500.00	99.436150	116.740074	146.306091	183.757416	234.461197	327.006805	487.288544	605.335388	764.949951
400.00	117.839516	145.453217	180.494553	242.299011	322.654999	481.871613	805.476624	1000.204100	1244.580200
300.00	151.430298	191.145859	234.414703	319.157898	486.168579	833.167908	1610.458980	2487.595210	2327.501460
200.00	191.585266	250.844986	342.317810	533.713806	724.444580	1511.048220	4737.755370	6781.504880	3756.853520
100.00	231.421204	316.427216	462.195709	746.875122	1449.939450	4242.443850	84731.460900	15416.812500	4981.960940
0.00	263.620087	365.506104	542.073792	887.339417	1923.170900	3587.982910	6406.804200	7037.712400	4189.274900
-100.00	269.097260	366.462006	520.046082	676.741028	962.031372	1180.996220	1658.751710	1842.414790	1952.973750
-200.00	243.962250	296.487885	360.651550	445.812531	502.200897	625.137695	740.497620	770.555176	872.966370
-300.00	195.093979	223.739731	258.808777	281.542633	332.548828	361.060974	423.465179	413.680389	503.591644
-400.00	152.972672	170.112747	181.273438	209.586731	251.645737	244.234924	275.290833	274.774109	328.678711
-500.00	121.307411	127.432785	144.330399	159.483704	168.592056	176.412308	194.040726	195.750366	199.791565
-600.00	95.049828	106.029625	116.393295	126.995071	130.178589	133.655945	144.626526	146.710403	151.840973
-700.00	81.429367	88.764580	95.121140	99.437759	103.636276	105.151100	112.456734	114.560844	119.516472
-800.00	70.611450	75.086258	78.795387	81.599106	84.482407	85.057137	90.194893	92.101646	96.498405
-900.00	61.628746	64.640724	69.158447	68.787918	70.267937	70.358398	74.123444	75.785179	79.598427
-1000.00	54.101212	56.121681	57.413910	59.211407	60.099201	59.902142	62.788490	64.175842	67.488037
-1100.00	47.777336	50.290356	50.323223	51.545807	52.069588	51.784466	54.044098	55.214912	58.030926
-1200.00	42.441765	43.183807	44.478127	45.317375	45.612774	45.292923	47.098724	48.093426	50.499672
-1300.00	37.916275	38.662777	39.609680	40.188366	40.338341	40.012035	41.480553	42.331684	44.400005
-1400.00	34.545612	34.816479	35.515106	35.913731	35.970318	35.652348	36.864567	37.598019	39.386948
-1500.00	30.791105	31.521509	32.040207	32.312698	32.309166	32.006931	33.020653	33.657001	35.213787

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4298

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE3 ***
INCLUDING SOURCE(S): SILO3 ,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 300.00	400.00	500.00	600.00	700.00	800.00	900.00	1000.00	1100.00
1500.00	75.189781	80.142097	83.920151	91.775497	95.212425	97.915337	99.254318	99.487679	98.843742
1400.00	86.044548	91.617569	95.689949	104.963181	109.148682	111.398392	112.088943	111.554176	110.080986
1300.00	99.486534	105.742386	116.797264	122.120949	125.868301	127.350121	127.069000	125.455917	122.868759
1200.00	116.396942	123.369690	136.882172	143.165955	146.041336	146.290359	144.584000	141.475204	139.945999
1100.00	138.055786	147.656662	163.783508	169.183746	170.505829	168.838943	165.074738	163.148605	153.737335
1000.00	166.734665	189.364105	198.082947	201.589111	200.295517	195.715988	193.240601	180.870102	167.872208
900.00	206.848328	236.302979	243.263382	242.204712	236.651993	233.394043	216.617752	199.148697	182.861160
800.00	294.350769	302.503510	303.736023	294.921783	289.028137	265.247559	240.906784	218.569946	198.444046
700.00	384.456635	394.085602	383.588928	374.043518	335.944519	298.642059	266.743469	238.677277	214.201019
600.00	535.132813	523.472412	507.955841	446.128754	386.635651	335.430573	293.273804	258.723480	229.513077
500.00	768.016724	741.196472	627.215271	523.699158	440.233032	373.014282	319.298859	289.250397	243.745499
400.00	1201.355350	963.058716	758.904480	604.616028	492.404053	421.628387	343.137878	293.433868	254.554398
300.00	1685.121830	1206.432740	936.075867	681.021362	536.603149	435.207489	360.348022	304.233124	261.994415
200.00	2446.266850	1422.462770	990.625183	730.020325	562.144958	449.994446	369.256226	309.462708	265.251282
100.00	2506.966060	1526.196530	1033.220340	749.559448	571.821350	455.073456	372.064240	311.155548	266.166656
0.00	2101.838620	1344.540410	936.376953	691.747437	534.233154	429.254181	353.439117	297.171722	255.342667
-100.00	1397.041750	1089.758300	811.125854	621.319702	491.930237	401.480469	334.299591	283.481659	245.199493
-200.00	917.637085	750.084778	614.380371	504.405060	449.463806	364.070343	308.354767	265.287628	231.616409
-300.00	515.218262	537.210693	467.927063	406.921478	353.874481	308.222076	282.502014	243.861786	215.483688
-400.00	344.591644	342.398834	355.498840	322.672607	292.014069	262.102386	235.306473	212.439102	192.440643
-500.00	237.597824	249.828949	247.025421	256.457214	238.022919	220.248840	203.218750	186.896484	171.679932
-600.00	171.779327	186.362732	191.264618	188.377258	194.868713	184.339203	174.177582	163.207687	152.239609
-700.00	121.292191	141.462280	149.744141	151.539047	149.838043	155.340546	148.476730	141.731354	134.257965
-800.00	97.761467	109.160400	118.769394	123.580009	124.709633	123.262215	127.364754	122.581696	117.904144
-900.00	81.457855	88.105148	95.906876	101.692657	104.390305	104.786758	103.531334	106.682129	103.217690
-1000.00	69.328323	69.827118	78.295578	84.381721	87.920662	89.467857	89.504944	88.432228	90.911514
-1100.00	59.762321	60.483479	65.738121	70.584961	74.514809	76.748726	77.642143	77.503006	76.589279
-1200.00	52.089222	52.905350	53.023064	59.498547	63.544579	66.158119	67.601471	68.110054	67.888176
-1300.00	45.841625	46.681973	46.969040	50.515900	54.514343	57.306446	59.086533	60.034252	60.310272
-1400.00	40.686806	41.512650	41.895657	43.356731	47.035168	49.875984	51.845669	53.081490	53.709450
-1500.00	36.383198	37.174091	37.607014	37.711788	40.802090	43.609371	45.668056	47.083408	47.954258

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE3 ***
INCLUDING SOURCE(S): SILO3 ,

4292

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 1200.00	1300.00	1400.00	1500.00
1500.00	97.519295	95.680199	94.880608	91.134048
1400.00	107.909325	106.896515	102.146782	97.092026
1300.00	121.633667	115.780052	109.527657	103.496262
1200.00	132.601669	124.790451	117.298897	110.203690
1100.00	143.780869	134.300339	125.397278	117.112770
1000.00	155.608246	144.212143	133.724258	124.129906
900.00	167.927811	154.372162	142.137543	131.127975
800.00	180.490982	164.556900	150.442780	137.941193
700.00	192.933731	174.460281	158.386841	149.040756
600.00	206.105225	185.685074	165.667831	149.994476
500.00	215.209671	191.427795	171.431534	154.474533
400.00	223.079208	197.257233	175.815308	157.814835
300.00	228.314453	201.006119	178.538727	159.816376
200.00	230.389084	202.324249	179.362610	160.312012
100.00	230.885223	202.565811	179.447556	160.300247
0.00	222.301285	195.629837	173.753281	155.560806
-100.00	214.520691	189.529861	168.880798	151.605515
-200.00	204.131042	181.415710	162.428574	146.393509
-300.00	191.720734	171.687973	154.676590	140.124985
-400.00	179.917358	160.778412	145.930725	133.020981
-500.00	157.774094	145.201263	139.736389	125.307014
-600.00	141.706787	131.821716	122.669380	114.262833
-700.00	126.594475	119.059921	111.834839	105.013046
-800.00	112.617409	107.086700	101.544724	96.135445
-900.00	99.856995	95.998978	91.897392	87.722763
-1000.00	88.322220	85.835869	82.945992	79.832802
-1100.00	78.580086	76.593979	74.708542	72.495018
-1200.00	67.108284	68.734337	67.177071	65.716713
-1300.00	60.054405	59.385609	60.733059	59.582325
-1400.00	53.842136	53.577869	53.097870	54.341629
-1500.00	48.370911	48.492939	48.338474	47.945961

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4262

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE3 ***
INCLUDING SOURCE(S): SILO3 ,

*** DISCRETE CARTESIAN RECEPTOR POINTS ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

X-COORD (M)	Y-COORD (M)	CONC	X-COORD (M)	Y-COORD (M)	CONC
-2800.00	-3400.00	7.201759	-3925.00	3400.00	4.212970
6510.00	2450.00	15.627891	6260.00	-5660.00	6.860738
6260.00	5660.00	10.883357	3430.00	2830.00	29.030754
2860.00	2260.00	39.613842			

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE3 ***
INCLUDING SOURCE(S): SILO3 ,

** CONC OF OTHER IN MICROGRAMS/M**3 **

BOUNDARY RECEPTOR NETWORK OF SOURCE ID: SILOO
OF SOURCE TYPE: AREA ; WITH ORIGIN AT (0.00, 0.00, 0.00)

(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC
1	187.0,	1060.6,	134.243912	2	386.5,	1061.9,	158.428497	3	615.0,	1065.2,	179.975952
4	935.9,	1115.4,	160.122147	5	1519.8,	1275.3,	103.921089	6	1507.8,	870.5,	132.330490
7	1457.5,	530.5,	159.958633	8	1463.4,	258.0,	166.746262	9	1469.0,	0.0,	160.859680
10	1475.2,	-260.1,	146.273804	11	1477.2,	-537.7,	126.151062	12	1487.8,	-859.0,	91.674179
13	1342.9,	-1126.8,	73.615646	14	1004.0,	-1196.6,	68.413132	15	735.0,	-1273.1,	57.878559
16	490.1,	-1346.6,	44.484261	17	229.6,	-1301.9,	44.784328	18	0.0,	-960.0,	66.953407
19	-133.2,	-755.3,	93.262428	20	-225.7,	-620.2,	122.473930	21	-279.0,	-483.2,	169.612473
22	-283.5,	-337.8,	258.057587	23	-304.1,	-255.2,	322.761078	24	-360.3,	-208.0,	375.893341
25	-318.6,	-115.9,	599.244385	26	-333.8,	-58.9,	779.239014	27	-350.0,	0.0,	683.181091
28	-374.2,	66.0,	593.678955	29	-392.8,	143.0,	416.953308	30	-422.6,	244.0,	285.420898
31	-432.8,	363.2,	184.206161	32	-512.3,	610.5,	95.343307	33	-597.5,	1034.9,	49.815548
34	-387.5,	1064.7,	62.339382	35	-186.8,	1059.7,	79.517616	36	0.0,	1060.0,	102.905403

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION- VALUES FOR SOURCE GROUP: SOURCE4 ***
INCLUDING SOURCE(S): BERMFILL,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -1500.00	-1400.00	-1300.00	-1200.00	-1100.00	-1000.00	-900.00	-800.00	-700.00
1500.00	277.518677	275.281067	286.717133	307.588470	329.973877	353.329437	377.440582	402.006226	444.554535
1400.00	274.233887	310.933838	308.713043	323.017120	348.534149	375.415955	403.444885	432.293243	461.502380
1300.00	284.835358	307.484650	352.065674	350.377228	367.807129	398.810486	431.498657	465.529694	500.389343
1200.00	304.975372	320.798492	348.919800	403.261414	401.762207	423.324432	461.550598	501.864899	543.712769
1100.00	326.538513	345.441071	365.162170	400.012177	467.314850	466.248749	493.393646	541.328369	591.848022
1000.00	348.974426	371.334076	395.106628	420.131012	464.118073	549.045654	548.851318	583.729797	645.028320
900.00	372.062622	398.251648	426.590179	457.056244	489.480927	546.214722	655.791565	657.273193	703.182861
800.00	395.497772	425.859192	459.260193	495.880676	535.790283	578.852112	653.947083	799.177734	803.854858
700.00	438.458435	453.693481	492.594574	536.036316	584.434814	638.079590	696.976379	799.560913	998.527161
600.00	523.110291	560.483765	572.395691	577.262878	634.465332	700.129089	774.478149	857.957764	1005.262820
500.00	535.870422	592.062805	668.446777	754.264343	781.124329	798.213318	855.221863	962.131165	1092.932620
400.00	584.118164	636.597229	696.513855	770.243286	889.105347	1035.038820	1132.835450	1186.676880	1244.800900
300.00	630.561707	691.954773	763.249329	846.674255	945.085083	1062.153690	1249.901610	1519.478880	1824.200680
200.00	674.191162	743.988342	826.053345	923.517395	1040.583980	1182.994630	1359.853030	1595.524540	1937.474980
100.00	714.010559	791.359680	883.095276	993.163086	1126.993530	1292.232300	1502.755000	1787.637080	2166.782470
0.00	878.895447	985.233154	1113.491090	1270.303830	1465.054930	1711.372440	2037.109860	2487.724610	3111.506590
-100.00	842.552246	942.046082	1061.532590	1206.892820	1386.367310	1611.788450	1906.185670	2312.439700	2867.955080
-200.00	862.785217	964.471558	1086.308960	1234.069950	1415.747920	1642.654540	1932.661990	2333.796390	2933.599120
-300.00	874.427612	976.127930	1097.405640	1243.610350	1422.013920	1642.668950	1992.746220	2505.091310	3107.657710
-400.00	877.997437	977.779175	1095.966920	1245.062870	1477.315060	1770.675900	1980.713260	2125.230710	2295.345700
-500.00	874.222900	990.200500	1146.392090	1327.289920	1400.193970	1467.462040	1578.310180	1741.358640	1937.705080
-600.00	919.916748	1005.776250	1047.490230	1084.236330	1175.087650	1275.493530	1384.365110	1499.764770	1681.047360
-700.00	816.559143	853.378784	914.813904	981.368774	1052.810550	1128.344600	1206.212890	1326.849370	1545.248660
-800.00	736.079224	782.653687	832.247986	884.489075	938.595703	993.140320	1078.666630	1235.233760	1153.119510
-900.00	677.418396	715.138855	754.245911	794.062073	833.472107	896.237122	1012.551880	947.060303	958.737671
-1000.00	621.545349	651.423157	681.405273	710.631592	758.022095	846.966125	793.890442	802.549866	855.291016
-1100.00	568.821533	591.854004	614.015869	650.660828	720.316162	676.680786	683.241455	724.916992	765.322327
-1200.00	519.451599	536.584717	565.501831	621.154785	584.818909	589.883789	623.396057	656.230225	687.202881
-1300.00	473.855499	496.736847	541.968384	511.365387	515.341614	542.705811	569.715271	595.594238	619.342224
-1400.00	441.084045	478.062439	451.619324	454.789093	477.437805	499.911530	521.685791	542.089600	560.288818
-1500.00	425.828522	403.026825	405.205139	423.836609	442.735352	461.195770	478.755219	494.841553	521.794800

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE4 ***
INCLUDING SOURCE(S): BERMFILL,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -600.00	-500.00	-400.00	-300.00	-200.00	-100.00	0.00	100.00	200.00
1500.00	523.067139	527.419250	566.725647	603.788635	637.717041	667.653320	874.369385	896.721069	973.896667
1400.00	563.083008	585.525146	619.720703	664.161621	704.850708	740.629150	983.527039	1008.964780	1097.598880
1300.00	577.928650	664.634766	680.659546	734.581726	783.993164	827.297913	1115.738160	1144.798830	1247.233640
1200.00	586.793579	754.210449	756.156311	817.406372	878.269714	931.449280	1278.116700	1311.415650	1430.572390
1100.00	644.019775	784.802063	877.892517	915.697021	991.898010	1058.309690	1480.770020	1518.975950	1658.491580
1000.00	709.486206	807.327087	1028.360960	1033.461550	1130.676150	1215.255370	1738.444820	1782.196660	1946.561280
900.00	783.386414	867.296814	1131.506100	1223.277100	1303.868530	1415.996950	2081.868160	2129.466310	2319.227290
800.00	866.052124	973.848816	1192.993900	1497.856450	1536.885130	1689.309080	2559.251950	2611.897950	2838.057620
700.00	1011.047120	1104.296140	1261.814940	1811.405520	1877.701170	2054.518800	3224.618900	3279.005130	3756.604740
600.00	1299.201290	1332.200440	1471.519040	1994.227780	2447.885990	2560.937010	4198.083500	4239.964360	5679.602050
500.00	1323.575810	1775.104370	1842.437870	2149.558840	3296.627930	3306.625000	5710.989260	5710.069820	8740.633790
400.00	1454.245480	1828.693240	2588.568120	2746.740230	4024.361080	4790.769530	8201.830080	9993.625980	12217.796900
300.00	1995.630490	2130.498540	2726.100590	4147.755860	5109.361330	7427.015140	12705.444300	18405.109400	19086.986300
200.00	2505.581540	3349.376220	4070.707030	5134.198730	7645.826660	12483.396500	27042.007800	37926.492200	35300.671900
100.00	2690.733890	3463.428470	4983.521970	7666.950200	12805.431600	27425.970700	79679.500000	101008.375000	55337.949200
0.00	4016.734380	5417.224120	7703.519040	11797.982400	22209.562500	55461.324200	0.000000	171380.047000	67916.226600
-100.00	3658.146730	4850.772950	7280.538570	11715.338900	19711.634800	37400.902300	58205.582000	72318.101600	43687.043000
-200.00	3946.551270	5489.438960	6795.901370	8573.712890	12130.510700	15009.873000	19465.128900	23302.584000	23146.400400
-300.00	3480.877690	3853.403560	4745.909670	6551.959470	6786.722660	7848.452640	9054.686520	10714.052700	11484.407200
-400.00	2627.619630	3145.205570	4074.712890	3883.950930	4674.712890	4695.595210	5849.648930	5857.574220	6967.631840
-500.00	2242.114990	2778.736570	2622.915530	2764.879880	3597.281740	3010.404540	4075.995120	3377.796140	4949.935060
-600.00	2019.465700	1899.448000	1950.149410	2358.134280	2512.749020	2284.395260	2998.265140	2541.982670	3227.616460
-700.00	1443.519650	1476.742920	1611.823000	2013.641600	1807.186040	1796.421020	2300.331540	1987.265140	2141.974610
-800.00	1169.247560	1259.133420	1422.255620	1578.174560	1425.586060	1451.377440	1822.846800	1597.631100	1633.192020
-900.00	1026.824580	1090.318240	1275.021850	1222.716060	1184.759520	1198.156130	1480.622680	1312.980960	1349.119870
-1000.00	905.643799	973.754883	1108.510500	989.822083	1011.612980	1016.342770	1236.675170	1108.217160	1143.880860
-1100.00	802.585754	898.641418	905.879456	861.465881	875.588196	876.851624	1053.962650	951.572754	983.751038
-1200.00	715.162964	828.667053	747.094604	756.982239	766.113892	765.383606	910.175537	827.069153	855.808777
-1300.00	670.686279	702.732300	658.215149	670.840149	676.664307	674.805176	794.897644	726.392883	751.957336
-1400.00	628.084412	595.885986	589.934692	598.998840	602.599792	600.127991	700.987732	643.762390	666.485779
-1500.00	563.729553	521.515259	531.937439	538.460510	540.550598	537.778809	623.417236	575.056702	595.277100

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE4 ***
INCLUDING SOURCE(S): BERMFILL,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 300.00	400.00	500.00	600.00	700.00	800.00	900.00	1000.00	1100.00
1500.00	1038.612180	1090.862790	1131.028200	1360.982670	1386.884280	1394.289060	1404.865600	1403.366330	1392.164310
1400.00	1170.512570	1227.826660	1341.103640	1579.672730	1546.208250	1565.058230	1567.396120	1556.581420	1535.519900
1300.00	1329.555180	1392.118650	1661.904790	1764.854130	1754.417480	1763.401610	1754.107910	1730.738650	1696.829960
1200.00	1523.590450	1619.246950	2051.473880	1980.050420	2000.033200	1994.414920	1968.917110	1928.767210	1949.361330
1100.00	1763.442020	2084.439450	2336.289790	2288.721190	2290.890140	2264.058110	2216.217040	2241.926510	2381.928960
1000.00	2064.316890	2692.365230	2676.283450	2662.396730	2636.407470	2579.168460	2612.048580	2783.611820	2457.043460
900.00	2707.680660	3265.523440	3135.909180	3116.104000	3047.699710	3091.037600	3304.751710	2882.395020	2613.354250
800.00	3727.193850	3869.162840	3749.444820	3668.859860	3728.231450	3999.543210	3438.197510	3082.366210	2828.723880
700.00	5036.817380	4672.609380	4551.656250	4610.980960	4957.398440	4185.776370	3700.138430	3357.034910	3050.327640
600.00	6291.552250	5868.693850	5959.614750	6387.332520	5234.526860	4538.750490	4058.275630	3638.072510	3272.360350
500.00	7987.310060	8052.567380	8633.066410	6850.332030	5757.505860	5017.911620	4421.207520	4023.358890	3785.524410
400.00	11649.744100	12417.965800	9393.138670	7622.403320	6455.486330	5863.420410	5378.539060	4756.075200	3945.876950
300.00	19562.773400	13858.860400	10899.488300	9608.505860	8438.739260	6765.267580	5355.186040	4400.445800	3841.148440
200.00	24500.253900	18948.937500	14967.925800	10684.588900	7899.403320	6327.433590	5301.083980	4540.695800	3940.042970
100.00	32580.377000	20037.859400	13209.345700	10063.761700	7983.661130	6506.632810	5413.695800	4608.317380	3984.038330
0.00	35799.902300	23422.746100	16497.744100	12248.642600	9517.416020	7636.808590	6273.131350	5278.776370	4522.047850
-100.00	27353.857400	17580.462900	12091.328100	9283.959960	7416.356930	6080.205570	5084.596190	4347.228520	3772.162350
-200.00	18011.855500	15039.934600	12388.489300	9163.569340	7025.672850	5726.549800	4833.091800	4165.169920	3633.600830
-300.00	12688.316400	9690.290040	8105.540530	7565.780760	6918.278320	5721.985350	4666.446290	3926.221440	3451.605710
-400.00	6947.679690	7984.891110	6469.097660	5518.212400	4834.160640	4599.839840	4377.711430	3980.323730	3386.842530
-500.00	4512.611820	4802.391110	5520.941890	4670.192380	4110.308110	3699.021000	3348.436770	3144.082280	3059.533200
-600.00	3534.378910	3338.986080	3563.593260	4071.776120	3538.286870	3200.002200	2948.592770	2713.003910	2496.736330
-700.00	2812.214840	2619.614500	2612.755860	2764.065920	3149.115230	2805.092040	2579.720950	2408.852780	2244.399900
-800.00	2080.690670	2155.657960	2124.049070	2119.685790	2236.721190	2531.595950	2287.269040	2128.346920	2007.821040
-900.00	1512.667360	1808.407710	1751.780640	1777.967410	1768.940310	1855.765870	2085.396970	1905.378660	1789.355590
-1000.00	1157.003660	1484.926270	1479.771970	1500.259280	1512.990720	1502.695800	1569.183590	1751.858890	1615.208980
-1100.00	999.072632	1149.689450	1285.014530	1273.656740	1299.968750	1305.515010	1295.352290	1347.582030	1495.551510
-1200.00	871.707458	892.743408	1122.277100	1088.195800	1122.203370	1138.257200	1139.877690	1130.399780	1172.301150
-1300.00	767.576355	773.928345	908.502319	965.492859	973.327576	996.131653	1005.939760	1005.400510	996.787109
-1400.00	681.390381	688.914795	732.575317	860.134705	848.128235	875.052734	890.419312	896.323425	894.610657
-1500.00	609.267395	617.315063	619.868896	739.108948	755.398193	771.583984	790.597473	801.064087	804.475952

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE4 ***
INCLUDING SOURCE(S): BERMFILL,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 1200.00	1300.00	1400.00	1500.00
1500.00	1373.321410	1350.883670	1365.174320	1438.421260
1400.00	1506.672000	1520.630130	1605.646730	1466.182370
1300.00	1713.651120	1810.771240	1640.273680	1533.015010
1200.00	2065.247800	1857.099000	1723.520020	1626.938600
1100.00	2123.668700	1958.209470	1838.778200	1726.534910
1000.00	2248.314700	2098.044430	1958.064450	1828.507450
900.00	2420.430660	2242.649900	2079.890140	1931.469970
800.00	2598.104980	2389.758790	2202.193360	2033.596680
700.00	2777.774660	2536.215820	2322.248290	2193.220210
600.00	2956.256840	2821.843510	2682.256100	2437.457520
500.00	3547.279300	3048.122560	2619.555910	2313.085450
400.00	3305.448490	2926.193120	2629.372560	2376.470460
300.00	3384.326420	3006.535400	2690.575680	2423.636720
200.00	3455.302730	3058.231450	2728.688960	2452.014160
100.00	3484.067140	3076.963620	2740.697510	2459.452880
0.00	3923.294920	3440.860840	3046.039550	2718.519530
-100.00	3309.502930	2931.241940	2617.649410	2354.494870
-200.00	3201.670900	2845.699950	2548.651120	2298.024410
-300.00	3060.159180	2733.665040	2458.537110	2224.520020
-400.00	2908.854250	2600.011720	2350.790040	2136.520020
-500.00	2943.697750	2586.515140	2272.075680	2036.824710
-600.00	2302.255370	2267.396730	2209.788090	2049.921880
-700.00	2089.691160	1946.126340	1813.992550	1753.614500
-800.00	1889.317630	1775.593750	1668.106320	1567.498410
-900.00	1701.675540	1613.958740	1528.384640	1446.249390
-1000.00	1528.039920	1462.575930	1396.139400	1330.425290
-1100.00	1389.234860	1322.147580	1272.172970	1220.842290
-1200.00	1294.026860	1209.578250	1156.873410	1117.981930
-1300.00	1030.998050	1132.480830	1064.205320	1023.558780
-1400.00	886.873901	915.223145	1002.613340	948.002747
-1500.00	802.151855	796.736572	822.202576	897.071472

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE4 ***
INCLUDING SOURCE(S): BERMFILL,

*** DISCRETE CARTESIAN RECEPTOR POINTS ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

X-COORD (M)	Y-COORD (M)	CONC	X-COORD (M)	Y-COORD (M)	CONC
-2800.00	-3400.00	116.617943	-3925.00	3400.00	65.691246
6510.00	2450.00	247.084396	6260.00	-5660.00	112.261101
6260.00	5660.00	171.633865	3430.00	2830.00	451.187561
2860.00	2260.00	611.064087			

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE4 ***
INCLUDING SOURCE(S): BERMFILL,

** CONC OF OTHER IN MICROGRAMS/M**3 **

BOUNDARY RECEPTOR NETWORK OF SOURCE ID: SILO0
OF SOURCE TYPE: AREA ; WITH ORIGIN AT (0.00, 0.00, 0.00)

(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC
1	187.0,	1060.6,	1746.542110	2	386.5,	1061.9,	2217.735110	3	615.0,	1065.2,	2412.033690
4	935.9,	1115.4,	2156.303470	5	1519.8,	1275.3,	1539.617550	6	1507.8,	870.5,	1950.442260
7	1457.5,	530.5,	2466.979490	8	1463.4,	258.0,	2532.120610	9	1469.0,	0.0,	2813.827880
10	1475.2,	-260.1,	2311.862550	11	1477.2,	-537.7,	2083.289060	12	1487.8,	-859.0,	1505.975710
13	1342.9,	-1126.8,	1267.010990	14	1004.0,	-1196.6,	1134.420170	15	735.0,	-1273.1,	1020.076720
16	490.1,	-1346.6,	803.147156	17	229.6,	-1301.9,	755.783691	18	0.0,	-960.0,	1325.272090
19	-133.2,	-755.3,	1585.529170	20	-225.7,	-620.2,	2437.088870	21	-279.0,	-483.2,	3043.837400
22	-283.5,	-337.8,	5394.714840	23	-304.1,	-255.2,	7089.401860	24	-360.3,	-208.0,	7030.992190
25	-318.6,	-115.9,	10828.676800	26	-333.8,	-58.9,	9878.127930	27	-350.0,	0.0,	9428.583980
28	-374.2,	66.0,	6398.696290	29	-392.8,	143.0,	5024.637700	30	-422.6,	244.0,	3107.565190
31	-432.8,	363.2,	2354.229000	32	-512.3,	610.5,	1291.325810	33	-597.5,	1034.9,	687.228455
34	-387.5,	1064.7,	926.996704	35	-186.8,	1059.7,	1054.774660	36	0.0,	1060.0,	1576.201420

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE5 ***
INCLUDING SOURCE(S): K65_SOIL,

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -1500.00	-1400.00	-1300.00	-1200.00	-1100.00	-1000.00	-900.00	-800.00	-700.00
1500.00	126.089516	125.125343	134.600647	144.782028	155.648132	167.017136	178.784515	190.801010	202.865326
1400.00	124.620682	141.235550	140.318512	151.951447	164.348648	177.451538	191.155670	205.299301	219.651810
1300.00	133.777542	139.722977	159.991562	159.179977	173.335419	188.465851	204.476639	221.200806	238.380615
1200.00	143.597092	150.975784	158.469177	183.267151	182.453247	199.946106	218.701324	238.561356	259.250275
1100.00	154.053925	162.938019	172.165176	181.593857	212.442093	211.686371	233.695984	257.366272	282.424988
1000.00	164.962540	175.545761	186.765579	198.523148	210.631622	249.765854	249.186691	277.473572	307.980957
900.00	176.215195	188.689911	202.168839	216.622345	231.937912	247.868881	298.692535	298.521942	335.811096
800.00	187.660110	202.204666	218.201920	235.724731	254.781250	275.259979	296.840118	364.755341	365.457428
700.00	199.094742	215.856934	234.602280	255.546432	278.876801	304.702179	332.960297	363.255249	457.584808
600.00	237.967789	253.964630	256.141907	275.657318	303.740479	335.686401	371.855957	412.379181	458.340546
500.00	251.440277	271.521240	304.173279	343.664703	351.085968	367.348083	412.565918	465.901642	531.228333
400.00	275.733643	300.500610	328.710754	360.928436	405.126892	473.352264	513.812012	526.250183	609.615051
300.00	299.234833	328.636353	362.796387	402.776550	449.924225	505.944397	573.793701	700.884644	842.943665
200.00	321.409729	355.213867	395.054413	442.495911	499.645569	569.389832	658.041260	774.641357	925.661926
100.00	341.724884	379.510986	424.488464	478.681671	544.898926	627.131836	734.567261	878.942505	1073.153320
0.00	405.163269	454.598694	514.396240	587.768860	679.303772	796.062317	953.080505	1170.207400	1474.651120
-100.00	397.567017	445.399963	503.089294	573.627258	661.251770	772.127625	920.976013	1125.520630	1409.403690
-200.00	408.464722	457.646393	516.849304	589.042297	678.383057	790.830444	938.869934	1142.410640	1420.645390
-300.00	415.036163	464.429504	523.609436	595.342712	683.428955	793.180359	932.998718	1188.019530	1488.835690
-400.00	417.524689	466.114594	523.929016	593.403381	689.160889	833.319519	931.274841	990.742004	1129.631230
-500.00	416.288727	463.223053	534.621460	622.402222	652.444275	693.207764	764.409180	845.038574	941.425842
-600.00	428.877350	469.024261	485.668121	520.567322	564.728577	612.990051	664.860474	718.946594	775.857239
-700.00	380.756592	407.852142	437.294678	469.062683	502.939789	538.368774	574.211853	608.355103	708.210999
-800.00	350.481506	372.604248	396.040894	420.534729	445.590118	470.334991	493.308624	563.701050	518.614441
-900.00	321.421417	339.094757	357.256439	375.498901	393.166168	409.234863	461.116882	426.364624	459.997131
-1000.00	293.848877	307.611633	321.225525	334.198303	345.800812	385.231842	357.819305	383.486664	408.979004
-1100.00	267.936310	278.314392	288.069244	296.672302	327.403381	305.356506	325.423737	345.481110	364.809052
-1200.00	243.773865	251.261124	257.786072	282.244232	264.216919	280.227142	296.297028	311.971283	326.632141
-1300.00	221.484192	226.433563	246.248718	231.296967	244.292847	257.374115	270.241577	282.494659	293.615448
-1400.00	201.029388	217.169342	204.497498	215.205353	226.003769	236.689850	246.995255	256.575806	265.003174
-1500.00	193.486588	182.633636	191.391266	200.319031	209.289429	218.020020	226.275497	233.764374	240.134918

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE5 ***
INCLUDING SOURCE(S): K65_SOIL,

4292

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -600.00	-500.00	-400.00	-300.00	-200.00	-100.00	0.00	100.00	200.00
1500.00	238.921890	248.115494	267.832947	286.512329	303.685059	318.895660	395.336517	418.387787	458.833374
1400.00	256.444061	269.337006	293.001404	315.495270	336.187469	354.457703	444.875610	471.762482	518.610352
1300.00	260.352997	303.604523	321.922241	349.346619	374.609344	396.848816	505.032135	536.670776	591.344055
1200.00	280.343262	345.327087	355.307434	389.212067	420.520874	448.010193	579.161255	616.755737	681.075928
1100.00	308.397949	355.075562	401.355042	436.575165	476.051910	510.641571	672.075378	717.227295	793.538330
1000.00	340.217133	373.329712	472.462128	493.365417	544.145874	588.591736	791.265320	845.745178	937.065063
900.00	376.114746	418.495453	516.469727	562.911316	631.334290	691.000610	952.735657	1020.089660	1128.293820
800.00	416.152832	471.626282	534.182007	693.764832	747.151184	829.364624	1177.322880	1262.004150	1394.129030
700.00	461.430511	536.720764	618.206726	842.128174	898.628113	1016.353520	1494.533810	1602.289180	1763.709350
600.00	599.779541	610.846985	724.147644	906.701538	1149.742550	1281.463620	1969.781370	2106.409910	2559.094730
500.00	606.115479	827.424744	851.580261	1037.482670	1579.861450	1676.635620	2724.288330	2896.491700	4171.252440
400.00	715.570190	844.013000	1228.692990	1288.092160	1904.039790	2321.679690	4013.328130	4366.703130	6004.485350
300.00	898.849915	1023.935240	1276.304930	2027.545290	2179.090090	3773.248050	6478.489750	9050.612300	8714.876950
200.00	1174.062500	1597.954100	1910.890140	2159.125730	3957.580320	6111.925290	12156.393600	18091.562500	18641.753900
100.00	1347.947140	1756.900510	2419.305660	3890.113040	6242.583980	12880.501000	44190.531300	53548.750000	28371.027300
0.00	1927.279050	2641.394780	3849.089110	6131.021970	11309.540000	32986.332000	0.000000	100933.414000	34146.480500
-100.00	1823.506100	2461.490720	3546.410160	6052.509280	10142.430700	19239.423800	32231.025400	36472.976600	22635.748000
-200.00	1889.472050	2702.699220	3339.844730	3942.494380	6283.838870	7060.345210	8708.825200	10445.925800	12105.198200
-300.00	1649.012570	1894.887820	2277.912350	3204.271240	2928.720700	3951.443600	4642.779790	5216.685060	4959.873050
-400.00	1294.977170	1480.049070	1934.497560	1767.079710	2266.337400	2197.782710	2879.415280	2538.203860	3380.025150
-500.00	1042.715330	1296.509160	1185.889400	1353.217770	1730.587040	1527.757080	1956.228150	1714.006230	2329.749510
-600.00	932.984924	856.644165	961.070068	1101.339720	1166.973140	1140.211910	1415.426760	1266.637210	1433.372800
-700.00	650.194885	720.196106	786.936462	945.419922	862.049622	885.282776	1073.135250	976.096313	997.147278
-800.00	563.983459	609.074036	654.025208	730.279114	697.150146	708.713196	843.788025	776.960449	799.893677
-900.00	493.072357	523.512451	588.870850	557.040161	575.474976	580.927063	681.603210	633.657410	655.581360
-1000.00	433.106537	454.207275	510.907837	476.692078	487.008911	488.365753	565.808044	530.026306	550.689331
-1100.00	382.417236	411.959991	412.502960	413.255280	419.750885	419.575897	480.772064	453.075409	471.253113
-1200.00	339.474213	381.598450	353.483398	361.930542	365.991730	364.990723	414.455200	392.378510	408.295532
-1300.00	306.379883	321.091309	313.899292	319.839020	322.319580	320.891510	361.519501	343.604279	357.538055
-1400.00	288.154266	274.121246	280.697968	284.896362	286.335693	284.709900	318.542938	303.780304	316.002319
-1500.00	258.203766	247.672134	252.598175	255.569107	256.315460	254.624344	283.138397	270.811646	281.566101

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE5 ***
INCLUDING SOURCE(S): K65_SOIL,

4292

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 300.00	400.00	500.00	600.00	700.00	800.00	900.00	1000.00	1100.00
1500.00	492.950012	520.670654	542.145264	619.230286	638.761597	654.202881	661.926453	663.309570	659.579712
1400.00	557.404297	588.121948	611.042542	723.656433	724.514099	737.228210	741.214722	738.220947	729.765808
1300.00	635.610291	669.542664	751.263123	809.950256	825.908569	834.243835	832.801147	823.794128	809.093933
1200.00	731.715210	768.939514	941.137817	930.680115	946.381104	947.974976	938.783813	921.600708	898.707275
1100.00	851.512695	932.579346	1074.825200	1082.767460	1090.160770	1081.646480	1061.542850	1033.339840	1104.560670
1000.00	1003.263790	1231.568240	1249.829350	1268.330570	1262.402220	1239.004150	1203.697880	1292.708500	1140.265010
900.00	1199.839480	1510.624270	1495.108760	1495.997920	1469.276860	1424.264890	1537.836300	1339.459960	1240.575930
800.00	1698.382570	1803.374880	1808.321900	1776.500370	1717.933350	1866.492920	1600.776730	1468.234250	1346.124020
700.00	2359.416260	2264.587890	2223.030520	2129.197270	2324.243160	1954.156860	1770.288090	1603.775760	1454.950200
600.00	2979.002930	2888.473880	2757.227050	3019.625980	2458.171140	2184.185060	1948.523070	1742.717650	1564.045530
500.00	3936.505620	3735.751220	4122.699710	3239.323730	2800.535160	2428.435060	2129.356690	1879.833620	1738.527340
400.00	5435.877930	6037.412600	4490.288570	3750.676760	3156.488530	2690.218990	2489.813230	2203.058350	1810.213010
300.00	9785.111330	6744.470210	5325.470700	4476.208500	3971.029790	3148.697510	2462.723140	2116.391110	1840.811040
200.00	11306.927700	9171.792970	7236.996090	5010.195310	3780.833250	3086.837650	2569.992430	2185.518550	1888.869260
100.00	16537.433600	9548.788090	6700.263670	5023.183590	3929.066410	3174.407470	2623.463620	2216.687740	1908.567260
0.00	18609.578100	11708.131800	8048.059570	5880.075200	4509.555180	3591.530270	2934.329100	2455.812010	2097.261960
-100.00	14033.117200	8592.299800	6132.485350	4639.883790	3657.385990	2974.303470	2471.576660	2098.212890	1813.516480
-200.00	8168.907710	7217.992190	6012.995120	4350.893070	3380.154300	2787.872070	2340.809570	2004.598140	1742.865600
-300.00	6276.666500	4747.844240	3938.644290	3492.040040	3257.401610	2680.493160	2169.206540	1881.734010	1650.082150
-400.00	3124.166020	3837.693850	3098.973630	2714.178220	2373.938480	2091.545410	2024.516480	1850.343510	1565.349850
-500.00	2213.114010	2161.199460	2605.094730	2206.394040	1994.059080	1793.134890	1620.583500	1468.010860	1402.417600
-600.00	1650.092290	1642.636720	1607.350100	1902.727910	1657.432370	1534.050660	1415.703250	1303.206670	1199.142580
-700.00	1298.582890	1265.950560	1276.761720	1248.895510	1460.511110	1304.936400	1228.280150	1149.197880	1071.826170
-800.00	933.963440	991.229858	1023.232060	1027.825680	1011.554200	1169.140260	1060.333500	1008.227910	953.191956
-900.00	660.209717	825.390442	832.803040	853.527222	854.263245	840.973511	960.721191	881.175781	844.368774
-1000.00	559.363098	669.734924	685.152405	713.623108	724.859924	723.244385	712.369080	805.760010	745.733704
-1100.00	480.590515	506.580414	583.685242	600.772827	618.221252	624.277771	621.687866	612.723877	687.143433
-1200.00	417.558899	420.687378	508.188568	509.194550	530.056274	541.006714	544.129517	541.215698	533.762024
-1300.00	366.371094	370.423584	405.004639	437.810242	456.856110	470.788696	477.763977	479.183411	476.255890
-1400.00	324.249634	328.722931	329.744659	389.257690	395.788666	411.398560	420.891754	425.361359	425.776764
-1500.00	289.177795	293.773926	295.571167	332.042877	344.582977	360.987213	372.046936	378.614685	381.464874

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE5 ***
INCLUDING SOURCE(S): K65_SOIL,

4292

*** NETWORK ID: COARSE1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 1200.00	1300.00	1400.00	1500.00
1500.00	651.806702	641.559448	629.513611	664.776978
1400.00	717.140259	701.420654	742.331787	678.320801
1300.00	790.244019	838.173462	759.578918	721.384949
1200.00	956.699341	860.416565	812.711670	767.052185
1100.00	984.604370	925.031433	868.390259	815.081848
1000.00	1064.398680	992.852600	926.119019	864.324524
900.00	1148.271970	1063.123780	985.157959	914.090088
800.00	1235.030270	1134.704220	1044.469600	963.461304
700.00	1322.857300	1205.988280	1102.670530	1011.264770
600.00	1409.180790	1290.739260	1234.242680	1121.225590
500.00	1639.692260	1400.476560	1210.587400	1096.983520
400.00	1564.626830	1393.737670	1249.836910	1127.614500
300.00	1616.966430	1432.739870	1279.312870	1150.166630
200.00	1651.020020	1457.253170	1297.186160	1163.331790
100.00	1663.484380	1465.051150	1301.919430	1166.024900
0.00	1815.754880	1589.953000	1405.818480	1253.510010
-100.00	1585.934200	1400.858890	1248.114140	1120.427490
-200.00	1531.329590	1357.789430	1213.541990	1092.249150
-300.00	1459.697140	1301.416990	1168.430420	1055.613650
-400.00	1374.772830	1234.324580	1114.607300	1011.842220
-500.00	1363.264650	1194.103030	1054.059570	962.386047
-600.00	1104.307620	1034.490360	1017.648800	945.916565
-700.00	998.340332	929.755005	866.411865	808.271667
-800.00	898.106567	844.664612	793.802612	745.980957
-900.00	804.765015	764.393433	724.539429	685.987915
-1000.00	718.898071	689.591858	659.266785	628.894165
-1100.00	640.654236	620.564026	598.357483	575.090820
-1200.00	594.146545	557.351807	541.968628	524.794495
-1300.00	470.000366	519.757263	490.094055	478.511078
-1400.00	422.978058	417.679199	459.740936	436.156494
-1500.00	381.285309	379.102539	375.372040	411.323547

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE5 ***
INCLUDING SOURCE(S): K65_SOIL,

*** DISCRETE CARTESIAN RECEPTOR POINTS ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

X-COORD (M)	Y-COORD (M)	CONC	X-COORD (M)	Y-COORD (M)	CONC
-2800.00	-3400.00	54.514477	-3925.00	3400.00	30.595001
6510.00	2450.00	115.156578	6260.00	-5660.00	52.117928
6260.00	5660.00	79.883301	3430.00	2830.00	210.506531
2860.00	2260.00	285.545502			

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE ANNUAL AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: SOURCE5 ***
INCLUDING SOURCE(S): K65_SOIL,

** CONC OF OTHER IN MICROGRAMS/M**3 **

BOUNDARY RECEPTOR NETWORK OF SOURCE ID: SIL00
OF SOURCE TYPE: AREA ; WITH ORIGIN AT (0.00, 0.00, 0.00)

(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC	(SEC.)	X-COORD	Y-COORD	CONC
1	187.0,	1060.6,	836.302368	2	386.5,	1061.9,	992.993958	3	615.0,	1065.2,	1144.907710
4	935.9,	1115.4,	1032.834470	5	1519.8,	1275.3,	724.734802	6	1507.8,	870.5,	923.311707
7	1457.5,	530.5,	1131.398800	8	1463.4,	258.0,	1202.407470	9	1469.0,	0.0,	1297.791380
10	1475.2,	-260.1,	1098.239010	11	1477.2,	-537.7,	961.524841	12	1487.8,	-859.0,	715.282043
13	1342.9,	-1126.8,	594.583496	14	1004.0,	-1196.6,	543.280518	15	735.0,	-1273.1,	480.845276
16	490.1,	-1346.6,	353.494019	17	229.6,	-1301.9,	359.789825	18	0.0,	-960.0,	607.246521
19	-133.2,	-755.3,	777.805481	20	-225.7,	-620.2,	1140.534060	21	-279.0,	-483.2,	1449.967650
22	-283.5,	-337.8,	2515.857420	23	-304.1,	-255.2,	3470.551030	24	-360.3,	-208.0,	3398.298100
25	-318.6,	-115.9,	5576.913090	26	-333.8,	-58.9,	4694.444820	27	-350.0,	0.0,	4792.667480
28	-374.2,	66.0,	2825.673830	29	-392.8,	143.0,	2458.391110	30	-422.6,	244.0,	1380.872070
31	-432.8,	363.2,	1088.596560	32	-512.3,	610.5,	589.994690	33	-597.5,	1034.9,	329.420013
34	-387.5,	1064.7,	424.097900	35	-186.8,	1059.7,	507.187561	36	0.0,	1060.0,	715.987366

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*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** THE MAXIMUM 10 ANNUAL AVERAGE CONCENTRATION VALUES FOR GROUP: SOURCE1 ***
INCLUDING SOURCE(S): SILO1 ,

** CONC OF OTHER IN MICROGRAMS/M**3 **

RANK	CONC	AT	RECEPTOR (XR,YR) OF TYPE			RANK	CONC	AT	RECEPTOR (XR,YR) OF TYPE		
1.	84731.460900	AT (	0.00,	0.00)	GC	6.	4981.960940	AT (	200.00,	0.00)	GC
2.	15416.812500	AT (	100.00,	0.00)	GC	7.	4737.755370	AT (	0.00,	100.00)	GC
3.	7037.712400	AT (	100.00,	-100.00)	GC	8.	4242.443850	AT (	-100.00,	0.00)	GC
4.	6781.504880	AT (	100.00,	100.00)	GC	9.	4189.274900	AT (	200.00,	-100.00)	GC
5.	6406.804200	AT (	0.00,	-100.00)	GC	10.	3756.853520	AT (	200.00,	100.00)	GC

*** THE MAXIMUM 10 ANNUAL AVERAGE CONCENTRATION VALUES FOR GROUP: SOURCE2 ***
INCLUDING SOURCE(S): SILO2 ,

RANK	CONC	AT	RECEPTOR (XR,YR) OF TYPE			RANK	CONC	AT	RECEPTOR (XR,YR) OF TYPE		
1.	62709.562500	AT (	0.00,	0.00)	GC	6.	5063.882810	AT (	200.00,	100.00)	GC
2.	14144.651400	AT (	100.00,	0.00)	GC	7.	4727.612790	AT (	200.00,	0.00)	GC
3.	10320.604500	AT (	100.00,	100.00)	GC	8.	4128.552730	AT (	100.00,	-100.00)	GC
4.	8811.853520	AT (	0.00,	100.00)	GC	9.	3449.159420	AT (	0.00,	-100.00)	GC
5.	5623.265140	AT (	-100.00,	0.00)	GC	10.	3297.393310	AT (	100.00,	200.00)	GC

*** THE MAXIMUM 10 ANNUAL AVERAGE CONCENTRATION VALUES FOR GROUP: SOURCE3 ***
INCLUDING SOURCE(S): SILO3 ,

RANK	CONC	AT	RECEPTOR (XR,YR) OF TYPE			RANK	CONC	AT	RECEPTOR (XR,YR) OF TYPE		
1.	84731.460900	AT (	0.00,	100.00)	GC	6.	4981.960940	AT (	200.00,	100.00)	GC
2.	15416.812500	AT (	100.00,	100.00)	GC	7.	4737.755370	AT (	0.00,	200.00)	GC
3.	7037.712400	AT (	100.00,	0.00)	GC	8.	4242.443850	AT (	-100.00,	100.00)	GC
4.	6781.504880	AT (	100.00,	200.00)	GC	9.	4189.274900	AT (	200.00,	0.00)	GC
5.	6406.804200	AT (	0.00,	0.00)	GC	10.	3756.853520	AT (	200.00,	200.00)	GC

*** RECEPTOR TYPES: GC = GRIDCART
GP = GRIDPOLR
DC = DISCCART
DP = DISCPOLR
BD = BOUNDARY

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

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*** THE MAXIMUM 10 ANNUAL AVERAGE CONCENTRATION VALUES FOR GROUP: SOURCE4 ***
INCLUDING SOURCE(S): BERMFILL,

** CONC OF OTHER IN MICROGRAMS/M**3 **

RANK	CONC	AT	RECEPTOR (XR,YR)		OF TYPE	RANK	CONC	AT	RECEPTOR (XR,YR)		OF TYPE
1.	171380.047000	AT (	100.00,	0.00)	GC	6.	58205.582000	AT (	0.00,	-100.00)	GC
2.	101008.375000	AT (	100.00,	100.00)	GC	7.	55461.324200	AT (	-100.00,	0.00)	GC
3.	79679.500000	AT (	0.00,	100.00)	GC	8.	55337.949200	AT (	200.00,	100.00)	GC
4.	72318.101600	AT (	100.00,	-100.00)	GC	9.	43687.043000	AT (	200.00,	-100.00)	GC
5.	67916.226600	AT (	200.00,	0.00)	GC	10.	37926.492200	AT (	100.00,	200.00)	GC

*** THE MAXIMUM 10 ANNUAL AVERAGE CONCENTRATION VALUES FOR GROUP: SOURCE5 ***
INCLUDING SOURCE(S): K65_SOIL,

RANK	CONC	AT	RECEPTOR (XR,YR)		OF TYPE	RANK	CONC	AT	RECEPTOR (XR,YR)		OF TYPE
1.	100933.414000	AT (	100.00,	0.00)	GC	6.	32986.332000	AT (	-100.00,	0.00)	GC
2.	53548.750000	AT (	100.00,	100.00)	GC	7.	32231.025400	AT (	0.00,	-100.00)	GC
3.	44190.531300	AT (	0.00,	100.00)	GC	8.	28371.027300	AT (	200.00,	100.00)	GC
4.	36472.976600	AT (	100.00,	-100.00)	GC	9.	22635.748000	AT (	200.00,	-100.00)	GC
5.	34146.480500	AT (	200.00,	0.00)	GC	10.	19239.423800	AT (	-100.00,	-100.00)	GC

*** RECEPTOR TYPES: GC = GRIDCART
GP = GRIDPOLR
DC = DISCCART
DP = DISCPOLR
BD = BOUNDARY

*** MODELING OPTIONS USED: CONC RURAL FLAT DFAULT

4292

*** Message Summary For ISC2 Model Execution ***

--------- Summary of Total Messages --------

A Total of 0 Fatal Error Message(s)
A Total of 1 Warning Message(s)
A Total of 0 Informational Message(s)

******** FATAL ERROR MESSAGES ********
*** NONE ***

******** WARNING MESSAGES ********
SO W320 24 APARM : Source Parameter May Be Out-of-Range for Parameter QS

****
*** ISCLT2 Finishes Successfully ***
****

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E.2.0 GROUNDWATER FATE AND TRANSPORT MODELING

E.2.1 INTRODUCTION

The objective of the groundwater modeling as described in this attachment is to evaluate the fate and transport of constituents as they migrate from the Operable Unit 4 waste areas through the vadose zone and into the Great Miami Aquifer. This section provides a more detailed discussion of modeling and provides the necessary support information that is discussed in the main text (Section 5.0). The Operable Unit 4 waste areas considered are Silos 1 and 2 (K-65 silos), and Silo 3 (Metal Oxide Silo).

Groundwater fate and transport models were used to predict contaminant movement from source volumes (waste areas) to receptor locations through the groundwater pathway. Used in conjunction with monitoring data, these models provide contaminant concentrations at potential exposure locations where measured contaminant concentration data are not available. The modeling provides the best data on contaminant migration into off-property locations or for future exposure predictions by extrapolating from known field data.

This attachment presents a description of the methods used to quantitatively predict contaminant concentrations for use in FEMP risk assessments, including discussions of the fate and transport models used for the groundwater pathway and their required data and default parameter values. Descriptions of the technical approach used to model environmental transport through the groundwater pathway are presented in this attachment. Figure E.2-1 is the conceptual groundwater fate and transport modeling flow diagram which shows the different steps that are involved in the overall groundwater modeling scenario.

The extent to which contaminants may migrate through the groundwater system depends both on site characteristics and the nature of the contaminants. Because of the variety of the contents in the waste areas and the heterogeneity in the vadose zone beneath the waste areas, a separate conceptual model was developed for each of the waste areas in Operable Unit 4. The development of these models involved the following steps:

- Review of the available information on the specific waste area to establish the characteristics of the waste
- Identification of constituents of potential concern by reviewing the production history and by analyzing site characterization data
- Identification of the hydrologic processes governing the fate and transport of the constituents within each hydrostratigraphic unit
- Development of a conceptual hydrogeologic model for each waste area, based on information about the contaminants present in that waste area and its location-specific geologic setting

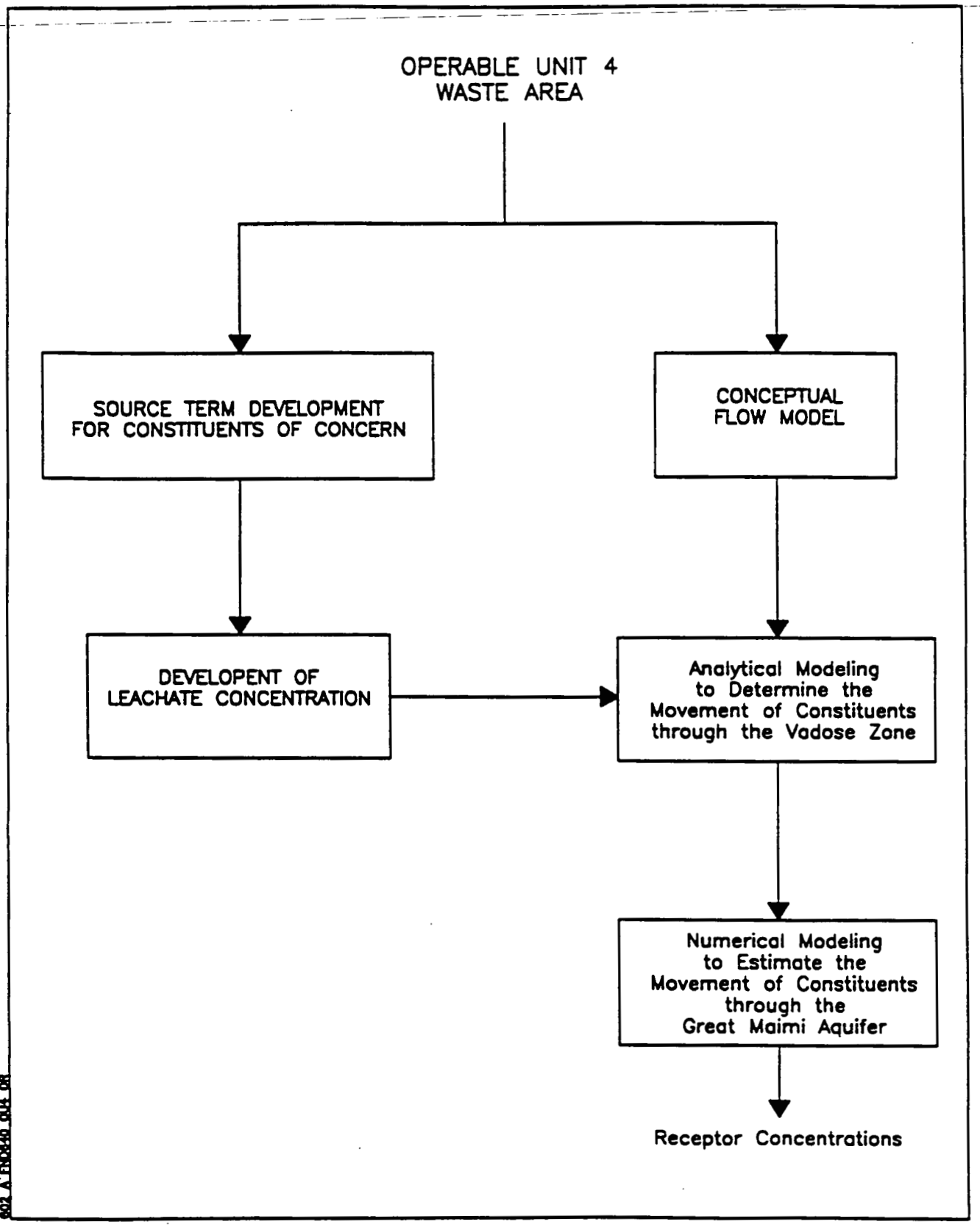

FIGURE E.2–1. CONCEPTUAL TRANSPORT MODELING DIAGRAM

Once the conceptual model was developed, existing computer codes that allowed the creation of a proper mathematical representation of the conceptual model were selected. The mathematical representations used at the FEMP generally consider the rate at which the modeled processes occur, the interaction of different processes with each other, and the initial conditions of both the waste area and the surrounding geologic formations. Some of the major steps involved in constructing mathematical representations of the conceptual models used at the FEMP include:

- Quantification of the concentrations of constituents in the waste area and the hydrologic processes previously identified
- Use of measured data and geochemical modeling, as described in Section E.3.0, to determine the chemical speciation projected to result from the reactions of infiltrating water with the waste materials and the matrix of the glacial overburden
- Estimation of the rate constants describing the cationic retardation of the predicted contaminants. These rate constants are based on partitioning coefficients selected during an extensive literature search.
- Estimation of the rate constants describing contaminant retardation attributable to interactions with organic carbon in the geological formation. These constants are based upon the grain-size distributions and organic carbon content of the glacial overburden matrix.
- Estimation of the rate constants describing the decay rates of the modeled contaminants. These first-order rate constants are based upon radioactive half-lives and biodegradation half-lives in groundwater for radionuclides and organic chemicals, respectively.

After existing computer codes and site-specific input parameters were selected, the codes were used to (1) calculate constituent loading rates to the aquifer beneath the selected waste area, and (2) perform flow and solute transport modeling to determine the effects of dispersion, retardation, and contaminant degradation or decay (for some organics and radionuclides excluding uranium) on the projected contaminant concentrations in the Great Miami Aquifer. Estimates of future concentrations in the aquifer were the desired result of the modeling effort.

E.2.2 HYDROGEOLOGIC SETTING

The first step in developing the pathway analysis is to develop a conceptual understanding of the depositional history of the site and the general hydrogeologic characteristics of the deposits. This section describes the general geology and hydrogeology of the FEMP. For a detailed discussion, refer to the draft Fernald Groundwater Report (DOE 1990).

E.2.2.1 Geologic Setting

The geology of the area is dominated by the glacial and glaciofluvial deposits formed during the most recent continental glaciation (approximately 70,000 years before present). Prior to the advancement of the glaciers, a large valley was eroded into the shale bedrock. This valley, which is approximately

200 ft below the existing land surface, was filled with well-sorted sand and gravel glacial outwash during the retreat of early glaciers. Beneath the site, this outwash is divided by a clay layer at a depth of 120 ft below the current surface. Later glacial advances (Shelbyville) caused the displacement of the Dry Fork of the Whitewater River from its historic channel into its present channel. The Shelbyville ice deposited a moraine in the historic channel which formed a dam. The meltwater lake that formed behind the dam gave rise to the lacustrine deposits found in the area. This dam was breached at least two times, with the final breach draining the lake permanently. The lake basin is now occupied by Paddys Run.

In the Paddys Run floodway, recent deposits of silt (loess, fluvial, and lacustrine) form a terrace above the current stream elevation. Paddys Run has cut through this recent terrace and the glacial drift. The bed of Paddys Run just upstream of the silos is located on the well-sorted, outwash material which fills the buried valley on preglacial Whitewater River deposits. Since the last retreat of the continental glaciers, the streams in the area have removed much of the till and lacustrine mantle left by the ice sheets. In the Great Miami River valley, the stream has eroded through the till and is now in direct contact with the glaciofluvial outwash deposits that contain the buried valley aquifer.

The term glacial overburden has been selected to describe the deposits located stratigraphically above the glaciofluvial material of the Great Miami Aquifer. The glacial overburden includes the following types of materials:

- Loess - Considered ubiquitous in the Fernald area, it generally forms the uppermost layer of the glacial overburden. Loess is generally a homogeneous fine-grained blanket deposit, buff to light yellow or yellowish-brown in color. The deposit originated from windblown dust of the Pleistocene age carried from the unconsolidated glacial and glaciofluvial deposits uncovered by glacial recession, but prior to the invasion of a vegetative cover.

- Lacustrine - Lacustrine deposits from the glacial lake consisting of well-sorted, stratified fine sands and clays formed in the Paddys Run valley. These clays can be interbedded with well-sorted beach deposits along the margins of the former lake basin.

- Till - Undifferentiated glacial till makes up the majority of the glacial overburden at the FEMP site. Because of its location at the ice margin, the till is likely to have been deposited by several modes including moraine deposits, ablation till, and subglacial till sheets arising from differing ice lobes. The primary feature of tills is that they are deposited directly by a glacier without fluvial sorting. The till at the site is a heterogeneous mixture of clays, silts, and pebbles.

- Glaciofluvial - Interbedded with the overburden are glaciofluvial beds that originated from meltwater streams that occurred along the margins of the ice sheets. These deposits of varying extent consist of well-sorted sands and fine gavels.

E.2.2.2 Vadose Zone

The unsaturated or vadose zone exists above the groundwater table or phreatic surface of the outwash aquifer. In this zone, the interstices are occupied partially by water and partially by air. The partially filled soil water in the unsaturated zone is known as vadose water. Overlying the Great Miami Aquifer at the FEMP are approximately 15 to 35 ft (4.6 to 11 m) of unsaturated sand and gravel outwash deposits. These deposits are assumed to have the same hydraulic characteristics as the underlying saturated material since their depositional histories are the same.

Dense, fine-grained glacial overburden overlie the unsaturated sand and gravel outwash deposits. These types of deposits have intergranular hydraulic conductivities that are very low, with values in the range of 10^{-7} to 10^{-5} ft/day (10^{-11} to 10^{-9} cm/s) (Heath 1983). Extensive deposits of clayey till can cause isolation from zones of near-surface groundwater flow.

In the Great Plains region and in parts of the Midwest, deposits of clayey, or silty clay, and glaciolacustrine clay have networks of predominantly vertical joints or fractures. This jointing pattern in the Wisconsin tills has also been noted in the area surrounding the FEMP (Brockman 1988). In the FEMP area, the joints which are commonly near vertical have a polygonal expression and are typically 18 to 25 inches (0.46 to 0.63 m) across. The joints are generally oxidized approximately two inches on either side of the joint. Within the FEMP, fractures have been noted in the till during the RI/FS drilling program and field reconnaissance. These fractures can impart an enhanced bulk hydraulic conductivity of up to 1000 times greater than that of an unweathered till (Hendry 1988). As a result of increased lateral stresses caused by overburden loading, the hydraulic conductivity of fractured till and clay decreases with depth.

Recent investigations in similar geologic settings indicate that till deposits can be divided from a hydrogeologic standpoint into a brown weathered zone and a gray unweathered zone (Barari and Hedges 1985; Hendry 1988; Cravens and Ruedisili 1987). These studies indicate that infiltration is primarily limited to the weathered till. While precipitation enters this upper zone, it does not act as a significant source of recharge to deeper aquifer zones, and the majority of the water lost from till deposits is from evapotranspiration. In addition to the losses due to evapotranspiration, some water may be discharged to small seeps or drainages.

Although the degree of fracturing within the brown tills at the FEMP has not been documented, sufficient observations have been made at the site and in the literature to indicate their presence is a characteristic physical property of these tills. Since fractures have been noted as a dominant feature in most brown tills, it is necessary to consider the effect that these fractures have on water and contaminant transport within the tills. As stated earlier, fractures have been reported to enhance the bulk hydraulic conductivity of till as much as 1000 times with an expected increase of 1 to 3 times. It is reasonable to expect that contaminants will be transported by seepage more quickly through fractured

till than unfractured till. In the OU4 study area, Silos 1 and 2 rest directly on unweathered till due to the excavation, which took place during their construction. Silo 3 has approximately 5 feet of weathered till beneath it, which is assumed to minimally impede the vertical migration of contaminants. At the FEMP, the till, with its appreciable silt and clay content, was regarded as providing the Great Miami Aquifer with protection from activities at the site (Dove and Norris 1951). This line of reasoning has justification because the low hydraulic conductivity produces very low velocities even if the hydraulic gradients are large. In addition, most contaminants being transported by seepage through the till matrix undergo attenuation and retardation.

If the till is fractured, these generalizations are not applicable because the velocities of water in the fractures are relatively large compared to the intergranular pore velocities in the unfractured matrix. It should be kept in mind that although the velocities are relatively large, the contaminant flux may be relatively small because the flow rate through the fractures is small.

Fractures not only control velocity, but they generally impart a lower capability for attenuation and retardation by adsorption of contaminants. The adsorption processes are capable of removing more contaminant mass from solution if the water is in contact with larger surface areas in the matrix. Contaminants transported by seepage through till fractures only have an opportunity to react with the mineral constituents present in a veneer layer on the exterior of the fracture. Therefore, when flow occurs in the fractures, there is less surface area available for geochemical reactions that reduce the concentration of a contaminant or slow the movement of that contaminant. The exact nature of attenuation in fractured till is highly site specific and not well quantified. For example, if till fractures are coated with iron oxides, they may impart significant retardation on ionic solutions (Grisak et al. 1976).

Within the till deposits, there are numerous water-bearing zones that have limited interconnection. The majority of these zones are of glaciofluvial origin and consist of small beds of highly-sorted sands and gavels. These beds are probably the result of small meltwater streams that occurred along the ice margin and within the glacier itself. These intertill perched zones have the following general characteristics:

- High variability in areal extent, thickness, and volume
- Based upon hydrograph analysis, the interconnection between the intertill aquifers is limited
- Hydraulic conductivities are highly variable with an expected range of 2.8×10^{-5} to 280 ft/day (10^{-8} to 0.1 cm/s) (Freeze and Cherry 1979)
- Porosities range from 22.1 to 36.7, with a mean of 31 percent (Morris and Johnson 1967)

Generally these glaciofluvial interbeds are considered to be water-bearing units within the glacial overburden. However, movement of water and contaminants within these units may be limited due to their limited areal and vertical extent. The perched groundwater zones (saturated lenses of higher permeability sands) present beneath Operable Unit 4 waste areas are not modeled separately, but the thickness of the sand lenses are included in the vadose zone modeling. In addition, an alternate conceptual model dealing with a semi-continuous silty/clayey sand lens under the silos is addressed qualitatively. At the FEMP, a series of slug tests on these perched aquifers found hydraulic conductivities ranging from 0.0071 ft/day (2.5×10^{-5} cm/s) (Well 1025) to 14.7 ft/day (5.2×10^{-3} cm/s) (Well 1339).

E.2.2.3 Great Miami Aquifer

The hydrogeology of the FEMP and the surrounding area is a textbook example of a glaciofluvial buried valley aquifer (Walton 1970; Fetter 1989; Freeze and Cherry 1979). The primary aquifer in the region is the Great Miami Aquifer, a well-sorted sand and gravel water table system. Groundwater in the aquifer enters the FEMP area via buried channels on the west, north, and east. Under natural conditions, the primary flow would be across the site to the south. However, large pumping wells east of the FEMP in the Big Bend area of the Great Miami River have created a pronounced cone of depression causing flow at the FEMP to have easterly, southeasterly, and southerly components.

The aquifer beneath the site is divided by a clay aquitard 1 to 20 ft (0.3 to 6.1 m) thick at a depth of approximately 120 ft (37 m). Flow direction and magnitude of the Great Miami Aquifer were simulated using SWIFT III, a numerical groundwater flow and solute transport model. Subsequent text describes the modeling effort in more detail.

E.2.2.4 General Contaminant Hydrogeology At The FEMP

The depositional characteristics and the hydrostratigraphic units present at the FEMP impart general contaminant transport characteristics on solutes migrating from the individual waste areas to receptor locations. These characteristics include:

- Solute migration potential: Solutes have a high migration potential through the upper weathered tills due to the fractured nature of the layer. Solute migration can also occur through the unweathered till, however, at a much slower rate. Once the solute reaches the glacial outwash, the solute migration potential is high, based on the high hydraulic conductivity and low adsorption capacity of the matrix.

- Aquifer intercommunication: The intercommunication between perched water-bearing zones is limited in the glacial environment. Communication between the upper water-bearing zones within the till and the Great Miami Aquifer is also limited, but may occur over an extended period of time.

- Adsorption/attenuation characteristics: The layers found within the glacial overburden generally have sufficient organic carbon content to cause retardation of organic constitu-

ents. The clay mineralogy would result in significant cation retardation for inorganic constituents. Given the till matrix, it is also unlikely that all of the available sites for adsorption would be used by solutes. Therefore, it is unlikely that adsorption/attenuation breakthrough would occur. Adsorption/attenuation will occur at lower rates in the regional aquifer due to the lower organic carbon and clay content in the outwash.

Based upon the general hydrogeologic and contaminant transport characteristics, there is a potential pathway from the waste areas through the vadose zone to the regional aquifer. Given the high permeability of the glacial outwash, the pathway would extend from the aquifer-vadose interface to downgradient receptors.

E.2.3 CONCEPTUAL FLOW MODEL

Based on characteristics of the material underlying the Operable Unit 4 waste areas, a conceptual model was developed for the pathway between the waste areas and receptor locations. This conceptual models is summarized in the following sections. The model was developed to account for the variable stratigraphies of the soils as a result of the two separate locations of the waste areas of Operable Unit 4. Fluids and/or leachate entering from the waste areas migrates first through the unsaturated glacial overburden, then through the unsaturated outwash deposits, and finally into the Great Miami Aquifer.

The waste areas contained in Operable Unit 4, Silos 1 and 2 and Silo 3, were assumed to remain in their existing locations for the purposes of the fate and transport modeling. The silos would have no maintenance performed on them, and thus would become subject to weathering and structural failure. At some point in the future, containment within the silos was assumed to fail and contaminants will be released to the environment. Silos 1 and 2 are assumed to experience a collapse of their roofs, but to still maintain structural integrity along the tank walls due to the supporting earth surrounding them. However, both the walls and the flooring are assumed to partially fail to the point where cracks and openings allow for leachate to escape. Silo 3 is assumed to fail completely as it is self supported, with all the wastes contained within forming an uncovered pile at its location. All silos are then assumed to be exposed to normal weathering and precipitation. Due to the harsh nature of the wastes, no vegetative cover was assumed to form on the wastes, and thus no transpiration is allowed in the water balance model used to calculate seepage rates from the silos.

Once through the silos, water filters through the vadose zone and dissolves materials, forming an aqueous solution (leachate). This solution continues to percolate through the soil/waste matrix in the vadose zone as it moves toward the aquifer. The leachate often reacts with the soil/waste matrix through which it flows. These interactions determine what chemical species are present in the percolating water (leachate), and how fast they will move in the unsaturated zone. In this analysis, the composition of the leachate and the speed at which individual constituents migrate are treated individually.

Contaminant transport in the vadose zone includes the bulk migration of water and dissolved materials from waste (source) areas at the FEMP to the Great Miami Aquifer. This occurs as surface water infiltrates from the surface and percolates through the source of contamination, and its surrounding soil, into the saturated zone. Downward movement of water, driven by the forces resulting from gravitational potential, capillary pressure, and other components of total fluid potential, mobilize the contaminants for transport through the vadose zone. Vertical transport down through the vadose zone to the aquifer followed by horizontal transport through the aquifer to the well of a potential human receptor is illustrated in Figure E.2-2.

The flow and contaminant transport process in the vadose zone is conceptualized from the hydrogeology of the site and in the media. As discussed previously, the geology of the FEMP site is dominated by glacial sediments. Well-sorted sand and gravel glacial outwash forms the regional Great Miami Aquifer. This aquifer is divided by a 0.3- to 6-m-thick (1- to 20-foot-thick) clay interbed at an approximate depth of 36.6 m (120 ft). The receptor pathway considered for this analysis is the upper part of the Great Miami Aquifer above the clay interbed. The uppermost 6.1 to 7.6 m (20 to 25 ft) of the outwash deposits is unsaturated and forms model Layer 2 of the vadose zone conceptual flow model. Overlying the outwash deposits is an unweathered till interbedded with sand and gravel glaciofluvial stringers. The thickness of this unit (referred to as glacial overburden) which makes up model Layer 1 ranges between 4.6 and 7.6 m (15 and 25 ft) for waste areas, as indicated in Table E.2-1. A layer of weathered till overlies the gray clay. However, this layer is not included in the vadose zone modeling because of numerous fractures present within this zone. All layer thicknesses were estimated based on geologic boring logs from subsurface investigations conducted across the site.

Using the results of the vadose zone modeling, the loading rates of each compound were used to calculate the expected maximum concentration which would occur in the Great Miami Aquifer. These expected maximum concentrations were then compared to risk-based screening concentrations to determine if a significant amount of risk would be developed from each compound.

The calibrated groundwater flow model for the FEMP was used to simulate the solute transport of the compounds in the Great Miami Aquifer. Based on the aquifer loading rates derived from the vadose zone modeling, loading periods were defined for each compound to reduce the amount of data entry required. In general, loading periods ranged from 10 to 200 years in length and were defined in direct proportion to the changes in loading rates for each compound. Thus, compounds with steady loading rates had long loading periods, while compounds with variable loading rates used short loading periods. This allowed the simulation of short loading "spikes" while at the same time minimizing data input and runtimes. Compounds were simulated for a total of 1000 years in the Great Miami Aquifer or until their concentrations reduced below 1 microgram per liter (µg/L).

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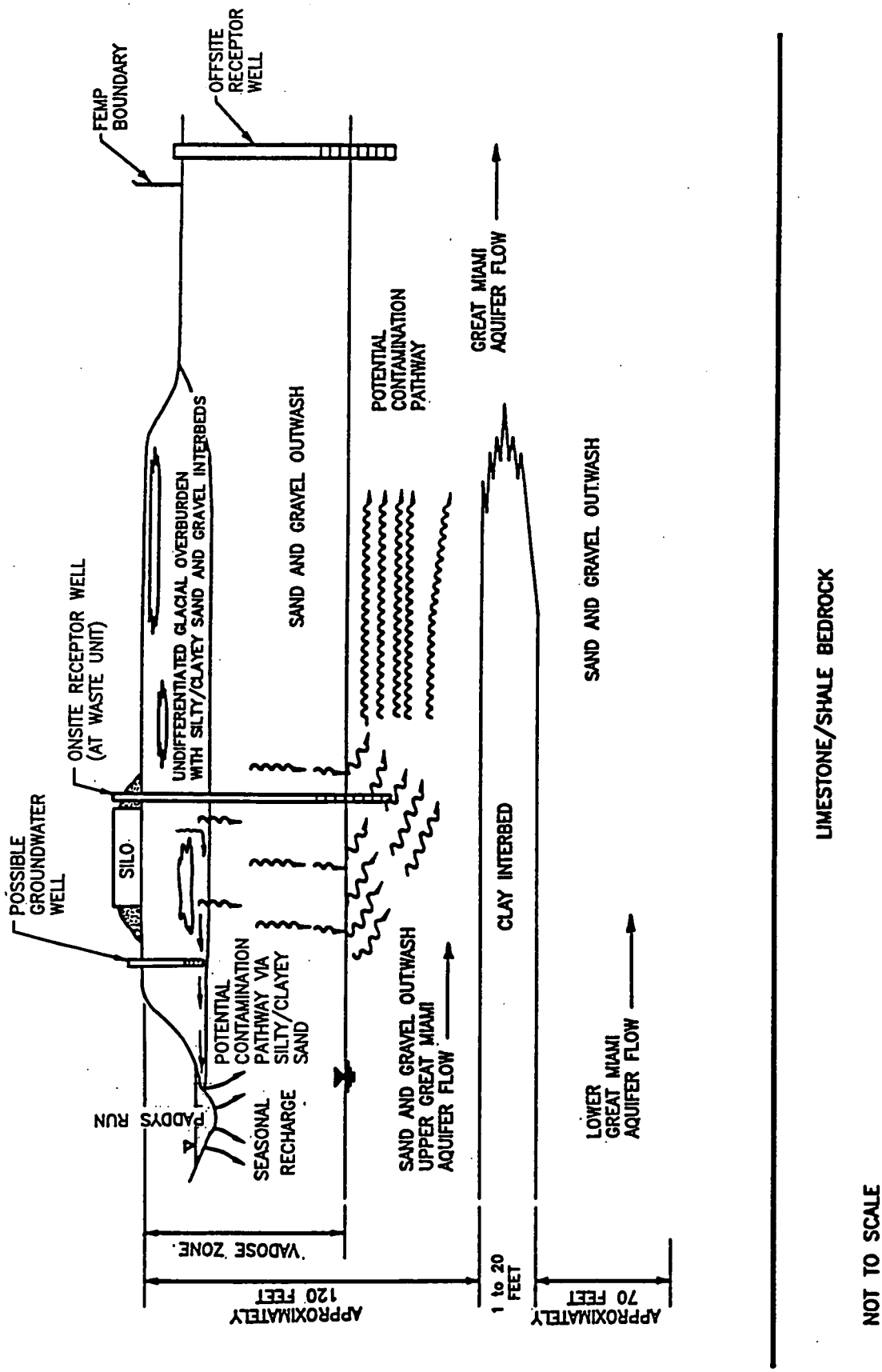

FIGURE E.2-2. CONDEPTUAL MODEL OF CONTAMINANT TRANSPORT BY GROUNDWATER AT THE FEMP

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TABLE E.2-1

CONCEPTUAL MODEL AND FLOW PARAMETERS FOR THE VADOSE ZONE OPERABLE UNIT 4

Waste Unit	Layer[a,b]	Thickness m (ft)	Vertical Hydraulic Conductivity K_v cm/s	(ft/day)	Seepage Velocity U_x cm/s	(ft/day)	Dispersion Coefficient D_x cm^2/s	(ft^2/day)
Silos 1 and 2	1	4.57 (15)	1.252×10^{-6}	(0.00355)	1.2×10^{-6}	(3.4×10^{-3})	1.5×10^{-6}	(9.0×10^{-4})
(K-65 Silos)	2	7.62 (25)	1.588×10^{-2}	(45.0)	2.2×10^{-6}	(6.2×10^{-3})	1.2×10^{-5}	(1.1×10^{-3})
Silo 3	1	7.62 (25)	1.252×10^{-6}	(0.00355)	1.2×10^{-6}	(3.4×10^{-3})	1.5×10^{-6}	(9.0×10^{-4})
(Metal Oxide Silo)	2	6.10 (20)	1.588×10^{-2}	(45.0)	2.3×10^{-6}	(6.5×10^{-3})	1.3×10^{-5}	(1.1×10^{-3})

[a]Layer 1 consists of a clay-rich till interbedded with glaciofluvial sand and gravel stringers.
[b]Layer 2 consists of well-sorted sand and gravel outwash deposits existing above the Great Miami Aquifer.

An alternate flow pathway for contaminants to enter the groundwater system has been found to exist in the area of Operable Unit 4. A semi-continuous silty/clayey sand lens has been mapped by ongoing site characterization activities for Operable Unit 5 and has been established to lie beneath the silos extending toward Paddys Run. Wells and borings installed into this lens have shown it to have a perched water zone with a gradient towards Paddys Run.

In this alternate flow path, leachate and surface infiltration from the silos and surrounding areas would flow vertically into the lens. Due to the higher hydraulic conductivities present in the lens, the contaminants would be transported laterally toward Paddys Run where they would outcrop on the slope of the stream channel. Here the contaminants would be available for transport by stream flow or, if flows from the lens are minimal, be deposited in the soils of the stream bank.

The more significant exposure, however, would result from the consumption of water from a well installed in the perched zone. Due to the limited water-bearing capacity of such a well, only domestic water use is possible. This pathway has been evaluated semi-quantitatively through dilution calculations using to the limited amount of data available on the lens. As additional field and laboratory data is gathered, a fate and transport model could be constructed of transport through the lens and into Paddys Run.

E.2.4 PARAMETERS

The parameters used to perform the long-term migration analysis can be divided into flow parameters and contaminant transport parameters. Flow parameters affect the velocity of groundwater movement.

Contaminant transport parameters affect the rate of migration and the fate of the contaminant. Wherever possible, site-specific values were used for the analyses. Certain parameters, however, were areas, and were estimated based on a pertinent scientific literature search, geochemical investigations, and were checked for consistency between model results and historical data. Conservative estimates were used when a range of values was indicated or parameter values were not available. The formulations employed for the estimation of the parameters are described in the Risk Assessment Work Plan Addendum (DOE 1992). Uncertainty in the selection of model parameter values is addressed by performing sensitivity analyses. Sensitivity analyses were performed by varying parameters within reasonable ranges. Additional information regarding the sensitivity is presented in Section 6.

The conceptual model and media parameters for Operable Unit 4 waste areas are presented in Tables E.2-1 and E.2-2, respectively. The vertical hydraulic conductivity values for Layer 1 were obtained by dividing the horizontal hydraulic conductivities (representing the results of slug tests conducted in 1000-series wells nearest to the waste area) by 20 (Djafari 1990). This estimate was based on typical vertical/horizontal ratios for glacial clays. The vertical hydraulic conductivity for Layer 2 was

TABLE E.2-2

MEDIA PARAMETERS FOR VADOSE ZONE MODEL OPERABLE UNIT 4

	Vadose Zone	
Parameter	Layer 1[a]	Layer 2[b]
Porosity (%)	34	39
Specific yield (%)	6	25
Bulk density (g/cc)	1.78	1.60
Field capacity (%)	28	14
Organic content (%)	4	1
Fines passing less than 200 mesh (%)	70	16

[a]Layer 1 consists of a clay-rich till interbedded with glaciofluvial sand and gravel stringers.
[b]Layer 2 consists of well-sorted sand and gravel outwash deposits existing above the Great Miami Aquifer.

obtained by dividing the known horizontal hydraulic conductivity by 10 to maintain the same unisotropy ratio as was used in the model of the Great Miami Aquifer. The estimates of the vertical seepage velocities used in the vadose zone transport model were based on the methods presented in the Risk Assessment Work Plan Addendum (DOE 1992). The longitudinal dispersion coefficients (D_x), a function of dispersivity, interstitial seepage velocity, and molecular diffusion coefficient were estimated by the methods presented by Biggar and Nielsen (1976), and Mills et al. (1982). Flow and solute transport through the porous media are not only determined by the parameters listed in the conceptual model, they are also affected by retardation factors (R_f) and decay rates. These parameters are both chemical- and media-specific. Tables E.2-3 through E.2-5 show the retardation factors for the vadose zone Layers 1 and 2 for all the constituents of concern for Operable Unit 4 waste areas. These tables also present the radioactive decay constants for radionuclides and the biodegradation coefficients for the organic constituents that were used in the transport model. The retardation factor is used to account for those reversible reactions that slow the arrival of a contaminant front, but do not act as a sink. The R_f can be expressed as the ratio between the rate of groundwater movement and the rate of contaminant movement. The R_f as function of the partitioning coefficient of the constituent, the bulk density and moisture content in the vadose zone, was calculated using the formula described by Walton (1984) and Mills, et al. (1982). The partitioning coefficients were taken from the Risk Assessment Work Plan Addendum (DOE 1992). The radioactive decay constants and biodegradation coefficients were estimated based on the degradation rates (Howard et al. 1991) using the formulation presented in the Risk Assessment Work Plan Addendum (DOE 1992).

Operable Unit 4 consists of Silos 1 and 2 (K-65 Silos), and Silo 3 (Metal Oxide Silo). These areas exhibit considerable diversity in their contents and in the physical and chemical characteristics of the vadose zone beneath them. Because of this diversity, the modeling of the contaminant migration through the vadose zone was considered imperative for the estimation of contaminant loading rates to the regional aquifer model. In order to model the transport of these contaminants, it was necessary to adapt the generic conceptual model presented in the Risk Assessment Work Plan Addendum (DOE 1992) to a series of specific conceptual models for each distinct waste area. These conceptual models considered the following:

- The contents of the waste area
- The presence of standing water in the waste area
- The presence or absence of a discrete cap
- The identifiable geologic strata beneath the waste area
- The thickness of each layer in the vadose zone
- The vertical permeability of the layers
- The interstitial fluid velocity through each layer based on saturation
- The dispersion coefficients of each layer

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TABLE E.2-3

RETARDATION FACTORS AND DECAY CONSTANTS FOR RADIONUCLIDES AT THE FEMP

Radionuclides	Retardation Factor Vadose 1	Retardation Factor Vadose 2	Radioactive Decay Constant (Day^{-1})
Actinium-227	1.53×10^4	5.14×10^3	8.721×10^{-5}
Polonium-210	1.91×10^4	1.72×10^3	5.007×10^{-3}
Protactinium-231	1.72×10^4	6.29×10^3	5.796×10^{-8}
Lead-210	1.91×10^4	4.35×10^2	8.531×10^{-5}
Radium-224	4.43×10^3	1.21×10^3	1.915×10^{-1}
Radium-226	4.43×10^3	1.21×10^3	1.187×10^{-6}
Radium-228	4.43×10^3	1.21×10^3	3.297×10^{-4}
Thorium-228	3.69×10^4	3.66×10^4	9.926×10^{-4}
Thorium-230	3.69×10^4	3.66×10^4	2.466×10^{-8}
Thorium-232	3.69×10^4	3.66×10^4	1.360×10^{-13}
Uranium-234	1.24×10^1	1.79×10^1	7.767×10^{-9}
Uranium-235	1.24×10^1	1.79×10^1	2.698×10^{-12}
Uranium-238	1.24×10^1	1.79×10^1	4.250×10^{-13}

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TABLE E.2-4

RETARDATION FACTORS FOR INORGANIC COMPOUNDS AT THE FEMP

Inorganics	Retardation Factor Vadose 1	Retardation Factor Vadose 2
Antimony	1.59×10^3	5.15×10^2
Arsenic	1.27×10^3	2.29×10^3
Barium	7.25×10^3	2.30×10^2
Beryllium	8.27×10^3	2.86×10^3
Boron	2.01×10^1	3.53×10^1
Cadmium	3.18×10^3	1.38×10^2
Chromium	9.54×10^3	8.01×10^2
Cobalt	3.50×10^3	6.87×10^2
Copper	7.96×10^2	4.01×10^2
Cyanide	1.27×10^0	1.21×10^0
Lead	1.91×10^4	4.35×10^2
Manganese	1.15×10^3	5.72×10^2
Mercury	6.46×10^1	1.15×10^2
Molybdenum	5.73×10^2	1.15×10^2
Nickel	4.13×10^3	4.57×10^3
Selenium	4.71×10^3	1.72×10^3
Silver	1.15×10^3	1.03×10^3
Thallium	9.54×10^3	1.71×10^4
Vanadium	6.36×10^3	2.29×10^3
Zinc	1.53×10^4	2.29 x 103

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TABLE E.2-5

RETARDATION FACTORS AND BIODEGRADATION COEFFICIENTS FOR ORGANIC COMPOUNDS AT THE FEMP

Organics	Retardation Factor Vadose 1	Retardation Factor Vadose 2	Organic Decay Constant (Day^{-1})
2-Butanone	1.22×10^0	1.17×10^0	2.48×10^{-2}
2-Hexanone	3.92×10^0	3.27×10^0	NA[a]
4,4-Dichloro-diphenyl-dichloroethylene	5.97×10^4	4.63×10^4	6.16×10^{-5}
4,4-Dichloro-diphenyl-trichloroethane	1.89×10^5	1.46×10^5	1.20×10^{-4}
4-Methyl-2-pentanone	2.50×10^0	2.16×10^0	2.48×10^{-2}
Acetone	1.07×10^0	1.05×10^0	2.48×10^{-2}
Aldrin	1.57×10^4	1.22×10^4	5.86×10^{-4}
Aroclor-1254	1.31×10^4	1.01×10^5	NA
Aroclor-1260	1.57×10^5	1.22×10^5	NA
Benzoic acid	1.00×10^1	8.00×10^0	NA
Bis(2-ethylhexyl)phthalate	2.44×10^4	1.89×10^4	1.78×10^{-3}
Carbon tetrachloride	6.64×10^1	5.17×10^1	1.90×10^{-3}
Chloroform	1.24×10^1	9.81×10^0	3.79×10^{-3}
Cyanide[b]	1.27×10^0	1.21×10^0	9.50×10^{-4}
Diethylphthalate	1.12×10^2	8.72×10^1	3.09×10^{-3}
Dieldrin	1.50×10^3	1.16×10^3	3.21×10^{-4}
Dimethylphthalate	1.00×10^1	8.00×10^0	2.48×10^{-2}
Di-n-octyl phthalate	1.92×10^8	1.49×10^8	1.90×10^{-3}
Endosulfan I	5.09×10^2	3.95×10^2	1.24×10^{-2}
Endosulfan II	4.33×10^2	3.36×10^2	1.24×10^{-2}
Endrin	4.86×10^4	3.77×10^4	NA
Fluoranthene	2.60×10^4	2.02×10^4	3.90×10^{-4}
Heptachlor epoxide	1.30×10^4	1.01×10^4	6.28×10^{-4}
Methylene chloride	3.17×10^0	2.68×10^0	2.48×10^{-2}
N-Nitroso-di-n-propylamine	3.49×10^0	2.93×10^0	9.50×10^{-4}
Phenol	4.51×10^0	3.72×10^0	2.48×10^{-2}
Pyrene	1.84×10^4	1.43×10^4	9.00×10^{-5}
Styrene	1.77×10^2	1.38×10^2	3.30×10^{-3}
Tetrachloroethene	4.22×10^1	3.30×10^1	4.20×10^{-4}
Toluene	6.07×10^1	4.73×10^1	3.30×10^{-3}
Total Xylenes	1.35×10^2	1.05×10^2	1.90×10^{-3}
Tributyl phosphate	1.22×10^3	9.46×10^2	NA

[a]NA denotes not available
[b]Cyanide is an inorganic compound but it has an organic decay constant.

E.2.4.1 Silos 1 and 2 (K-65 Silos)

The conceptual model depicting flow in the vadose zone at the Silos 1 and 2 (K-65 Silos) considers two layers. Layer 1 soils consist of unweathered tills, estimated at 15 ft thick. Beneath the unweathered till layer at the Silos 1 and 2 is the unsaturated sand and gravel layer (Layer 2) with an estimated depth of 25 ft. The vertical hydraulic conductivity is estimated at 0.00355 ft per day for Layer 1. The vertical hydraulic conductivity of Layer 2 is 45 ft per day for all of the Operable Unit 4 waste areas. As expected, the hydraulic conductivity of the sand and gravel layer is several orders of magnitude greater then the till layer. Additional information regarding flow and media parameters such as seepage velocity, dispersion co-efficient, and soil characteristics (EPA 1985) are presented in Tables E.2-1 and E.2-2.

E.2.4.2 Silo 3 (Metal Oxide Silo)

The stratigraphic units beneath Silo 3 consists of 5 ft of weathered till, 25 ft of unweathered till forming model Layer 1, and 20 ft of buried valley glaciofluvial material forming model Layer 2. The vertical hydraulic conductivity of Layer 1 is 0.00355 ft per day and 45 ft per day for Layer 2.

E.2.5 VADOSE ZONE MODELING

Vadose zone modeling was performed to estimate contaminant loading rates to the Great Miami Aquifer from a given source as a function of time. The overburden may have great capacity for immobilization and retardation of contaminants due to adsorption, precipitation, biodegradation, and radioactive decay. This capacity to prevent or slow the movement of contaminants to the aquifer was evaluated with respect to future risk.

Analytical models were selected for use based upon the following factors:

- Analytical methods are the most efficient alternative when data necessary for the characterization of the system is sparse and uncertain.
- The method is consistent with approaches used for similar radionuclide assessment codes such as the flow portions of PRESTO (EPA 1987) and other site studies.
- The basis of the solution is well documented and the code has been verified.

The following criteria were used in selecting specific analytical models:

- Capability of treating adsorption, radioactive and organic decay, and longitudinal dispersion
- Capability of calculating concentrations at large times and distances
- Availability of code

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- Degree of code documentation
- Degree of code verification

E.2.5.1 Description of Models

Leachate infiltration rates through the waste areas were necessary for calculating the total time for source depletion. They were also necessary for calculating the vertical seepage velocities that were used in vadose zone models. Infiltration rates were estimated using the HELP model (EPA 1984), assuming steady state infiltration conditions. The HELP model is a deterministic quasi-two-dimensional model that predicts evapotranspiration using the modified Penman method (EPA 1984) by incorporating the effect of site-specific default values of temperature, solar radiation, and evaporation coefficients. The model computes surface runoff by the U.S. Soil Conservation Service curve number method using default values of runoff curve numbers. The amount of precipitation, minus surface runoff and surface water evaporation, percolates through the soil layer producing vertical leakage and lateral drainage flow.

The models selected to evaluate flow in the vadose zone are ST1D (IT 1990), and ODAST (Javandel et al. 1984). ST1D, a one-dimensional analytical solution, was used for the initial screening of constituents for mobility. ST1D evaluates solute transport using terms for groundwater velocity, dispersion, and retardation. As it does not take into account radioactive or biologic decay, this yields a conservative solution for contaminant transport through the vadose zone. ODAST, also a one-dimensional analytical solution, was used for determining fate and transport of the remaining constituents in the unsaturated zone. This computer code is based on the solution originally developed by Ogata and Banks (1961), as was ST1D, and calculates the normalized concentrations of a given constituent in a uniform flow field from a source having a constant or varying concentration in the initial layer. ODAST evaluates the basic one-dimensional analytical solute transport equation as a function of seepage velocity, dispersion coefficient, source decay, retardation factor, depletion time, and source rate. ST1D and ODAST have been extensively verified against STRIP1B (Batu 1989). The computer code ODAST was used to provide the final leachate concentrations.

The model code ODAST was originally selected in 1990 during preliminary fate and transport analyses for the operable units at the FEMP. This code was selected primarily because of its ability to simulate transport through a vadose zone with only a limited amount of data. The model code was modified by altering the darcy velocity and dispersivity values used as input to simulate vadose zone transport, rather than saturated flow. Other codes currently available for simulating vadose zones require a large database of conditions present within the vadose zone, including detailed stratigraphies, soil moisture profiles, pressure-saturation relationships, and evapotranspiration data. Much of these data are presently unquantified at the FEMP, and thus would have to be assumed from the literature. An effort is currently underway to gather additional information for characterization of the glacial overburden,

but this is currently uncompleted. Thus, rather than using a complex model with non-site-specific data, it was decided to use a simpler model with site-specific data. Until additional characterization data are available, this code represents a valid method for evaluating contaminant transport through the vadose zone.

E.2.5.2 Model Application

To accomplish the simulation of the hydraulic system in Operable Unit 4, the Hydrologic Evaluation of Landfill Performance (HELP) was used to determine the infiltration rates through the waste units. The HELP model (EPA, 1984) is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of a waste unit. The model accepts climatologic, soil, and design data and simulates a number of hydraulic processes including surface storage, runoff, infiltration, percolation, evapotranspiration, soil moisture storage, and lateral drainage. The systems that can be modeled by HELP include various combinations of vegetation, cover soils, waste cells, special drainage layers, and relatively impermeable barrier soils.

The HELP model is designed to perform water budget calculations for a system having as many as nine layers by modeling each of the hydrologic processes that occur. Runoff is computed using the Soil Conservation Service (SCS) runoff curve number method by considering daily precipitation totals. Percolation and vertical water routing are modeled using Darcy's Law for saturated flow with modifications for unsaturated conditions. Evapotranspiration is estimated by a modified Penman method adjusted for limiting soil moisture conditions.

The HELP model requires three basic types of input data for use in its calculations. It requires climatologic data, soils data, and design data, all of which are input interactively when a run is made. The model uses this data to produce daily estimates of water movement across, into, through, and out of the modeled system. To accomplish this, daily precipitation is partitioned into surface storage (snow), runoff, infiltration, surface evaporation, evapotranspiration, percolation, stored soil moisture, and subsurface drainage to maintain a water budget. Default climatologic and soil data are internally available for various regions of the country and various soil types.

Input climatologic data for HELP model includes:

- Daily precipitation in inches
- Mean monthly temperature in degree of Fahrenheit (°F)
- Mean monthly insolation (solar radiation) in langleys
- Leaf area indices (dimensionless)
- Winter cover factors (dimensionless)

The data can be entered manually or selected from a default value. Default climatologic data are available for 102 cities, but the precipitation database is limited to five years of records (usually 1974-1978). Default data sets include daily precipitation data, data for mean monthly temperature, and data for mean monthly insolation.

Leaf area index (LAI) and winter cover factor are the two variables controlling evapotranspiration. LAI is defined as the dimensionless ratio of the leaf area of active transpiring vegetation to the nominal surface area of land on which the vegetation is growing. The HELP program assumes that LAI may vary from a minimum value of 0 to a maximum value of 3. The LAI value of 0 is representative of no actively growing vegetation (bare ground or dormant vegetation), and the value of 3 represents the most dense stand of actively growing vegetation considered.

The HELP program can simulate up to nine layers in the soil profile. Each layer must be identified as either a vertical percolation, lateral drainage, waste, or barrier soil layer. The identification of each layer used in the model is critical because the program models water flow through the various types of layers in different ways.

In vertical percolation layers, lateral drainage is not permitted. The layers are assumed to have large hydraulic conductivities which do not restrict vertical flow in the downward direction (percolation). Water can move upward and be lost to evapotranspiration if the layer is within the specified evaporation zone; thus, a layer designed to support vegetation generally is designated as a vertical percolation zone. Lateral drainage layers are assumed to have hydraulic conductivities large enough that little resistance to flow is offered. The hydraulic conductivity of a drainage layer should be equal to or greater than that of the overlying layer. Both lateral and vertical flow are permitted within drainage layers. A barrier soil layer is a layer with a low hydraulic conductivity which restricts lateral flow; only downward flow is allowed. Since the HELP model is designed for the hydrologic evaluation of landfills, identifying a layer as a waste layer indicates to the program that the layer is not part of the landfill cap, cover, or part of the liner/drainage system. Water movement through a waste layer is modeled in the same manner as a vertical percolation layer.

To describe the soil characteristics of the layers used in the model, HELP uses the soil properties of porosity, field capacity, wilting point, and hydraulic conductivity (saturated zones) as input data. The porosity of soil is the ratio of the volume of voids to the total volume occupied by a soil. The field capacity represents the amount of water a soil can hold in the unsaturated zone against the pull of gravity. The wilting point is the soil moisture content below which plants no longer can take in water from the soil. This value limits the total amount of water that can be taken out of the soil, as very little evapotranspiration will occur when the moisture content drops below this level. Hydraulic conductivity is the rate at which water moves through soil in response to gravitational forces. The porosity and wilting point are not used for barrier soils, and the wilting point is not used for any layer

below the effective evaporation zone. These data can be input either using the default or manual data input options, or a combination of default and manual input.

The HELP model output consists of input data echo, simulation results, and a summary. The input data echo includes all the information used for input, including the values chosen from the model's built-in database and any manually input data. Following the input data echo, the program produces a table of the daily results, monthly totals, and annual totals for each year if the options for detailed output are used. Following these outputs, the summary output is given. The summary includes average monthly totals, average annual totals, and peak daily values for the simulation variables. The average monthly total reports precipitation, runoff, evapotranspiration, percolation through the base of each layer, and lateral drainage through each layer for a particular month for all the years of a simulation. The average annual total reports the values on an annual basis. The summary of peak daily values represents the maximum values that occurred on any day during the simulation period.

A one-dimensional, analytical solute transport model ST1D (IT 1990) was used to screen the list of constituents of concern to reject those that would not reach the Great Miami Aquifer within the time period of interest under conservative conditions. ST1D calculates a normalized concentration in a uniform porous media flow field from a source having a constant concentration. The model used the same input values for groundwater velocity and dispersion as the ODAST model used to perform the final vadose zone modeling. Each constituent was evaluated under the 1000-year scenario. For a given waste area, a range of retardation factors was evaluated using the seepage velocities and dispersion coefficients for each layer of vadose zone. The critical retardation factor, for which the contaminant would reach the Great Miami Aquifer within a 1000-year period, was identified. After eliminating the constituents having a retardation factor greater than the critical value, the remaining constituents were given a more detailed analysis using ODAST. This allowed the screening of some contaminants having high retardation factors and reduced the number of simulations required.

The program ODAST was used for individual layers to calculate the normalized concentration at the bottom of each layer for every time step. In general, movement of contaminant through the lower layer would not come into effect until the constituent reached the bottom of the upper adjacent layer. This can be seen by identifying the time step when the concentration appears at the base of the first layer. Consequently, the onset of the simulation in the lower layer is considered when the contaminant reaches the base of the upper layer.

For the 1000-year scenario, the projected concentration of the leachate entering the Great Miami Aquifer beneath the waste area was calculated by multiplying the normalized concentration at the base of the lowest layer by the source term (initial contaminant concentration at the source). The loading rates were calculated by multiplying the projected concentration beneath the waste area by the recharge rate from the source. The plots of loading rates versus time were then produced for the constituents

which were projected to reach the aquifer within 1000 years. The peak values in these plots were considered as the maximum loading rates to be observed in the aquifer for the contaminants over 1000 years.

E.2.5.3 Vadose Zone Modeling Results

HELP modeling for Operable Unit 4 included two separate runs: simulation of a water budget for Silos 1 and 2, and simulation for Silo 3. In both simulations, the climatologic data of precipitation, mean monthly temperature, and mean monthly insolation data were taken from the model built-in data base for Cincinnati, Ohio. Average rainfall in the period was 40.64 in./yr. A value of LAI of 0 is used in the calculation, corresponding to no vegetative cover. The soil physical parameters and the design data used in the simulations are listed in Table E.2-6. Three layers are used in both simulations. Layer 1 is defined to be lateral drainage layer with a drainage length of 143 ft for Silos 1 and 2, and 190 for Silo 3. Layer 2 is barrier soil liner and layer 3 is vertical percolation layer in both simulations. The average monthly and annual totals output summary are obtained for a five year simulation period. The water budget results summary of average totals are listed in Table E.2-7. The average recharge rate from the ground surface to the aquifer (percolation through layer three) over the simulated five-year period is 3.99 in./yr in Silos 1 and 2, area and 4.24 in./yr in Silo 3 area.

Loading rates to the Great Miami Aquifer were estimated for each constituent of concern for the individual waste area using ODAST. Tables E.2-8 and E.2-9 provide a summary of the constituents of concern which will reach the Great Miami Aquifer within 1000 years from each waste area. The loading rates were used as input data for SWIFT III to model the groundwater movement and solute transport in the Great Miami Aquifer. These tables also present the approximate number of years for the projected constituents from each of the waste areas to reach the Great Miami Aquifer, and the maximum concentrations of the leachate that would be expected before being diluted in the aquifer. In addition, the tables also present the maximum loading concentration and the corresponding time.

Loading rates of a constituent to the outwash aquifer from a given source vary over time. Loading rates versus time for the constituents that reach the aquifer have been plotted. Typically, loading rates experience a sharp increase during the initial time period. They can then stabilize or decrease depending upon the depletion time of the source. Figures E.2-3 and E.2-4 show the time variations in the loading rates of U-238 in the Great Miami Aquifer from the Operable Unit 4 Silos 1 and 2, and Silo 3, respectively. For a long depletion time, the source remains active for a longer period during the simulation. The depletion rate is low for long depletion times; this ensures a mild change in the source term with time, and helps to approach a steady-state condition within the simulation time of 1000 years as shown in Figure E.2-4. For short depletion time, the source term vanishes earlier during the simulation period. For high depletion rates, the source term decreases faster during the simulation period. These factors cause an unsteady variation along with a sharp decline in the loading rates . The selected constituents to be modeled using SWIFT III were based on the risk associated with

TABLE E.2-6

WATER BUDGET INPUT SUMMARY
FOR HELP MODEL

Parameters	Silos 1 & 2			Silo 3		
	Layer 1	Layer 2	Layer 3	Layer 1	Layer 2	Layer 3
Porosity (vol/vol)	0.4710	0.4750	0.4170	0.4710	0.4750	0.4170
Field Capacity (vol/vol)	0.3418	0.3777	0.0454	0.3418	0.3777	0.0454
Wilting Point (vol/vol)	0.2099	0.2648	0.0200	0.2099	0.2648	0.0220
Hydraulic Conductivity (cm/s)	4.2×10^{-5}	1.25×10^{-6}	0.0159	4.2×10^{-5}	1.25×10^{-6}	0.0159
Thickness (inches)	232.30	180.00	300.00	330.72	300.00	240.00
Slope (%)	1.00	--	--	1.00	--	--
Drainage Length (feet)	143.0	--	--	190.0	--	--
SCS Runoff Curve Number		95			95	
Total Area of Cover (ft^2)		10055			5027	
Total Area of Cover (ft^2)		9			9	

TABLE E.2-7

AVERAGE ANNUAL TOTAL SUMMARY FROM HELP MODEL OUTPUT

Simulation Area	Precipitation (in./yr)	Surface Runoff (in./yr)	Evaporation (in./yr)	Aquifer Recharge from Layer 3 (in./yr)	Lateral Drainage from Layer 1 (in./yr)
Silos 1 & 2	40.64	10.80	25.11	3.99	0.74
Silo 3	40.64	10.80	25.11	4.24	1.21

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TABLE E.2-8

SUMMARY RESULTS OF VADOSE ZONE MODELING
CONSTITUENTS OF CONCERN WHICH WILL REACH THE
AQUIFER IN 1000 YEARS FROM SILOS 1 AND 2 (K-65 SILOS)

Constituents	Time of Arrival to the Aquifer (years)	Time of Maximum Loading Concentration (years)	Maximum Loading Concentration (mg/L)	Maximum Concentration in the Aquifer (mg/L)[a]	Maximum Concentration at the FEMP Boundary (mg/L)[a]	Screening Levels (mg/L)[b]
Radionuclides						
Uranium-234	140	320	1.049×10^{-3}	4.041×10^{-6}	5.942×10^{-7}	1.95×10^{-8}
Uranium-235	140	320	2.622×10^{-1}	1.009×10^{-3}	1.483×10^{-4}	5.64×10^{-5}
Uranium-238	140	320	1.742×10^{1}	6.699×10^{-2}	9.852×10^{-3}	2.08×10^{-4}
Inorganics						
Boron	240	620	3.449×10^{-1}	1.326×10^{-3}	1.951×10^{-4}	6.57×10^{-1}
Cyanide	20	30	3.474×10^{-4}	1.336×10^{-6}	1.965×10^{-7}	1.46×10^{-1}
Mercury	760	1000	3.714×10^{-9}	1.428×10^{-11}	2.101×10^{-12}	2.19×10^{-3}
Organics						
2-Hexanone	30	90	1.132×10^{-2}	4.354×10^{-5}	6.403×10^{-6}	NA
Benzoic acid	80	160	5.133×10^{-2}	1.974×10^{-4}	2.903×10^{-5}	2.92×10^{1}

[a]Maximum concentrations in the aquifer and at the FEMP boundary for all constituents except uranium were calculated using dilution factors. Uranium values were obtained from groundwater modeling using SWIFT-III.
[b]NA indicates screening level is not available.

TABLE E.2-9

SUMMARY RESULTS OF VADOSE ZONE MODELING
CONSTITUENTS OF CONCERN WHICH WILL REACH THE
AQUIFER IN 1000 YEARS FROM SILO 3 (METAL OXIDE SILO)

Constituents	Time of Arrival to the Aquifer (years)	Time of Maximum Loading Concentration (years)	Maximum Loading Concentration (mg/L)	Maximum Concentration in the Aquifer (mg/L)	Maximum Concentration at the FEMP Boundary (mg/L)	Screening Levels (mg/L)
Radionuclides						
Uranium-234	120	260	1.46×10^{-5}	3.02×10^{-8}	6.84×10^{-10}	1.95×10^{-8}
Uranium-235	120	260	1.84×10^{-3}	3.82×10^{-6}	8.64×10^{-8}	5.64×10^{-5}
Uranium-238	120	260	2.54×10^{-1}	5.26×10^{-4}	1.19×10^{-5}	2.08×10^{-4}
Inorganics						
Mercury	840	1000	4.604×10^{-11}			2.19×10^{-3}

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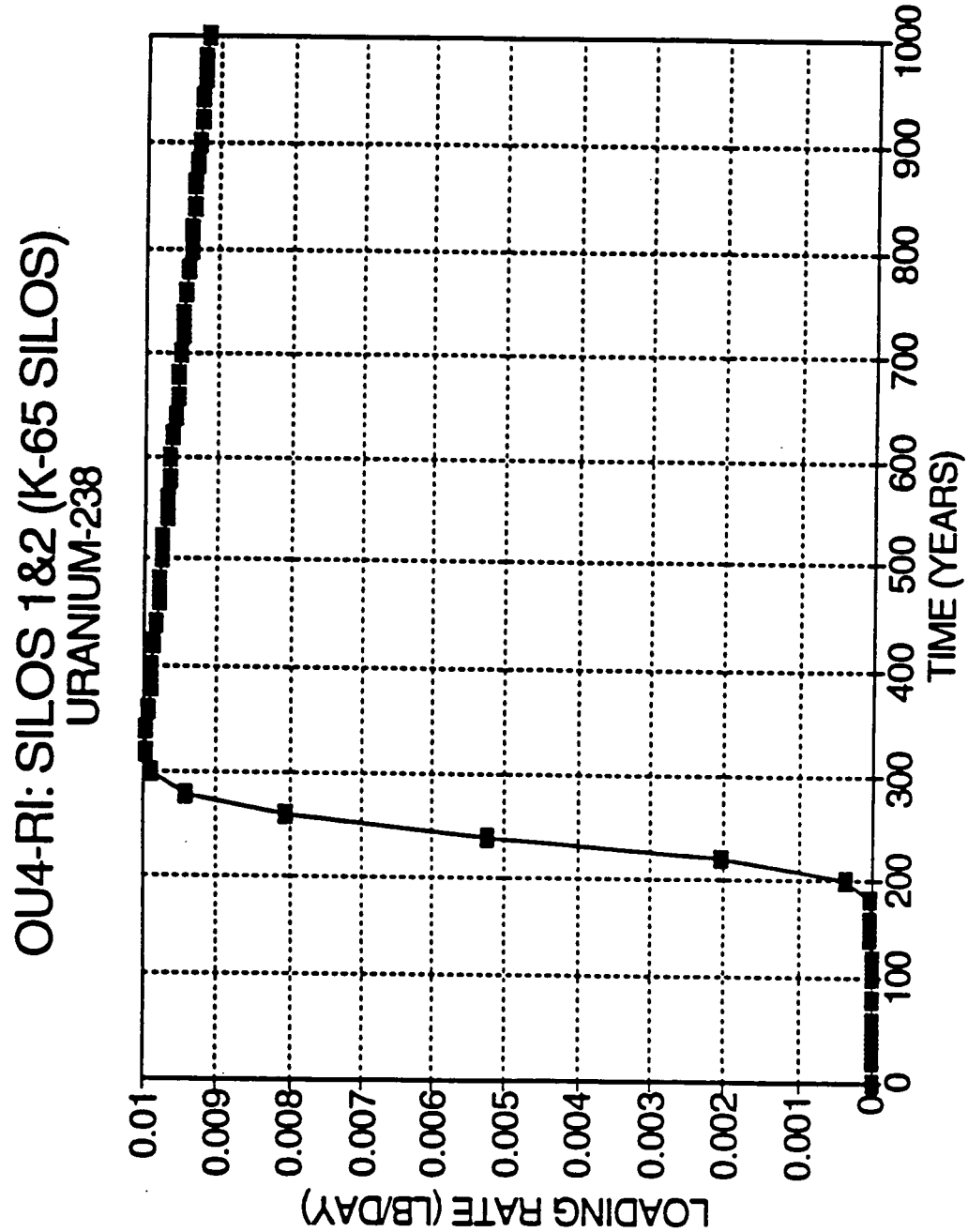

FIGURE E.2-3. PROJECTED MASS LOADING OF URANIUM-238 INTO THE GREAT MIAMI AQUIFER FROM SILOS 1 AND 2

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602 A FN0659 OU4 OR

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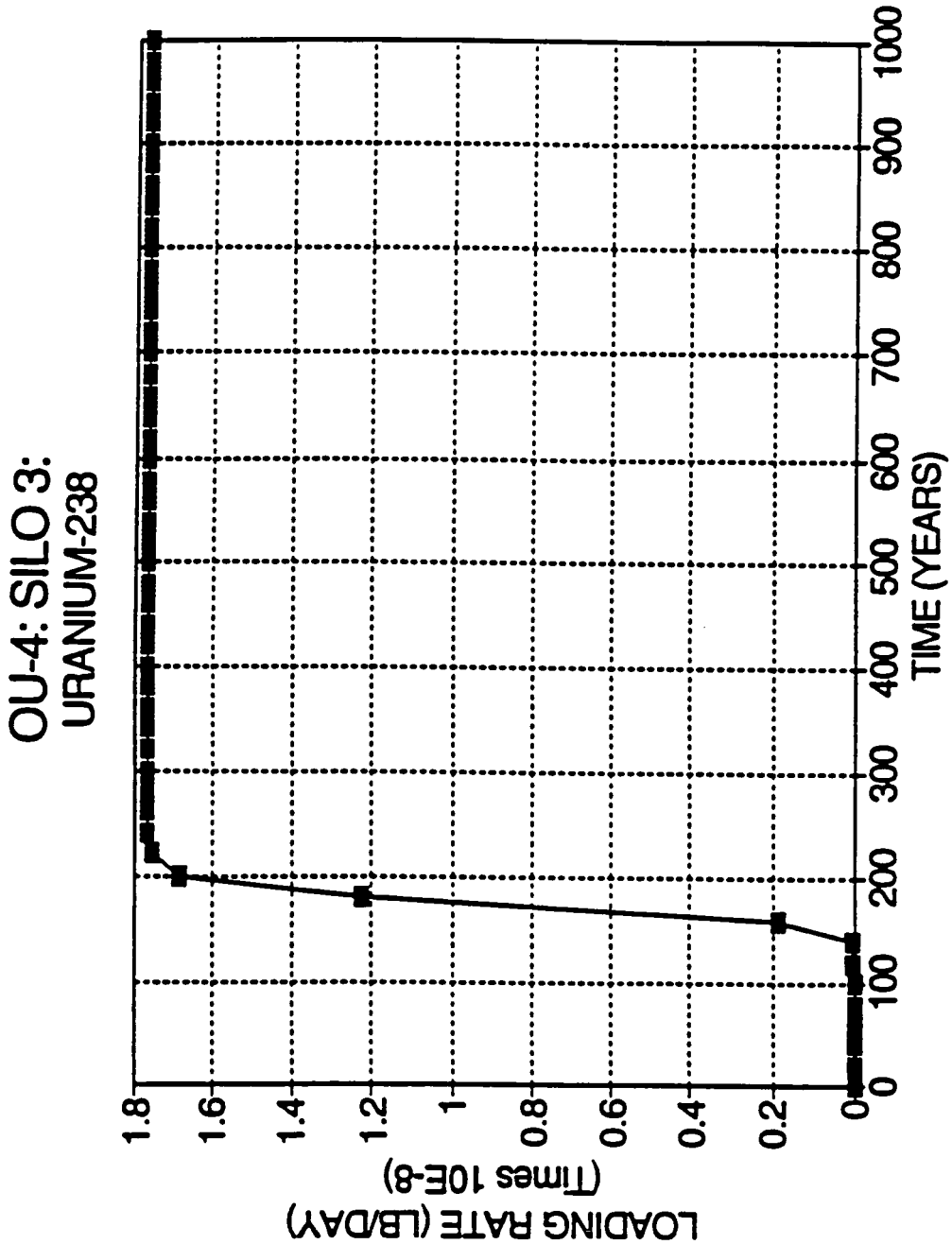

FIGURE E.2-4. PROJECTED MASS LOADING OF URANIUM-238 INTO THE GREAT MIAMI AQUIFER FROM SILO 3

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902 A FNO4RI9 OU4 OR

human health from the ingestion of water from the Great Miami Aquifer. The modeling of contaminant migration through the vadose zone to the Great Miami Aquifer revealed that the peak concentrations of some constituents reaching the aquifer can be expected to be quite low. These concentrations would be further diluted in the aquifer. Consequently, the modeling of these contaminants in the aquifer was not considered justifiable for the human health risk assessment.

The decision to model a constituent in the aquifer was based on whether the concentration in the leachate exceeded a predetermined screening level. The concentration in the leachate (before dilution in the aquifer), capable of producing a 10^{-7} lifetime risk of cancer, was selected to be an appropriate and conservative screening level. These screening levels are presented in Tables E.2-8 and E.2-9 to provide a basis for selection of the constituents to be used for aquifer modeling. If the predicted concentration of a given constituent as it enters the aquifer equals or exceeds the respective screening level concentration, the constituent was selected for aquifer modeling. From Tables E.2-8 and E.2-9, it can be observed that the maximum loading concentration of uranium from Silos 1 and 2, and from Silo 3, exceeds the screening level. All other compounds either do not reach the aquifer or do not produce significant risk levels. This matches current interpretations of the groundwater of the FEMP which show uranium to be the primary constituent of concern in the groundwater. Other radionuclides such as radium and thorium have not been detected in the groundwater system and do not appear to be transported through the vadose zone. This agrees with the modeling results which indicate that these compounds attenuate in the glacial overburden due to their high retardation factors. Other compounds such as heavy metals and organics have been detected in the groundwater, but only at low levels, particularly within Operable Unit 4. This field observation also agrees with the results of the vadose zone models, which predict these compounds to reach the aquifer only in low concentrations.

E.2.6 AQUIFER MODELING

E.2.6.1 Description of Model, Background, and Development

Groundwater modeling for the Operable Unit 4 risk analysis was performed with the calibrated groundwater flow model for the FEMP. This model utilizes the SWIFT III (Geotrans 1987) code and was previously calibrated using groundwater elevations obtained during the April 1986 monitoring period. A brief summary of the calibration and the results of the calibration are presented in this section.

The groundwater modeling program was initiated to define groundwater transport in and around the FEMP. The selection, verification, calibration, and results of groundwater modeling are presented in two separate reports (IT 1990 and DOE 1990). The groundwater model used in support of the risk analysis is a finite-difference computer model of groundwater flow and solute transport. The computer program used is SWIFT III, version 2.25. A detailed presentation of the model, its development, and the baseline input data was issued as a part of the overall modeling report prepared under the RI/FS

(DOE 1990). Only the most pertinent information is presented here. A comprehensive verification study of the SWIFT III code has also been completed and a report issued (DOE 1990).

Steps in the development of the model for application to the FEMP have included:

- Construction and calibration of a regional, two-dimensional, steady-state groundwater flow model
- Construction and calibration of a regional, three-dimensional, steady-state groundwater flow model
- Application of a local, two-dimensional, analytical solute transport model to help strategize the numerical solute transport model
- Construction of a local, two-dimensional, transient solute transport model
- Construction and calibration of a local, three-dimensional, transient solute transport model with uranium concentration data from the monitoring wells

The regional model covers an area of 28.7 square miles (74.3 km^2), including the FEMP, the Southern Ohio Water Company (SOWC) collector wells, and a portion of the Great Miami River. The regional model's grid spacing varies between 250 ft and 2000 ft (76 m and 610 m), and has the closest grid spacing in the area of the SOWC collector wells. It was calibrated against field data using a steady-state flow condition, and calibration results were incorporated into the local area model.

The local model covers a smaller area than the regional model and uses a tighter grid spacing, with grid cells 125 ft (38 m) on a side. The smaller grid was established to include the area of the existing uranium plume, and extends from the northern part of the FEMP to approximately 1500 ft (460 m) north of the Great Miami River (Figure E.2-5). The grid size was selected based on the need to simulate a uranium dispersivity of 100 ft (30 m) longitudinally, which was the preferred value based on literature review (IT 1990). Using this dispersivity value, the grid size was selected to accommodate dispersivity values as low as 62.5 ft (19 m), or half the distance of the local grid area of 125 ft (38 m). The relationship between the local and regional models was established by imposing the steady-state flow field predicted by the regional model onto the local solute transport model.

The regional and local models each contain five layers. The uppermost two layers represent the upper and lower parts of the upper Great Miami Aquifer that underlies the area. The middle layer represents a clay interbed that is present in the immediate vicinity of the FEMP site, and the lowermost two layers represent the upper and lower parts of the Great Miami Aquifer. In regions where the clay interbed is not present, the middle layer has the same characteristics as the upper two layers. The layers extend laterally into bedrock to the edges of the buried valley that contains the aquifer. The number of aquifer cells in each layer was decreased with depth in the aquifer to simulate the

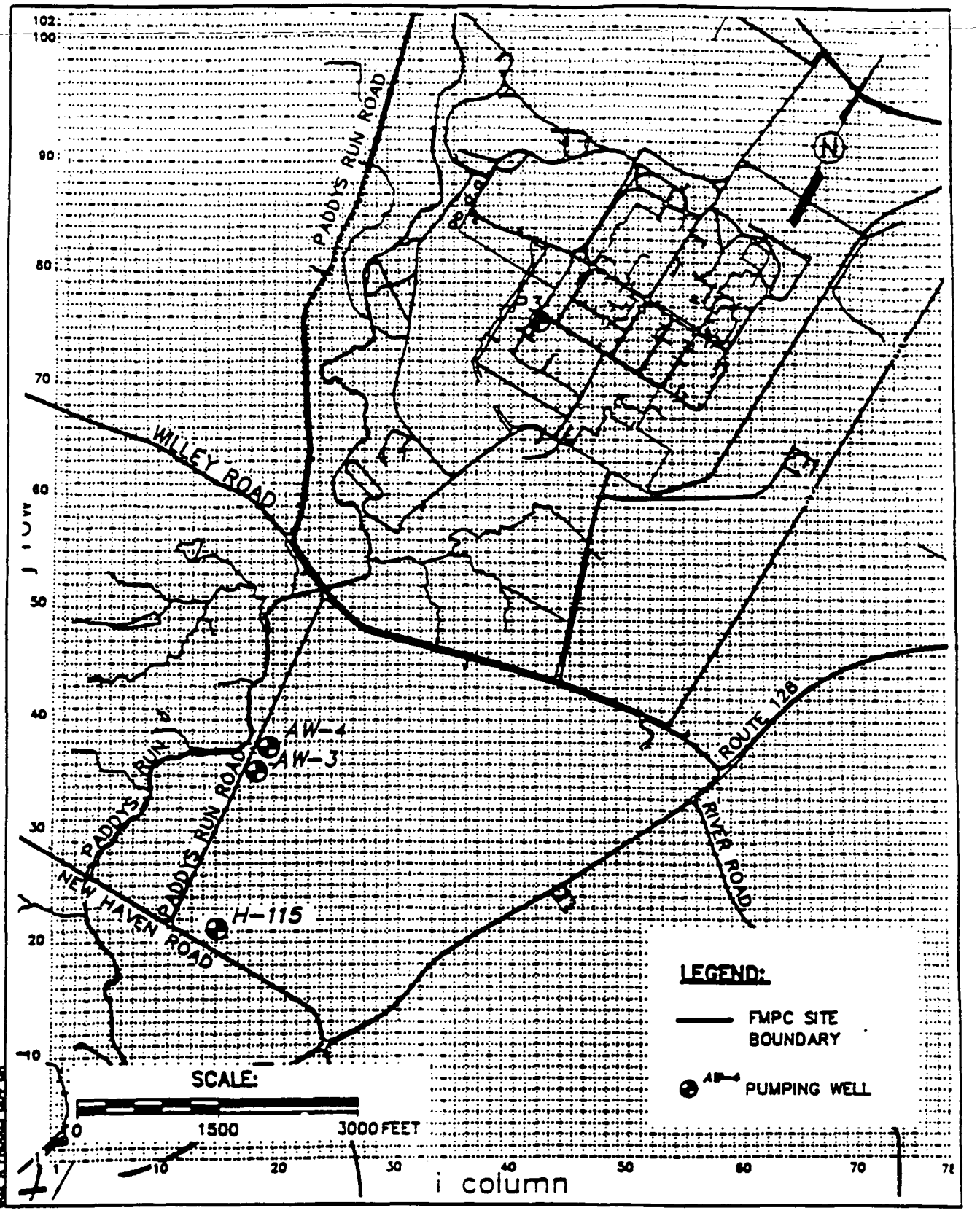

FIGURE E.2-5. SWIFT III LOCAL AREA MODEL GRID

narrowing bedrock valley. This was done using bedrock topography maps of the region and simulated the U-shaped buried valley which contains the Great Miami Aquifer.

Pumping wells are located in the area spanned by both the regional and local models. These include a FEMP production well and three industrial wells located south of the FEMP site in both models. Pumping from each of these wells was assigned to the proper cell and layer in the model. In addition, the regional model also simulates the presence of two large capacity collector wells owned by the SOWC located by the Great Miami River. Although they are not directly included in the local model, they do influence its results by way of the boundary conditions brought in from the regional model.

The calibration of the groundwater flow model was performed by comparing hydraulic heads calculated by the model against heads measured in numerous monitoring wells throughout the FEMP and surrounding areas. This calibration was performed using the regional flow model. Reasonable estimates of hydraulic conductivity and recharge were initially input into the model and then varied within an acceptable range to adjust model-computed heads into agreement with observed monitoring well heads. Calibration data used are presented in the draft Groundwater Report (DOE 1990).

The model used varying hydraulic conductivity values for the five layers based on the results of the calibration. The uppermost and middle layers were assigned hydraulic conductivity values of 450 ft per day (140 m/day), and the lowermost layers used 600 ft per day (180 m/day). In addition, a portion of the middle layer which underlies the FEMP was assigned 0.0003 ft per day (9×10^{-5} m/day) as a hydraulic conductivity value to represent the clay interbed (as shown by geologic borings). This simulated the presence of a low permeability clay and created a semi-confining layer underneath part of the FEMP and its surrounding area.

Recharge rates set as a result of the regional model calibration and presented in the draft Groundwater Report (DOE 1990) were assigned to several different zones. In areas where the sand and gravel aquifer is overlain by glacial overburden, a recharge of 6 in. per year (0.15 m/yr) was used. Regions where the Great Miami Aquifer is exposed at the surface use 14 in. per year (0.36 m/yr), with Paddys Run channel being assigned a value of 32 in. per year (0.81 m/yr) in the local model to simulate its increased infiltration. An additional region, the area covered by the FEMP was also included as a consequence of the sensitivity analysis. This region was assigned a value of 2 in. per year (0.05 m/yr) to simulate the developed nature of the site and the effects of stormwater drainage into the storm sewer system.

Groundwater flow conditions simulated by the model were successful and reproduced the observed flow conditions throughout the study area. Based on water levels from 55 wells, the arithmetic mean residual (observed head minus calculated head at the monitoring well) for the calibrated flow model was 0.33 ft (0.1 m). The excellent match portrayed by this residual value is realized when compared

to a total change in hydraulic head of approximately 20 ft (6.1 m) over the modeling area. The mean of the absolute values of the residuals was 1.08 ft (0.33 m), with a standard deviation of 1.36 ft (0.41 m). Water balances performed using the model showed total inflow and total outflow from the model to agree within 0.2 percent.

To maintain hydraulic similarity between the regional and local flow models, a computer program was used to check, cell by cell, the correspondence of heads in the local model with heads in the regional model. The program verified that the regional flow model calibration was preserved in the local model which was used for solute transport; thus, no new flow calibration was necessary. The local model used hydraulic parameters identical to those used in the calibrated regional model. Boundary conditions for the local model were set from corresponding cells in the regional model to maintain the hydraulic similarity.

E.2.6.2 Saturated Flow Modeling For Operable Unit 4 Risk Assessment

Saturated flow modeling for the Operable Unit 4 risk analysis was initiated by dividing each of the loading curves generated by the vadose zone modeling into loading periods. As stated previously, the lengths of the loading periods were varied based upon the change in loading experienced by each compound. Loading rates for each period were calculated by averaging the results of the vadose zone modeling over the length of each period. In this way, total mass inflow into the aquifer was maintained.

Loading rates were assigned to each of the two potential source areas in the model and were adjusted to account for the varying surface area occupied by each waste area. Model source areas were calculated by dividing the area of the actual source by the area of a model grid cell, which is 125 ft (38 m) on a side (a total of 15,625 square ft [1450 m^2]). This defined the number of cells needed for each source area in the model as shown in Table E.2-10. Cells in the model were then assigned to each source area to correspond with the physical location of the source. The loading rate for each compound was then divided by the number of model cells in each source area to derive the adjusted loading rate for each cell in the source area.

In the case of U-234, U-235, and U-238, all three uranium isotopes were modeled as one compound to simplify the modeling and to allow the use of the previously calibrated total-uranium solute transport model. Because the previous model utilizes total-uranium and because the uranium at the FEMP is mostly U-238 (approximately 99 percent by mass), this approach was used.

Initial background concentrations of each compound in the aquifer were set at zero, with the exception of uranium, which used the results of the calibrated local solute transport model for uranium at the FEMP to set initial concentrations. The construction, calibration, and results of this model have been presented in a previous report (DOE 1990) and will not be presented here. The uranium concentra-

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TABLE E.2-10

OPERABLE UNIT 4
SOURCE AREAS FOR FEMP AQUIFER MODEL

Location	Area m^2	Area (ft^2)	Number of Cells for Modeled Area
Silos 1 and 2 (K-65 Silos)	934	(10,054)	1
Silo 3 (Metal Oxide Silo)	467	(5,027)	1

tions for model Layer 1 (the uppermost layer) from the calibrated solute transport model are shown in Figure E.2-6.

The model simulations for the compounds at the FEMP used dispersivity values of 100 ft (30 m) longitudinal and 10 ft (3 m) in the transverse direction. These values were determined during the solute transport calibration for uranium and are based on values taken from the literature review (DOE 1990; Walton 1984).

Model simulations were done using SWIFT III on a Prime EXL325 minicomputer. Simulation execution times varied between 60 and 170 hours, and required extensive computing capacity. Output was written to a single file from which relevant data was extracted using data manipulation programs written for that purpose.

Contour plots were made for selected constituents at different simulation times. Figures E.2-7 through E.2-15 illustrate the change in uranium concentration in the groundwater beneath the FEMP due to loading from Silos 1 and 2. Figures E.2-16 through E.2-21 illustrate the change in uranium concentration in the groundwater beneath the FEMP due to loading from Silo 3. From Figures E.2-7 through E.2-21, it can be observed that the contaminant plume is moving towards the south and southeasterly direction. This flow direction is somewhat influenced by the water supply wells located east of the facility. It can be observed from the contour plots, illustrating the change of uranium concentration in the groundwater beneath the FEMP due to loading from Silos 1 and 2, that the concentration of the uranium at the FEMP boundary is above the screening level. Contour plots from Silo 3 shows uranium concentration at the FEMP boundary below the screening level. The difference in the leachate concentration (source term value) is the main reason.

No other radionuclide contaminants, although present in abundance in the silos, are projected to reach the Great Miami Aquifer due to high absorption coefficients of these constituents and the presence of a thick layer of unweathered till beneath the silos. The boron, cyanide, and mercury from Silos 1 and 2, and only mercury from Silo 3, are the only inorganic compounds that are projected to reach the aquifer but with maximum concentrations below their screening levels. Similarly, 2-hexanone and benzoic acid are the only organic compounds that are projected to reach the aquifer within the simulation period of 1000 years, but with concentrations less than the screening values.

In general, contaminants with low retardation factors reach the Great Miami Aquifer earlier than the contaminants with high retardation factors. Uranium is projected to arrive in the aquifer within 140 years due to loading from either of the Silos 1 and 2, or Silo 3. The contaminants that reach the aquifer are diluted and move laterally toward the site boundary. The maximum concentrations at the FEMP boundary that exceed the screening levels are the uranium isotopes from Silos 1 and 2.

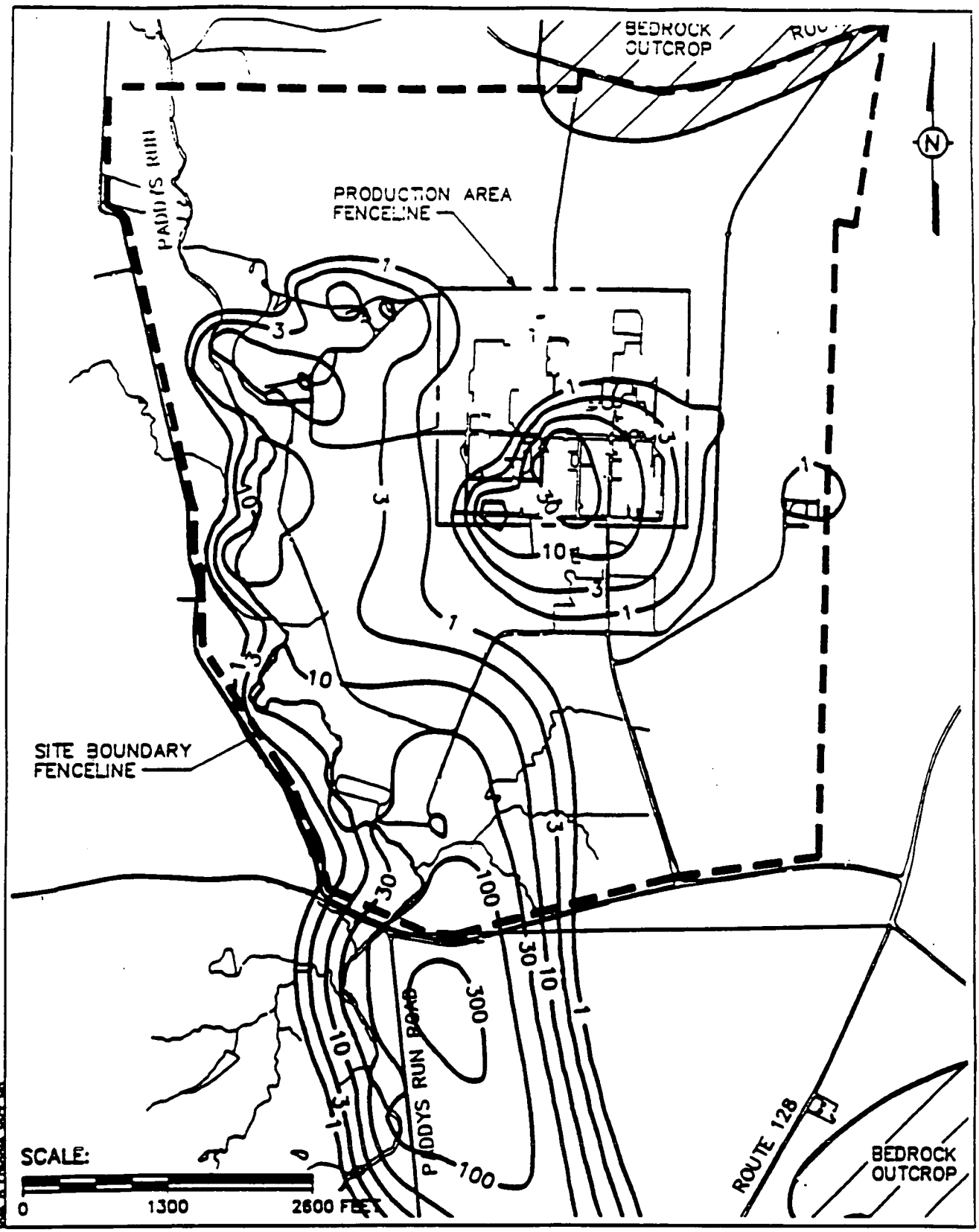


FIGURE E.2–6. INITIAL CONCENTRATION (ppb) OF URANIUM IN GROUNDWATER BENEATH THE FEMP

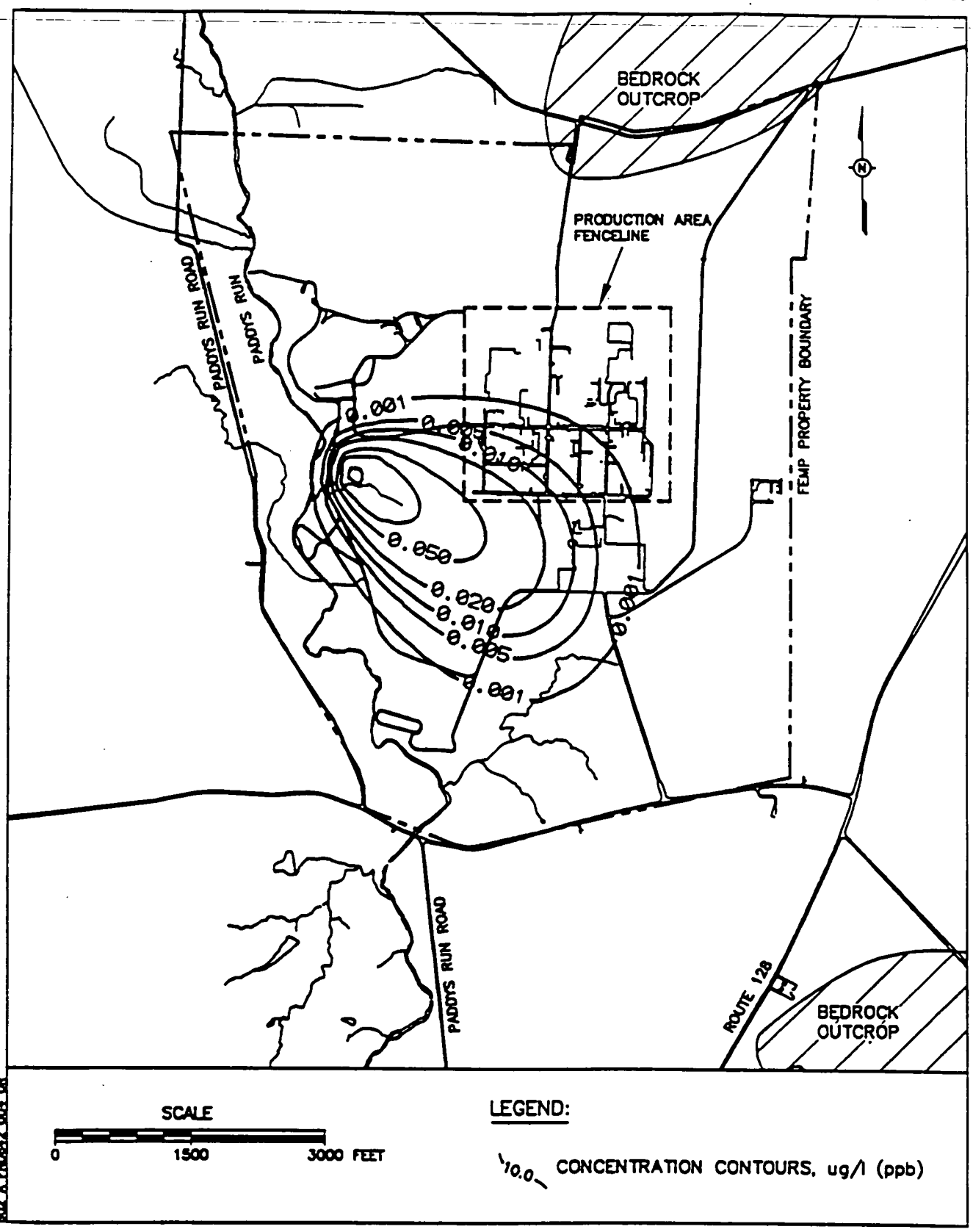


FIGURE E.2-7. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 200 YEARS DUE TO LOADING FROM SILOS 1 AND 2

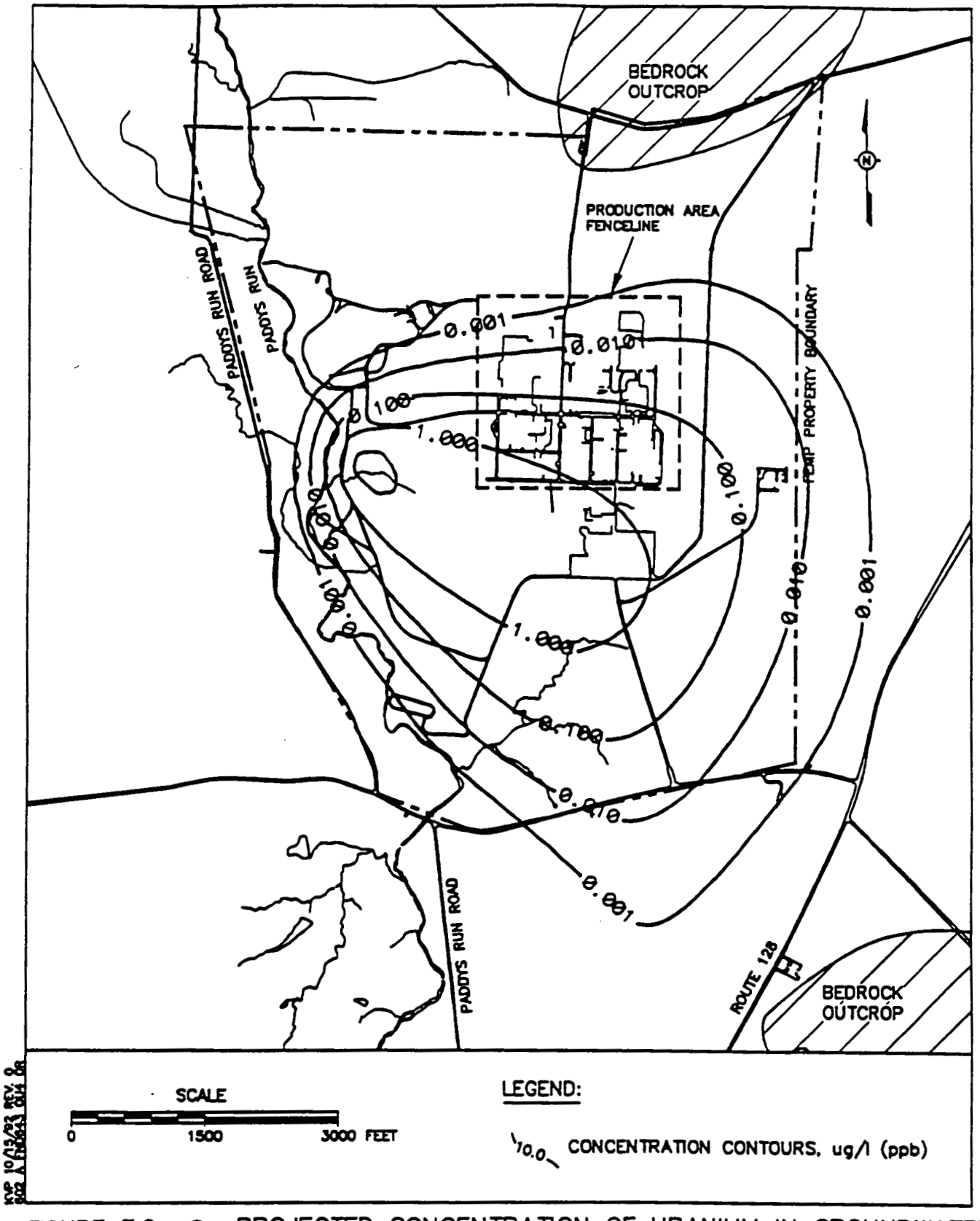


FIGURE E.2– 8. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 300 YEARS DUE TO LOADING FROM SILOS 1 AND 2

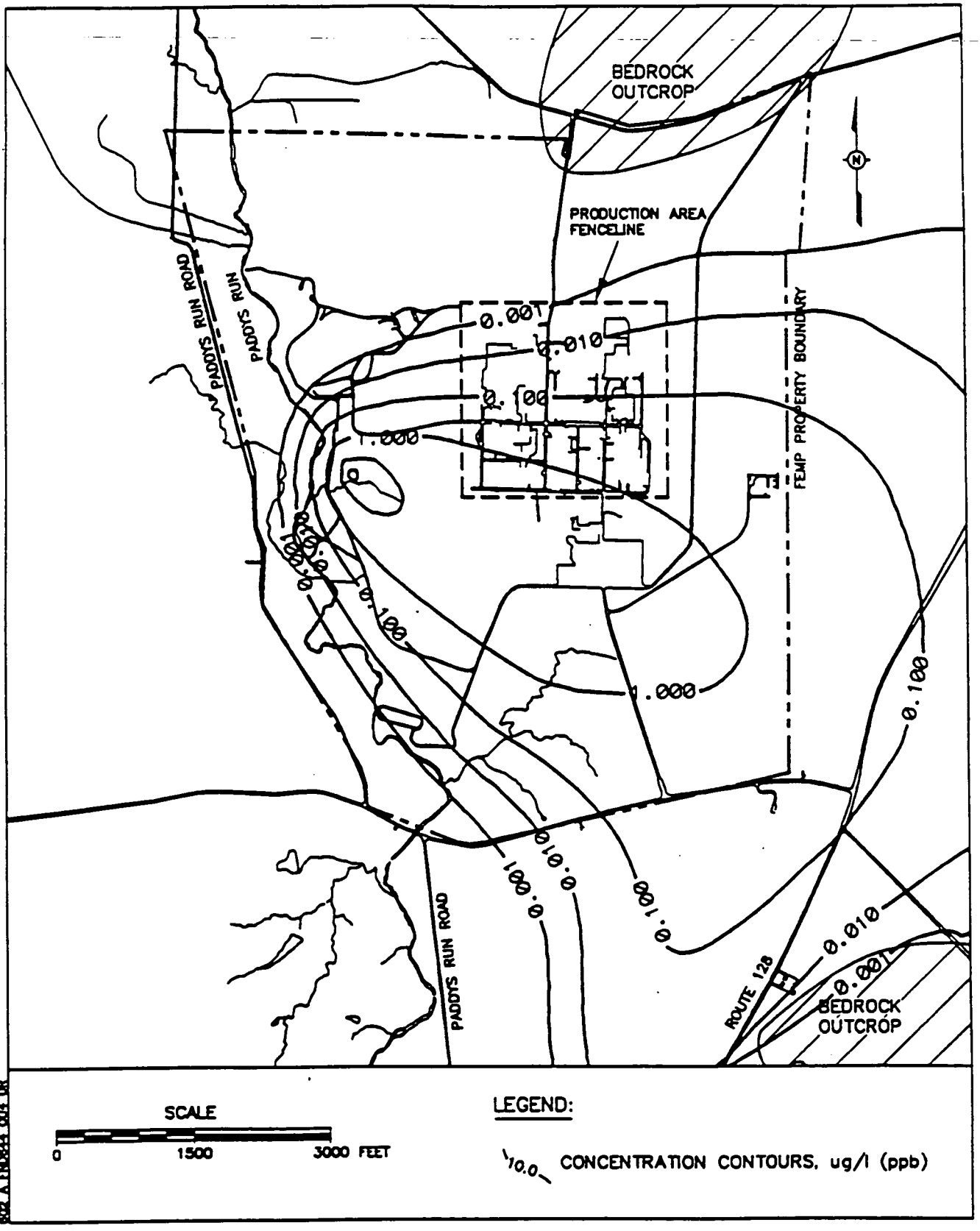


FIGURE E.2-9. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 400 YEARS DUE TO LOADING FROM SILOS 1 AND 2

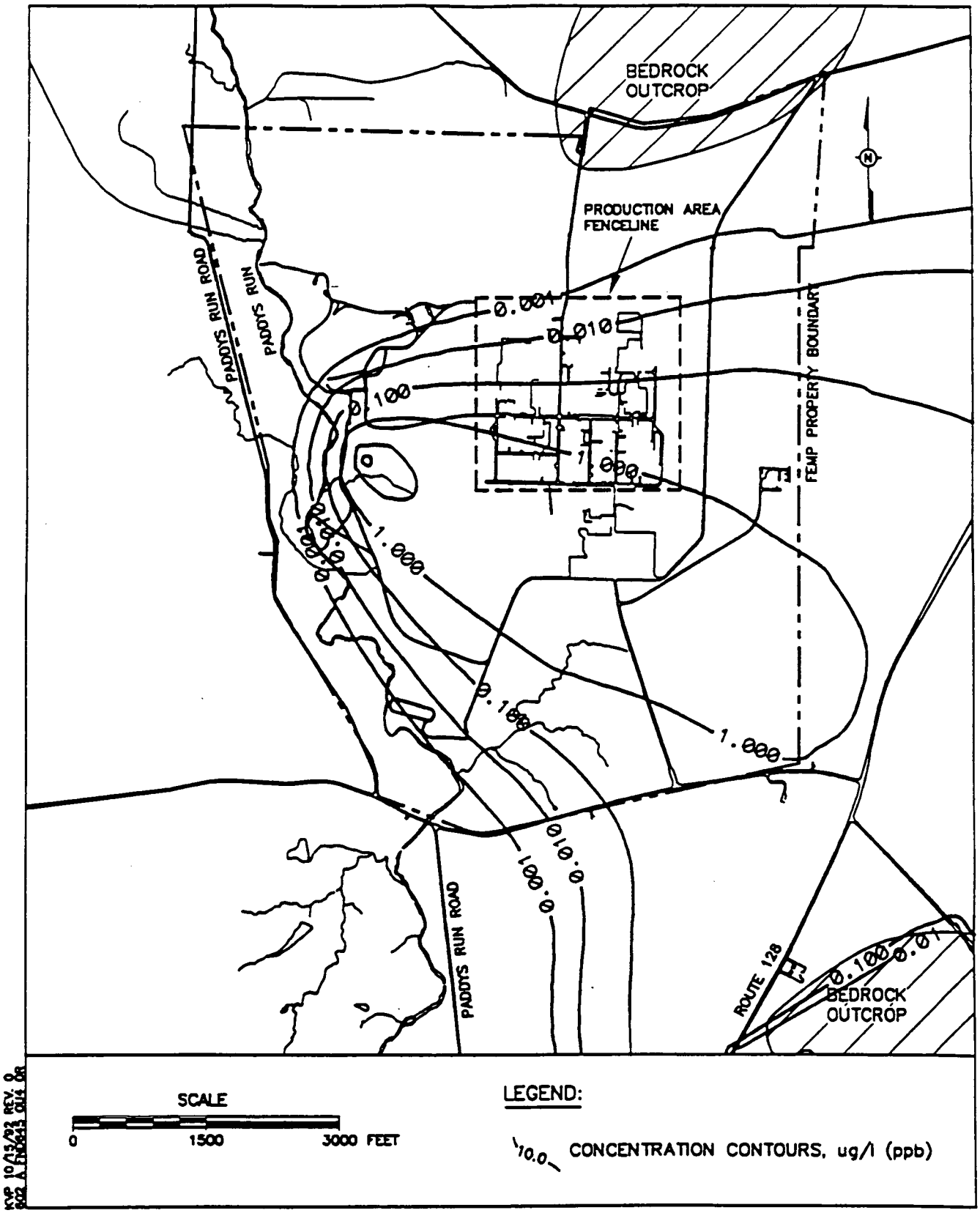


FIGURE E.2-10. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 500 YEARS DUE TO LOADING FROM SILOS 1 AND 2

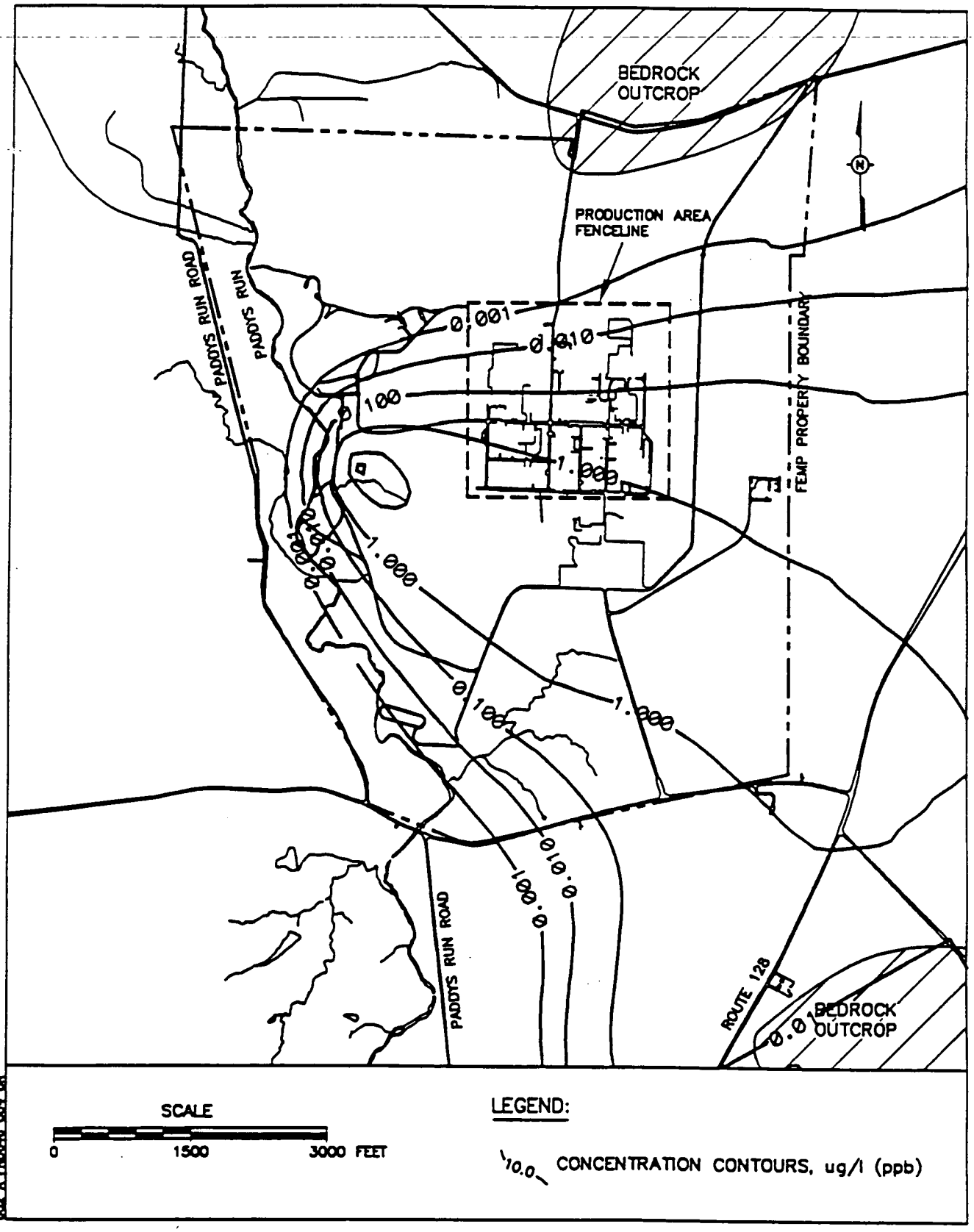


FIGURE E.2-11. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 600 YEARS DUE TO LOADING FROM SILOS 1 AND 2

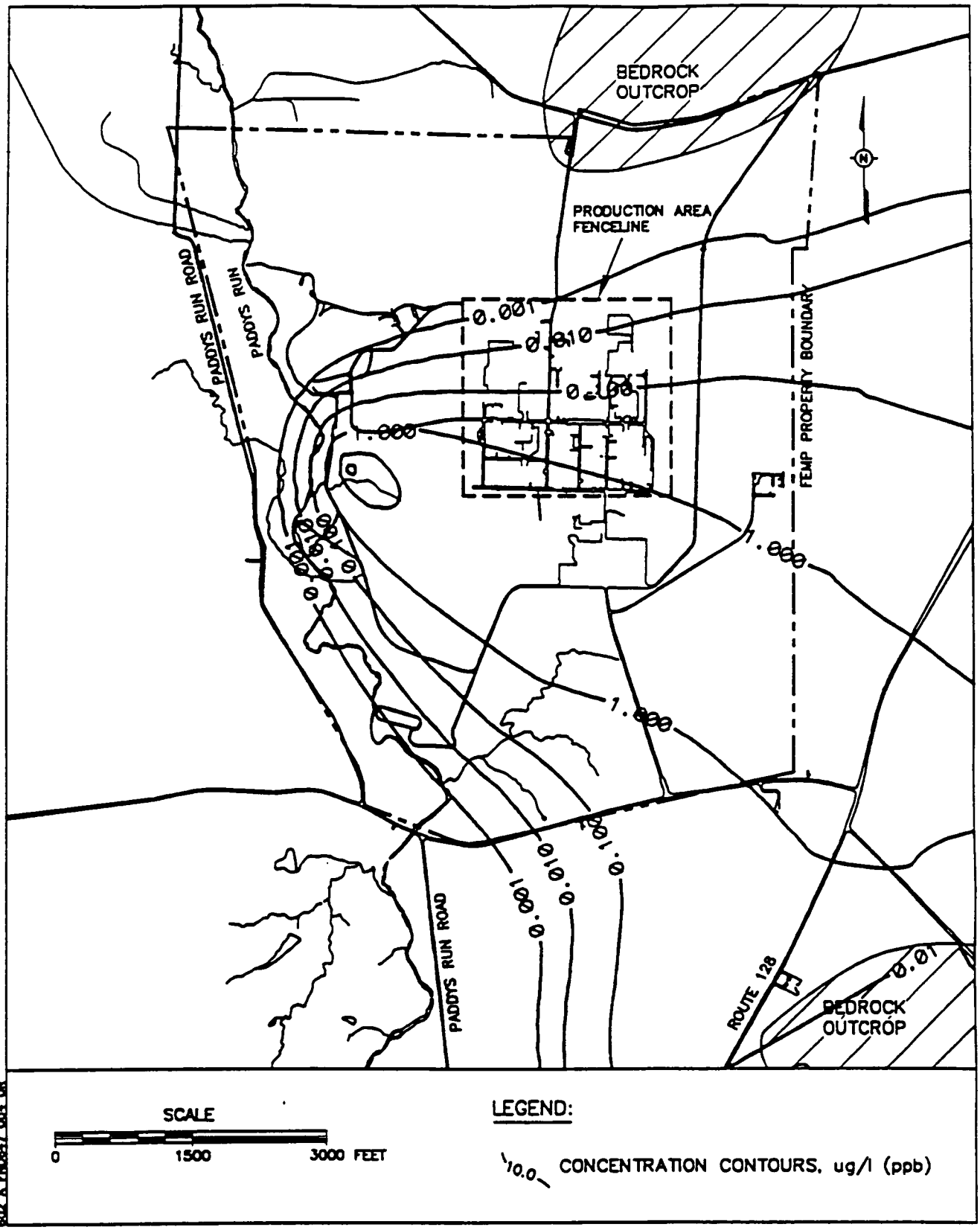


FIGURE E.2-12. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 700 YEARS DUE TO LOADING FROM SILOS 1 AND 2

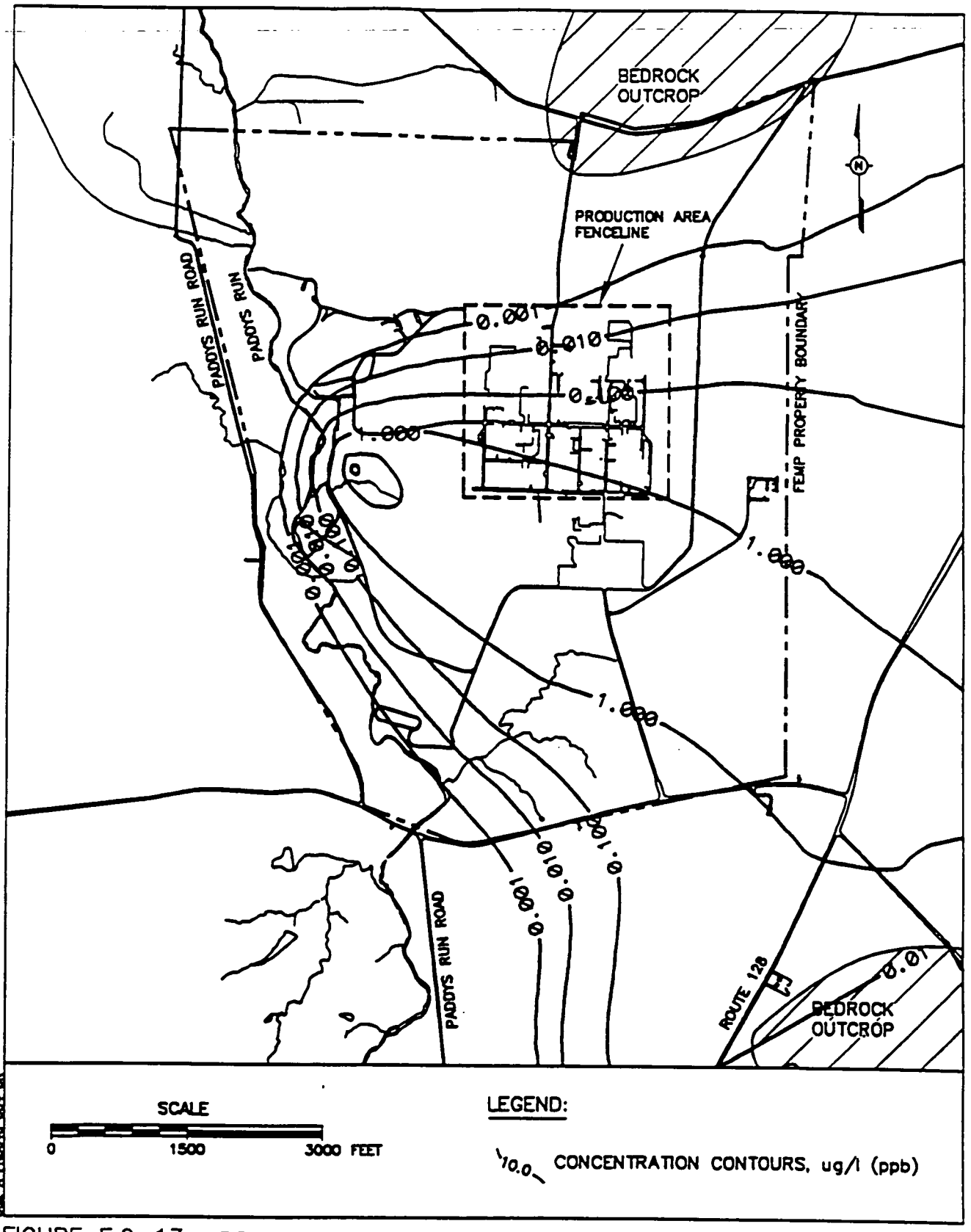


FIGURE E.2–13. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 800 YEARS DUE TO LOADING FROM SILOS 1 AND 2

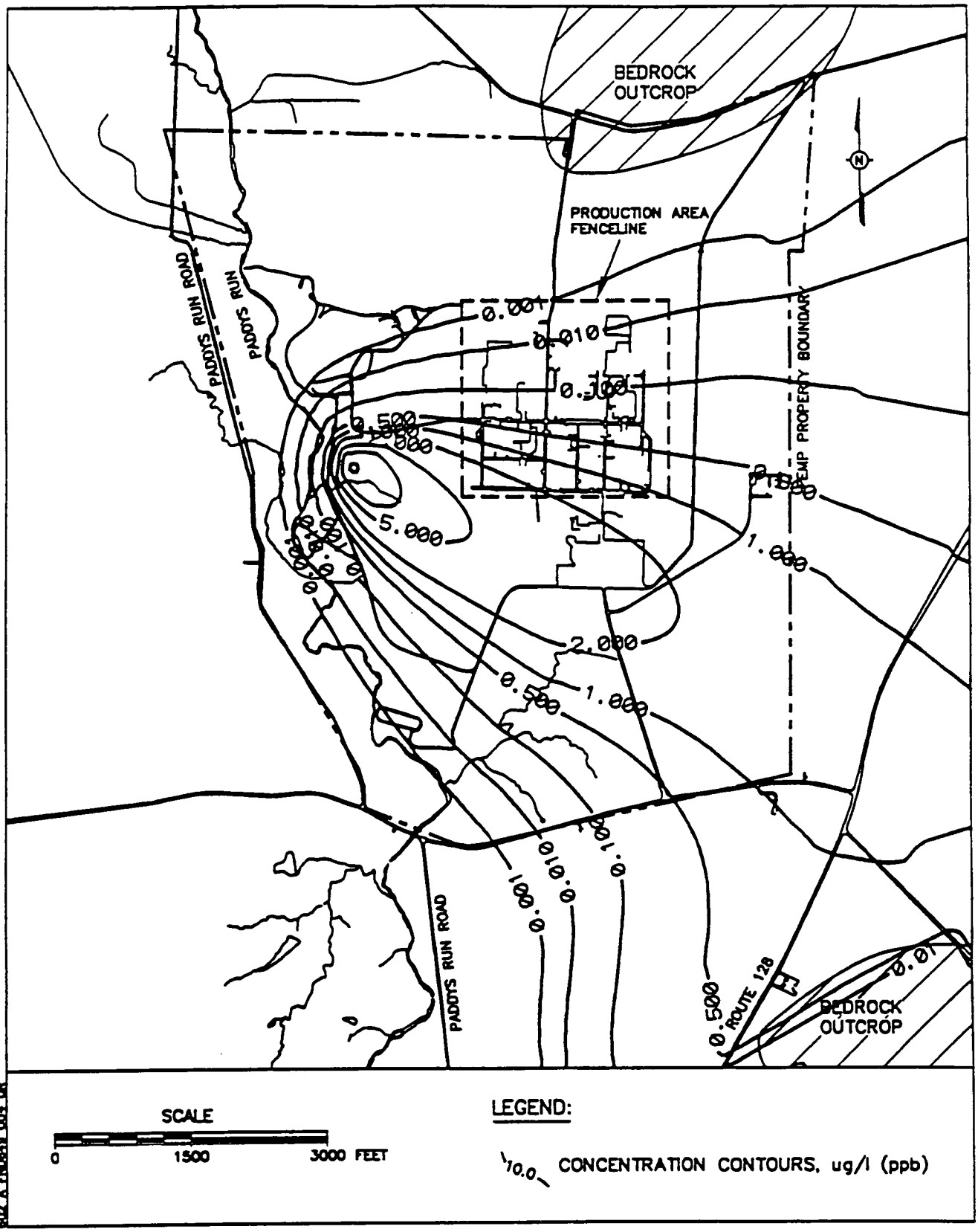


FIGURE E.2-14. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 900 YEARS DUE TO LOADING FROM SILOS 1 AND 2

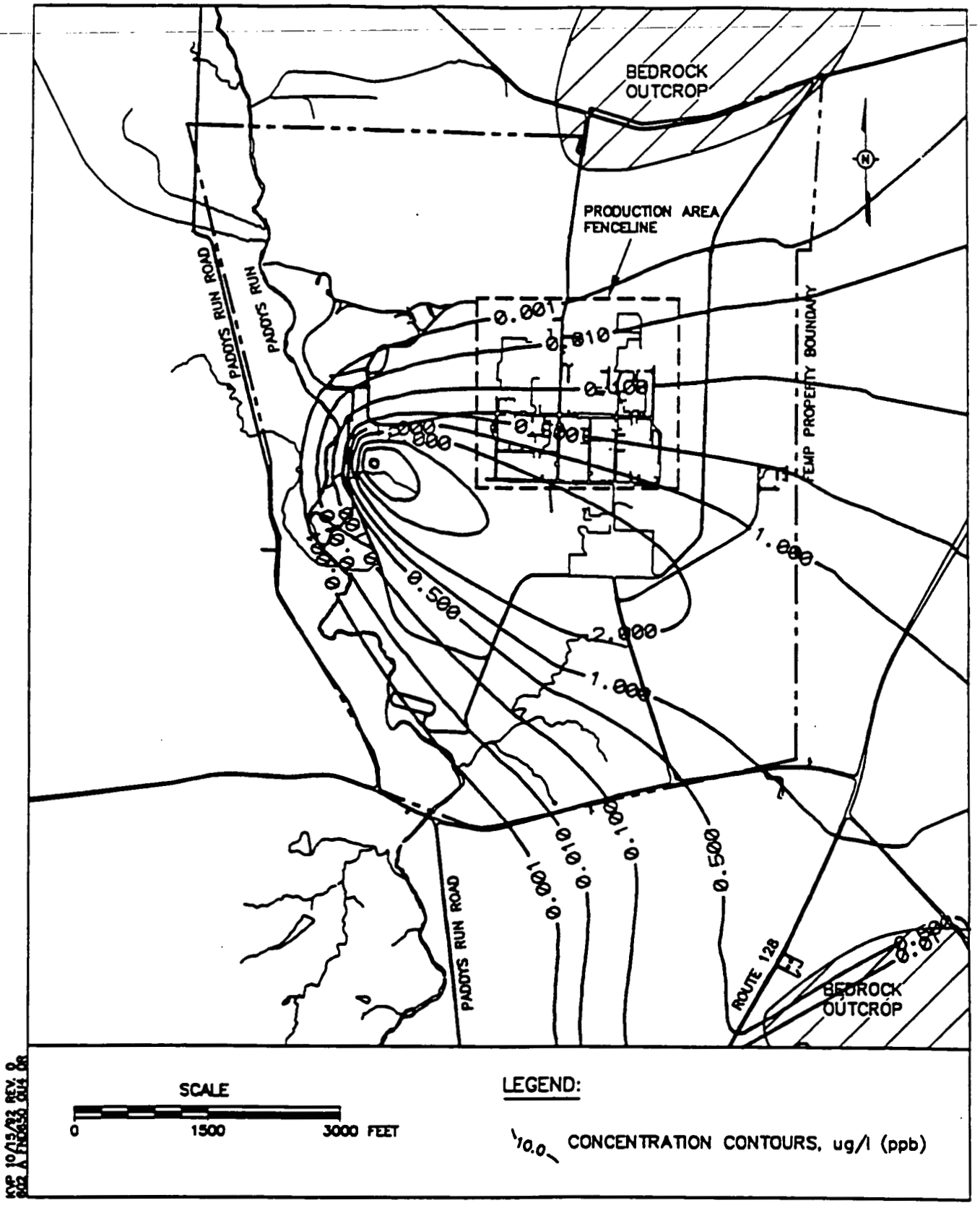
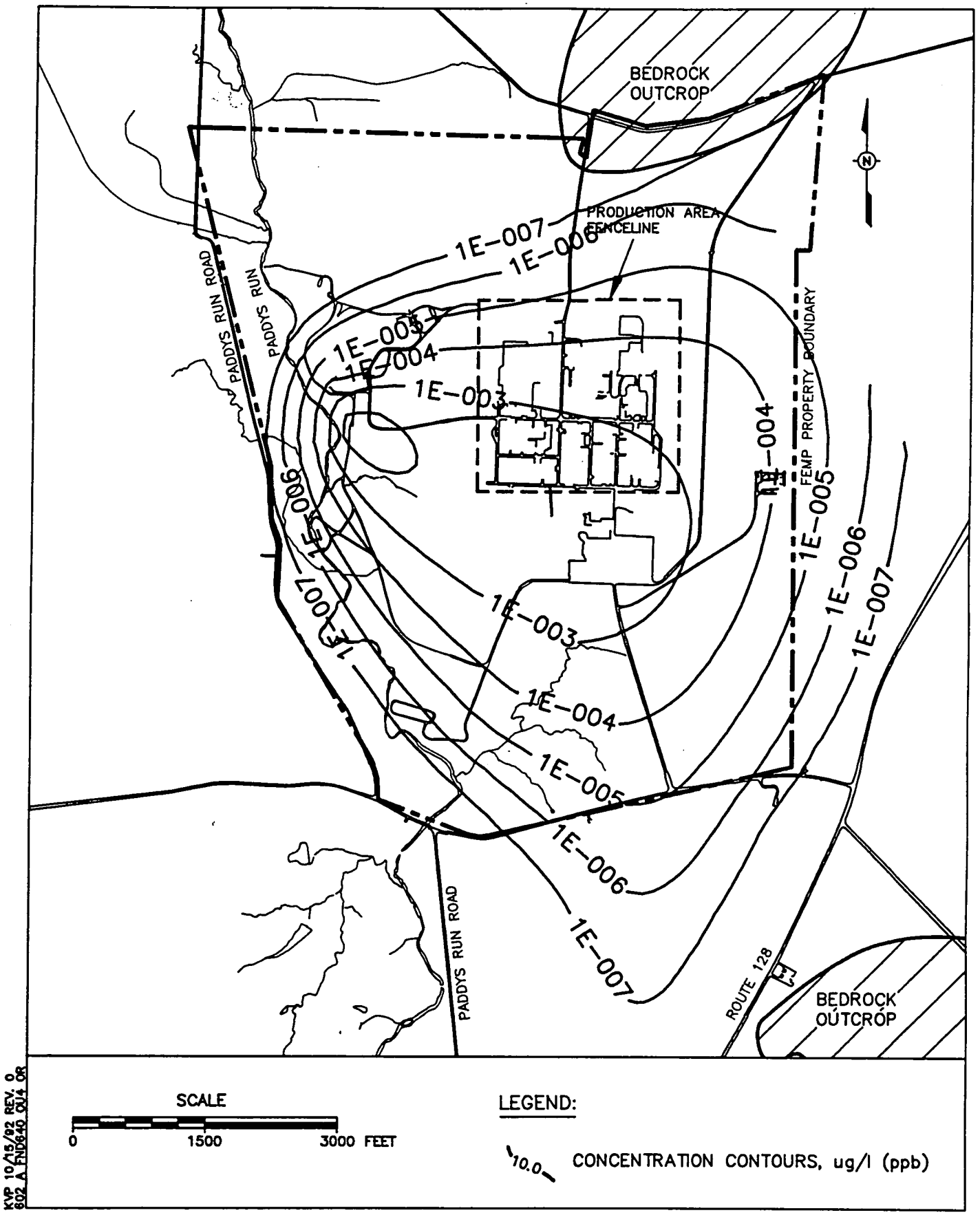
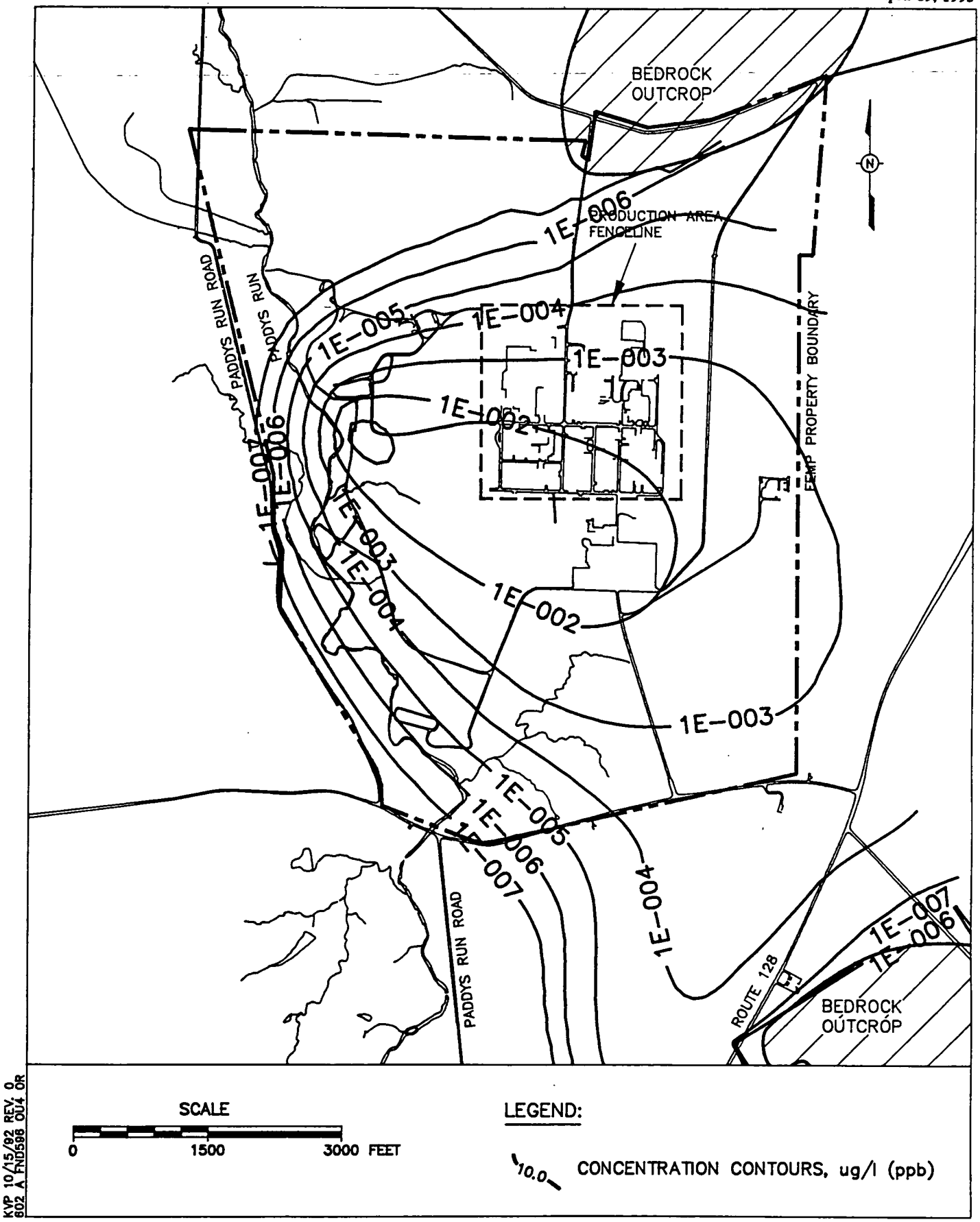


FIGURE E.2–15. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 1000 YEARS DUE TO LOADING FROM SILOS 1 AND 2



KVP 10/15/92 REV. 0
602 A FND640 OU4 OR

FIGURE E.2-16. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 400 YEARS DUE TO LOADING FROM SILOS 3



KVP 10/15/92 REV. 0
602 A FND596 OU4 OR

FIGURE E.2–17. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 500 YEARS DUE TO LOADING FROM SILOS 3.

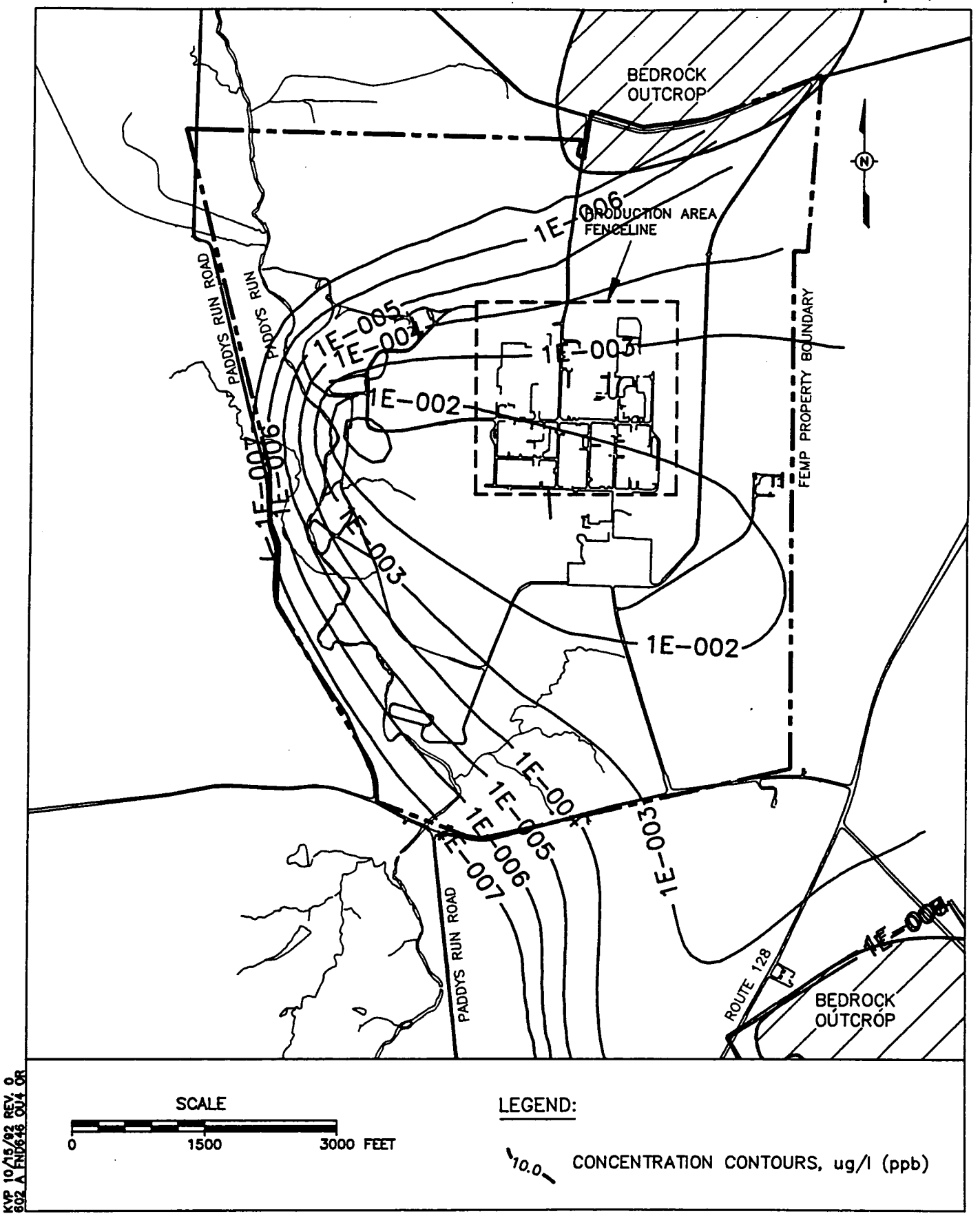
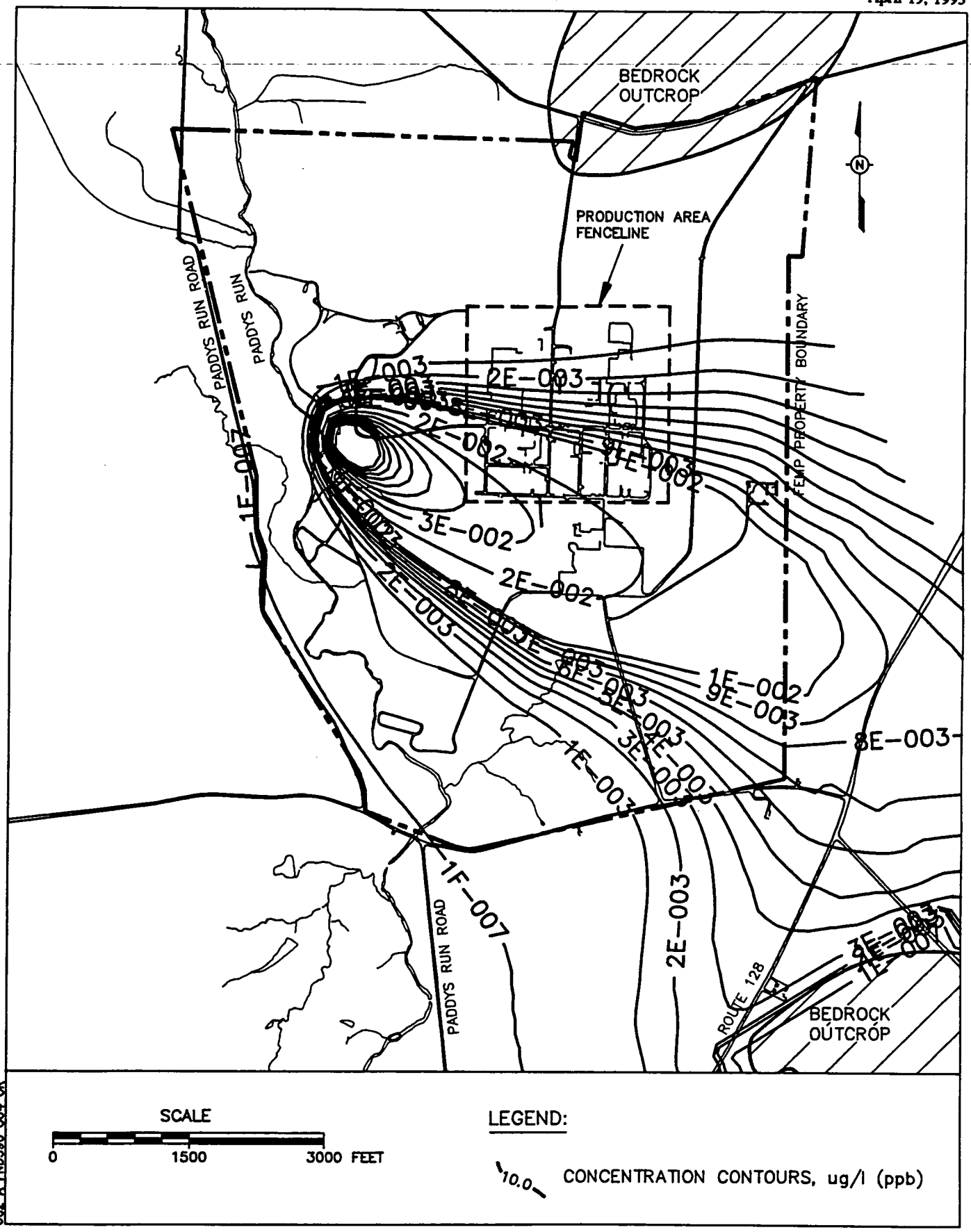
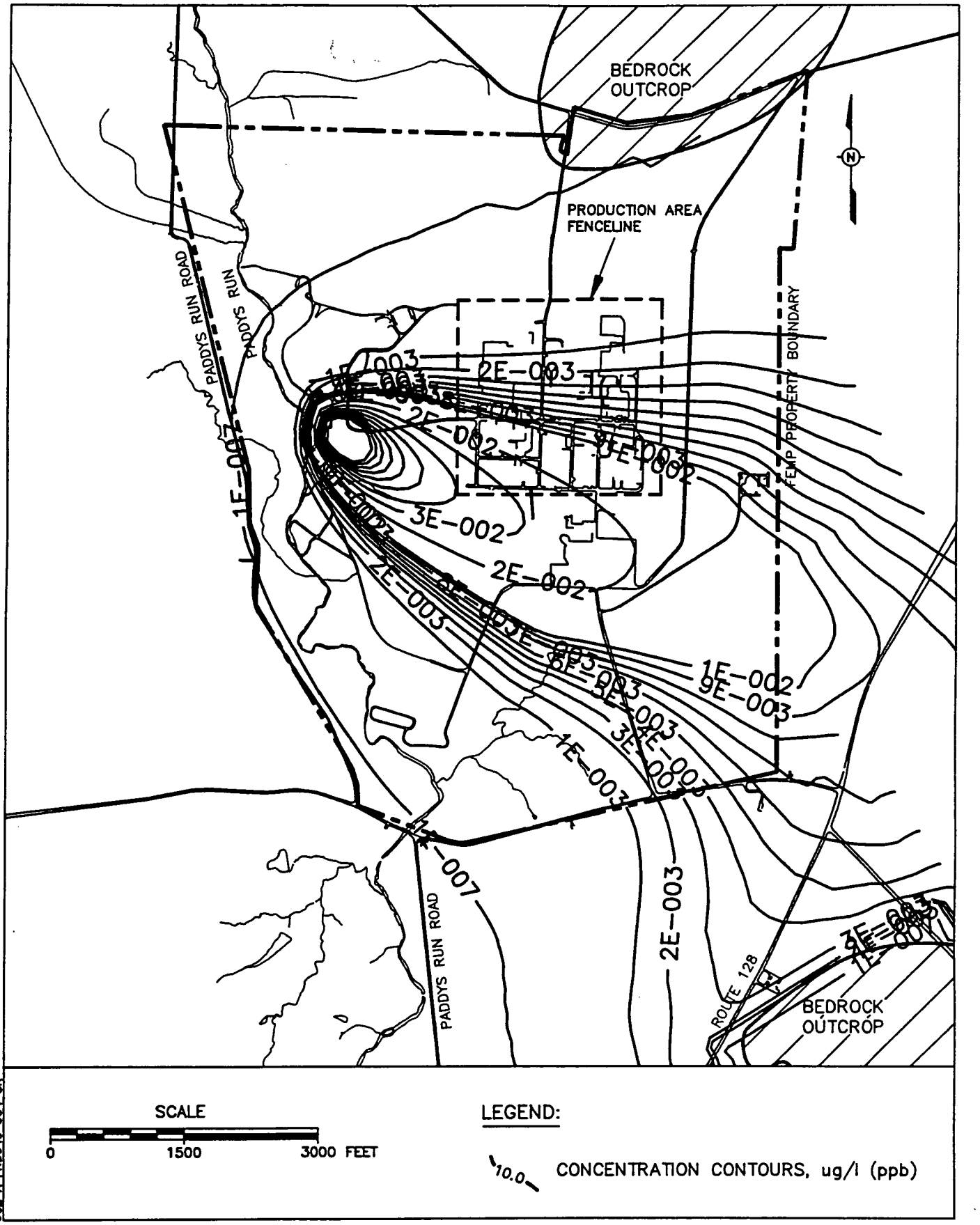


FIGURE E.2-18. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 600 YEARS DUE TO LOADING FROM SILOS 3



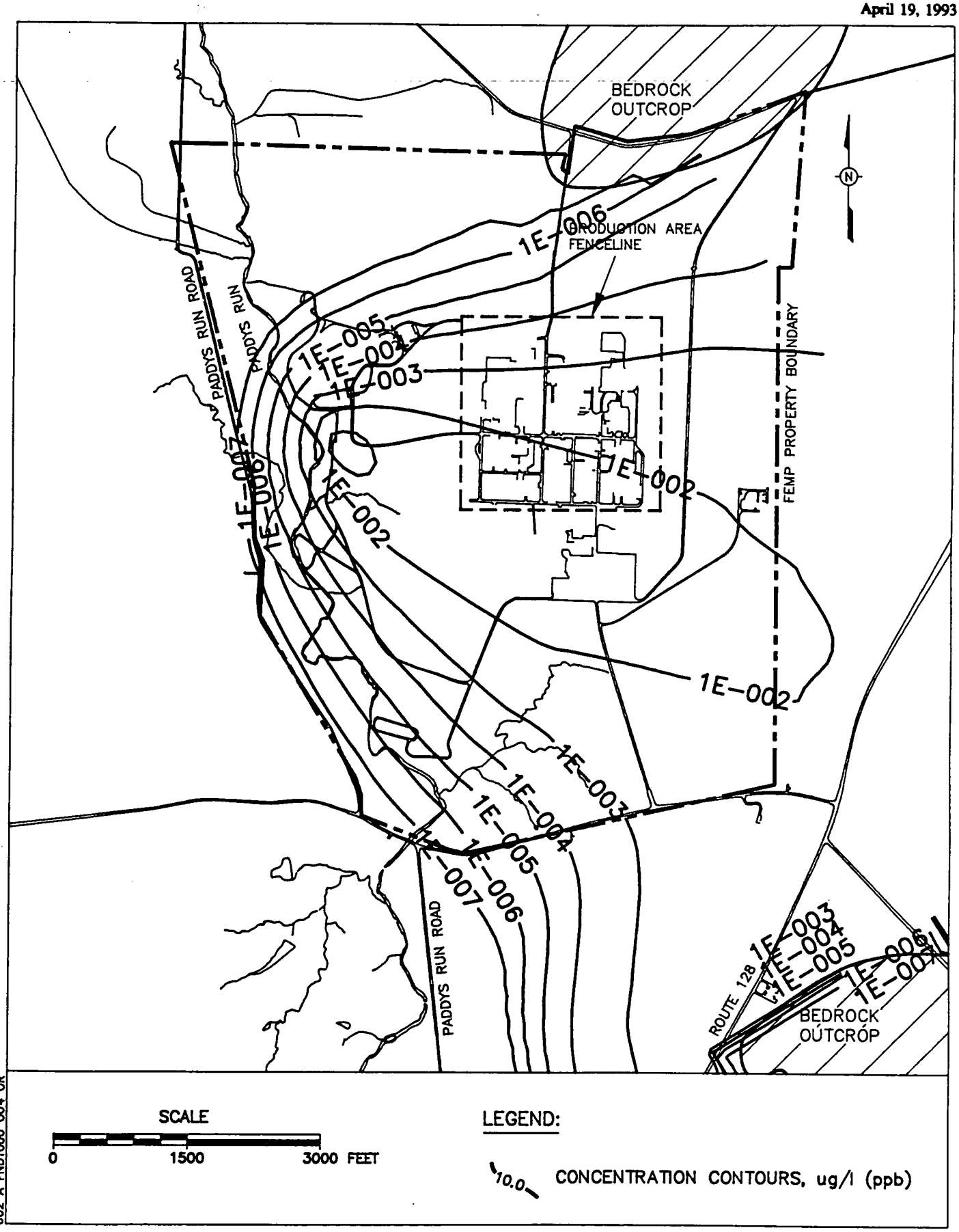
KVP 10/15/92 REV. 0
902 A FND590 OU4 OR

FIGURE E.2-19. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 800 YEARS DUE TO LOADING FROM SILOS 3



KVP 10/15/92 REV. 0
602 A FND649 QU4 OR

FIGURE E.2-20. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 900 YEARS DUE TO LOADING FROM SILOS 3



KVP 10/15/92 REV. 0
602 A FND1000 OU4 OR

FIGURE E.2-21. PROJECTED CONCENTRATION OF URANIUM IN GROUNDWATER BENEATH FEMP AFTER 1000 YEARS DUE TO LOADING FROM SILOS 3.

The majority of the organic compounds (retardation factor greater than 100) that have been identified as the constituents of concern in Silos 1 and 2 do not reach the aquifer within 1000 years. The organic compounds that are highly soluble (low retardation factors) are projected to reach the aquifer, but due to utilization of biodegradation rates, the concentrations of these compounds are significantly reduced (several orders of magnitude lower than their detection values) and are reported as not reaching the aquifer. Only the organic constituents with concentrations above 10^{-6} µg/L are reported in the summary tables. It should be noted here that the actual retardation factors, and especially the organic decay rates at the FEMP, may not closely follow the assumed literature values (used for contaminant fate and transport modeling), particularly over the long term. Deviations from assumed literature values may significantly affect contaminant fate predictions.

E.2.7 PERCHED LENS TRANSPORT

An alternate pathway for contamination to enter the groundwater system has been found to exist underneath the silos, in the form of a semi-continuous silty/clayey sand lens. This lens has been mapped by the RI boring program and has been correlated both underneath the silos and across Paddys Run (Figure E.2-2). Wells installed into the silty/clayey sand lens have shown it to have a perched water zone and to experience flow towards Paddys Run in the west.

Leachate entering the lens from the silos would experience a shortened transport time to the Great Miami Aquifer due to the relatively higher hydraulic conductivities present in the lens. As leachate enters the lens, an initial dilution with the water already present in the perched zone would occur. Once in the silty/clayey lens, leachate would migrate down gradient and could either enter the Great Miami Aquifer or Paddys Run stream bed. In either case, transport time would be significantly reduced compared to transport through the glacial overburden tills.

Based on recent field data obtained from the silty/clayey sand lens underneath Silos 1 and 2, a dilution calculation was made to determine the potential impact of this pathway on the groundwater system. Assuming the lens underneath the silos is continuous, leachate derived from the silos would enter into the lens and migrate horizontally until it passes into the unsaturated portion of the Great Miami Aquifer. This transport pathway could either be direct or through Paddys Run's stream bed. In either case, dilution would be occurring as leachate enters the lens and mixes with the perched waters already present.

Using data on the lens beneath the silos, a gradient of 0.07 was calculated for horizontal flow in the lens. The len's hydraulic conductivity was estimated to vary between 1×10^{-5} to 1×10^{-1} cm/sec and the porosity between 20 and 25 percent. Using these numbers, a maximum and minimum flow rate for the area of the unit underneath the silos was determined. These flow rates were 0.0288 and 144 $feet^3$/sec through the entire lens underneath Silos 1, 2, and 3.

Dilution ratios from the silos were calculated using these values and the results of the HELP model for the silos (see Attachment E.2-I). Using an average flow rate from all three silos of 0.000162 feet^3/sec dilution factors of 180 to 100,000 times were calculated. This represents the range of possibilities available based on the field data. Data from well 1034 in the vicinity of the silos suggests a hydraulic conductivity of 1 x 10^{-3} cm/sec, indicating a dilution ratio of 180 may be the most realistic.

This dilution ratio indicates only the dilution which occurs as leachate migrates from the silos and enters the silty/clayey sand lens. For off-site receptors, where the leachate would have to enter either Paddys Run or the Great Miami Aquifer to reach them, the dilution would be even higher. Additional dilution ratios of between 100 and 1000 times would occur on top of the dilution ratios already noted. This would greatly reduce the off-site risk level for exposure from the groundwater pathway.

E.2.8 UNCERTAINTY IN MODELING RESULTS

The fate and transport modeling performed for Operable Unit 4 is subject to uncertainty and variability due to factors such as the lack of compound specific characterization data, the inability of the models to simulate natural systems with 100 percent accuracy, and the assumptions for future site conditions for the silos. Of these factors, the assumptions made for the future conditions of the silos have the most impact on the modeling results. The silos are all assumed to fail and release contaminants to the environment as they will be unmaintained. This is a worst case scenario and thus yields higher contamination levels than would be considered if a vegetative cover or cap were developed. However, this type of assumption is the most conservative for the purpose of evaluating the risk from the groundwater pathway.

The inherent assumptions built into the models, and the assumptions made to develop input parameters for the models also have an impact on the final results. The major uncertainty in the analysis is the estimation of parameters related to the attenuation and retardation of constituents. Based upon the data available, a conservative approach was used which may overestimate the concentration of the leachate. The assumption of total contact between the waste and the leaching fluid and no containment of the leachate concentrations will produce higher concentrations than would be anticipated under actual conditions.

Uncertainty was also involved in the computation of seepage flow rates for the glacial till and the unsaturated sand and gravel layer. The unsaturated seepage flow rate is a function of the unsaturated hydraulic conductivity which depends on parameters such as porosity, residual saturation, and pore size distribution index. All of these parameters vary in a physical formation matrix and thus cannot be fully defined for use in a numerical model.

E.2.8.1 HELP

The HELP model is mainly sensitive to the parameters used to define evapotranspiration and runoff. The majority of water exiting the system is lost through one of these two mechanisms, and thus the remaining water becomes the seepage passing through the waste unit. Evapotranspiration is controlled by the plant cover type used, which was assumed to be bare ground for the Operable Unit 4 simulations. This would, in fact, cause a large decrease in contaminant seepage and loadings if vegetative cover were established, as the amount of water available for seepage would decrease. As this is currently not the case, the present results from the HELP model are more conservative.

Runoff in the HELP model is controlled by the SCS runoff curve number used, which in turn is derived from the ground type, vegetation type, and land use. Currently, the model uses an SCS runoff curve number of 95, which assumes no vegetative cover on a silt-clay type of soil. This runoff curve number generates a fairly large amount of runoff and is affected by the assumption that no vegetative cover has been established and that the soils are relatively impervious. If either of these factors are incorrect, available water for seepage could increase and thus loading to the aquifer would increase. However, physical descriptions of the waste and its characteristics tend to support the assumption that vegetative cover will not be able to become established until significant weathering occurs.

E.2.8.2 ST1D and ODAST

Sensitivity analyses were conducted on the vadose zone models ST1D and ODAST by varying the darcy velocity, the longitudinal dispersivity, and the layer thickness within the models to determine their impacts on the loading curves generated by the models. Data from Silos 1 and 2 were used as a baseline for comparison, and an unretarded, nondecaying contaminant was used. Darcy velocity, longitudinal dispersivity, and layer thickness were all varied by a factor of 2 by both doubling and halving each of the parameters while all other input was held constant. ODAST was used to evaluate the impacts of each of these parameters on final modeling results. The results of these analyses are presented in Figures E.2-22 through E.2-24.

All three figures illustrate that for a given source loading rate, the peak concentration reached for a non-decaying solute is the same regardless of the flow system used. This is shown by the peak loadings reached by the contaminant, which is 100 μg/L for all cases studied. The main influence noted in all three cases has to do with the time required for maximum loading to occur at the base of the vadose zone. Longitudinal dispersion (Figure E.2-22) has a negligible impact on the time for loading to reach the aquifer, and the vadose models are not sensitive to its value. The models are sensitive to both darcy velocity and layer thickness, as these both directly control the transport time required to pass through the vadose zone. Doubled layer thicknesses or halved Darcy velocities cause a significant increase in the time required for contaminant to reach the aquifer and for maximum loading to occur. Likewise, halving the layer thicknesses and doubling the Darcy velocity causes a decrease in the times.

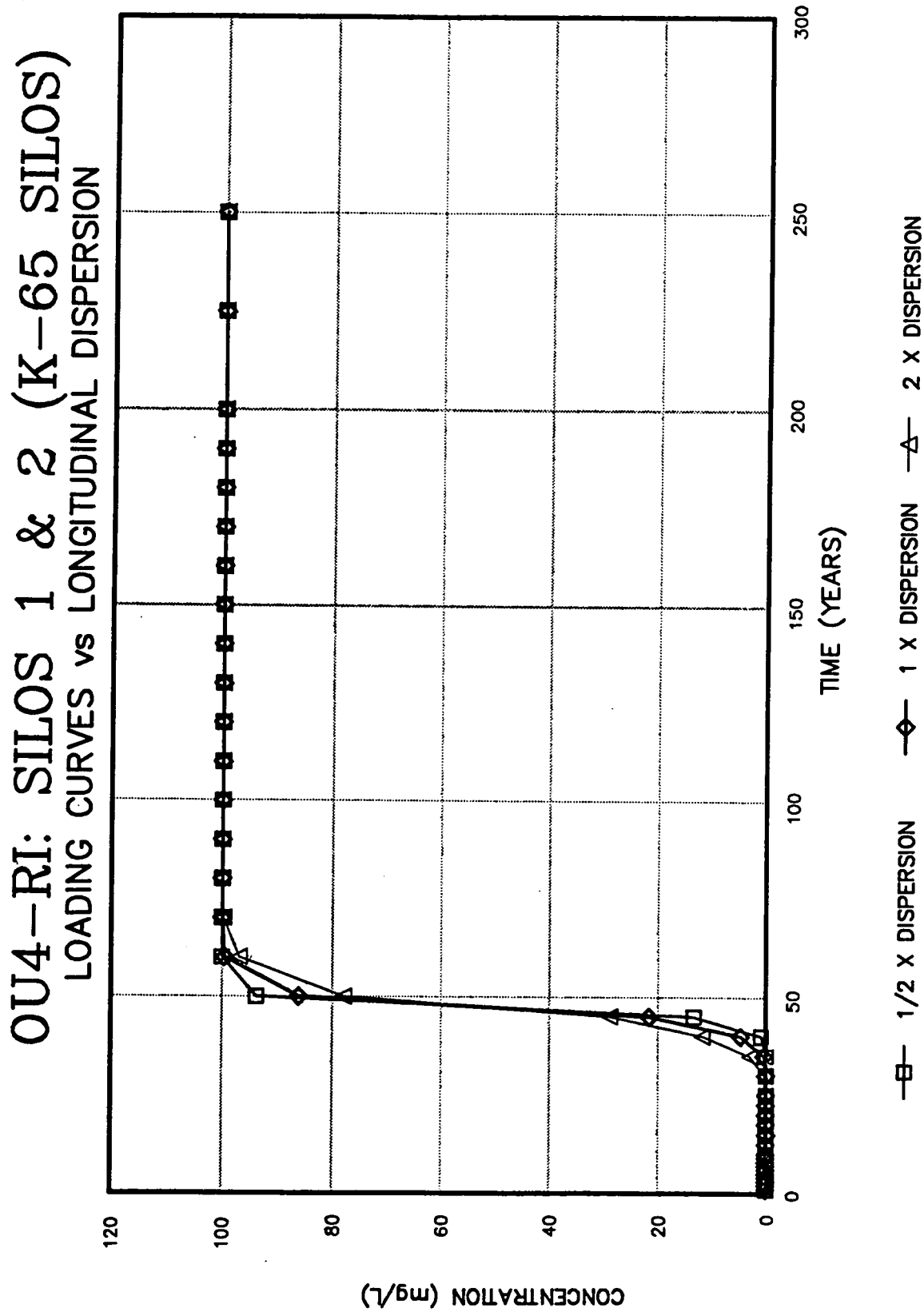


FIGURE E.2-22. ODAST MODEL SENSITIVITY ANALYSIS: LONGITUDINAL DISPERSION

409194-A-103 OU4 KNOX 2/19/93

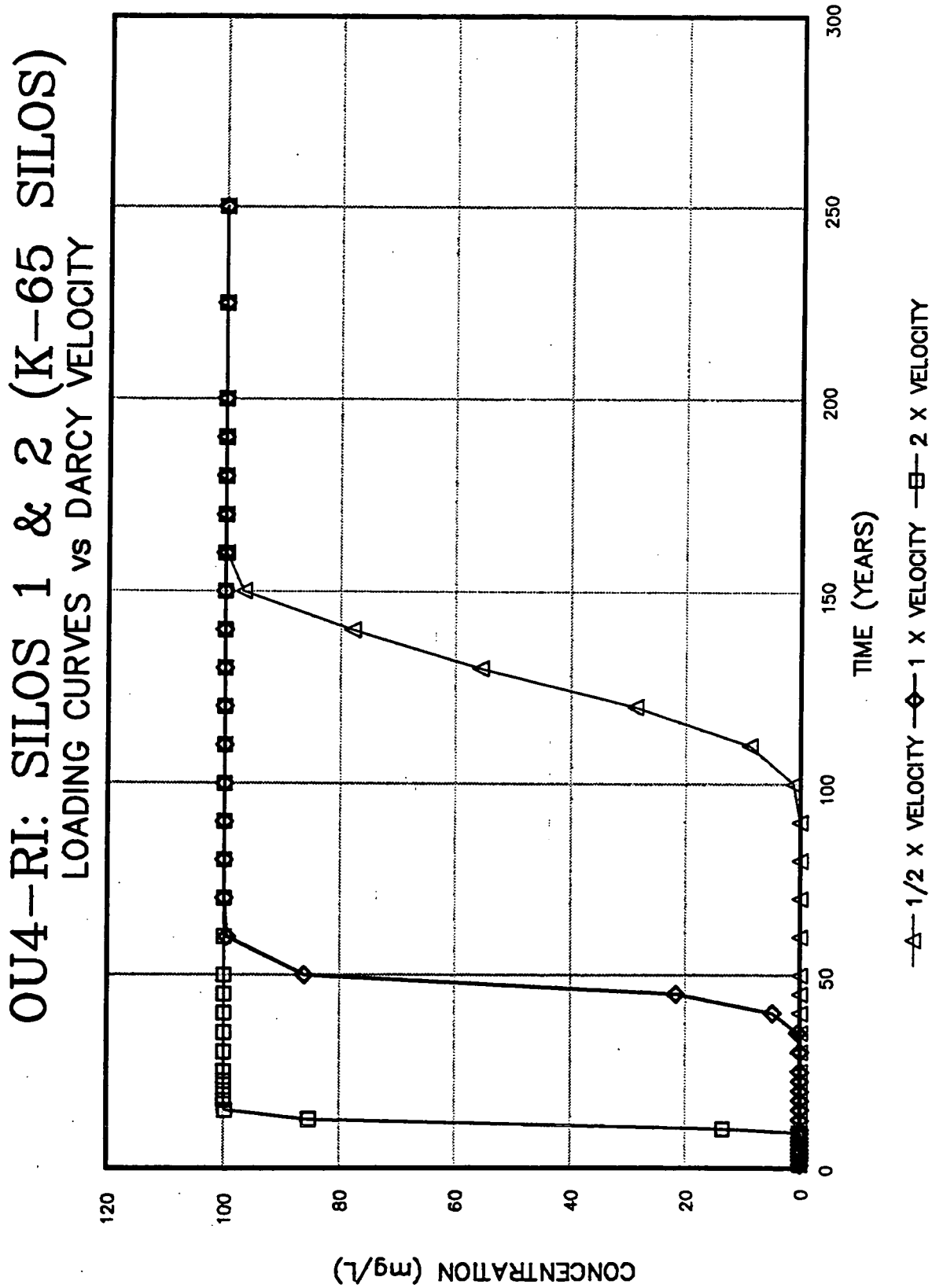


FIGURE E.2-23. ODAST MODEL SENSITIVITY ANALYSIS: DARCY VELOCITY

409194-A-102 OU4 KNOX 2/19/93

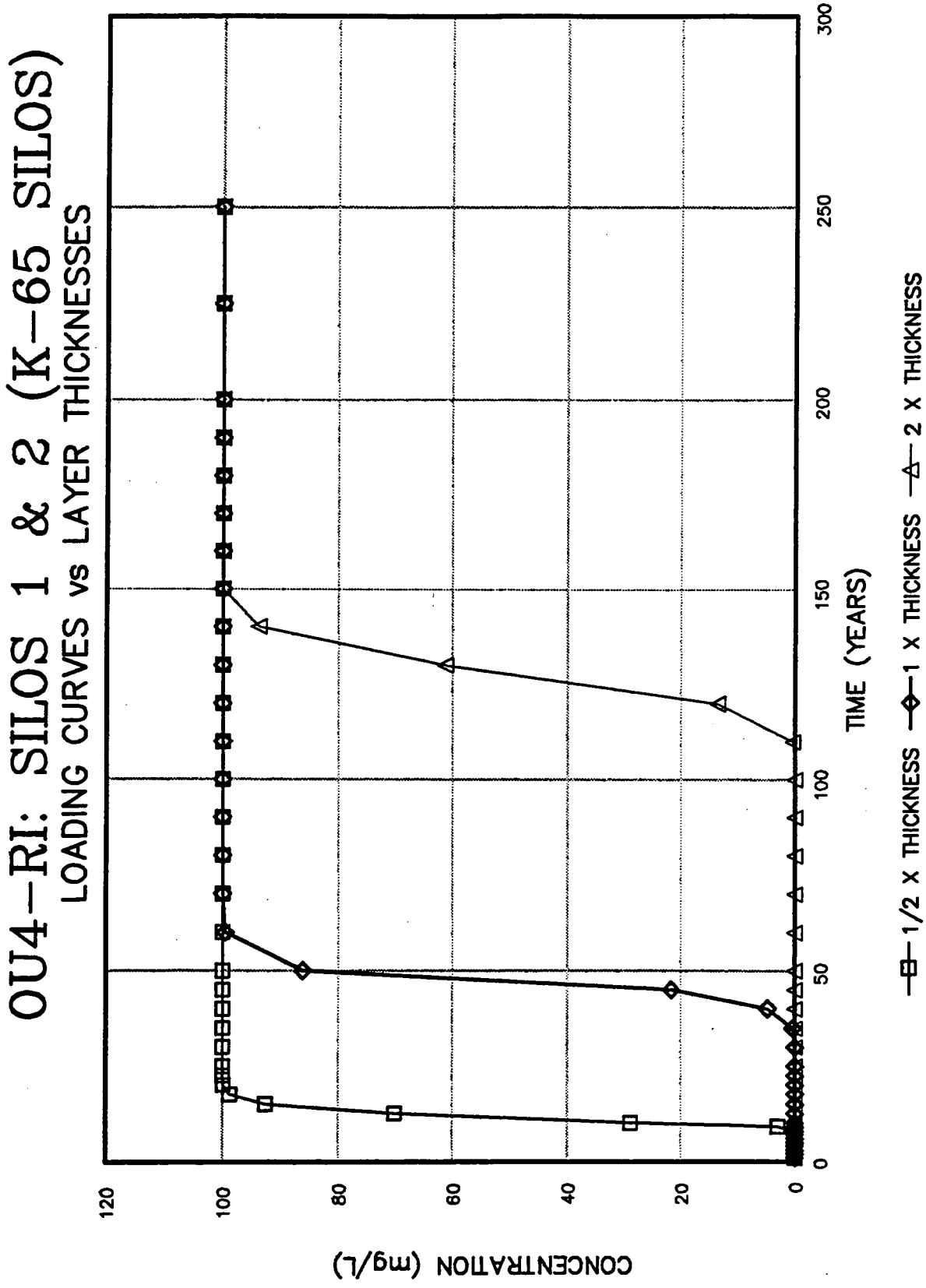


FIGURE E.2-24. ODAST MODEL SENSITIVITY ANALYSIS: LAYER THICKNESS

409194-A-101 OU4 KNOX 2/19/93

The impact of the Darcy velocity and layer thickness on the models is somewhat limited due to the derivation of the parameters themselves. Layer thicknesses were derived from Operable Unit 4 boring data, which should not vary over a large range within the operable unit. Darcy velocity is a function of the seepage rate, calculated by the HELP model and the formation porosity, which is fairly well-defined for the media simulated by the models.

A parameter-specific sensitivity analysis was conducted for uranium-234 as a part of the modeling analysis to observe the variation of the modeling results by changing the values of certain parameters. The sensitivity runs were performed by increasing and decreasing hydraulic conductivity, porosity, and distribution coefficient from the estimated values in a series of order-of-magnitude steps in the range of known site values. Hydraulic conductivity is a very important flow parameter. It is used as a direct input into the seepage velocity calculation, moreover, hydraulic conductivity is also a controlling factor in determining the seepage flow under both saturated and unsaturated conditions. With the estimated values of the hydraulic conductivity for uranium-234, the arrival time for the contaminant to the aquifer was 120 years and the peak concentration was 2.1375×10^{-5} mg/L.

Results indicate that the variation of hydraulic conductivity only effects the arrival time of the contaminant (uranium-234); however, there is no significant change in the peak concentration. The arrival times of the contaminant in the aquifer were estimated at 100 and 540 years, respectively, due to increase and decrease in the hydraulic conductivity value by one order of magnitude from the estimated value. Further decreasing the hydraulic conductivity by two order of magnitude, the arrival time was delayed to 2200 years. Sensitivity runs conducted by varying porosity (increasing as well as decreasing porosity by 30 percent) had no significant effect either on the arrival time or peak concentration. Results also indicate that the variation of distribution co-efficient effects the arrival time, whereas the peak concentration remains unchanged. Arrival times, for the sensitivity runs performed by decreasing and increasing distribution co-efficient by one order of magnitude were 40 years and 1200 years, respectively.

From sensitivity analysis, it was seen that the variation of different parameters effects the arrival time of the contaminant, however, there is no significant change in the peak concentration. It was observed that the peak concentration for uranium was always within one-order of magnitude when steady state or peak concentration was reached.

When decay is combined with low seepage velocities and/or retardation due to adsorption, the contaminant concentration at the Great Miami Aquifer is significantly reduced. However, the difference between the peak concentrations reaching the aquifer for low and high seepage velocities is sensitive to whether the contaminant concentration reached a steady state. For any contaminant, if the steady state condition was reached for both low and high seepage flow velocities, the peak concentra-

tions differ less compared to other constituents that did not reach a steady state concentrations at the aquifer within the simulation period of 1000 years.

The movement of organic constituents to the Great Miami Aquifer is greatly impeded by high biodegradation rates. For low seepage velocities and dispersion coefficients, the transport process is delayed and more time is available for degradation of the organic chemicals. Thus, for organic chemicals, the peak concentrations were several orders of magnitude lower (or zero) with low-end as compared to high-end seepage velocities and dispersion coefficients.

The range of hydraulic conductivities at a site is constrained by the geology. Nevertheless, the reasonable range of hydraulic conductivities at a site permits a high degree of variability in contaminant transport.

E.2.8.3 SWIFT

Like the vadose zone models, SWIFT is mostly influenced by the solute transport parameters it uses to simulate contaminant movement through the aquifer. Of these, retardation is the least well-defined and has the most impact on the fate of contaminants in the groundwater. As only uranium was simulated using SWIFT (as it was the only compound to pass the screening level), the impact is lessened. Calibration of the SWIFT model for uranium was performed as part of the RI/FS process and resulted in a historic simulation of uranium transport in the Great Miami Aquifer (IT 1990). A portion of this calibration involved testing uranium retardation values to determine which value fit historical loading data and present day groundwater concentration data most accurately. Uranium retardation factors below 4 were found to transport uranium too quickly through the system, and thus did not match historical data. Retardation factors above 15 were found to not match present day uranium distributions without large aquifer dispersion values, which were felt to be unrealistic. Consequently, a retardation factor of 12 was chosen for uranium during the modeling process, which also fell within the range of the geochemical studies performed for uranium at the FEMP (IT 1989). This same value was used in the fate and transport modeling.

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E.3.0 GEOCHEMICAL ANALYSIS

E.3.1 INTRODUCTION

This section describes the assessment of site-specific data and geochemical modeling, which were conducted to estimate initial contaminant concentrations for the fate and transport model of groundwater pathways. A summary of site-specific data is provided before the conceptual model is outlined and discussed. The conceptual model presented illustrates the formation of leachate and the migration of leachate into groundwater. Following the presentation of the conceptual model, a flow diagram is given to summarize the logic behind using a combination of site-specific data and theoretical mineral-solubility calculations to constrain the concentration of contaminants in leachate that may migrate from the waste units. Model results are then presented and compared to site-specific data, and model uncertainty is discussed with respect to observed boundary conditions and other geochemical models. Additionally, model results for contaminant speciation (e.g., $UO_2[CO_3]_2^{-2}$) in groundwater and leachate are discussed to gain insight on contaminant adsorption and retardation by the glacial overburden. The final parts of this section describe the geochemical code employed for the calculations and the limitations and assumptions required for estimating contaminant concentrations when using mineral solubility calculations.

E.3.2 SITE-SPECIFIC GROUNDWATER AND LEACHATE DATA

Groundwater data of interest to the geochemical assessment of leachate migration are restricted to analyses of samples recovered from the perched water bodies in the glacial overburden. Two sets of data are used:

- Range of constituent concentrations in perched groundwater samples obtained from background wells in the glacial overburden (Table 15-1 in the FEMP Groundwater Report draft of December 1990)
- Range of constituent concentrations in perched groundwater samples obtained from the slant borings under Silos 1 and 2 (Tables 4-34 and 4-38)

Analytical data reported for perched groundwater recovered from background wells are comprehensive in that they completely describe the composition of the groundwater with respect to pH, Eh (a measurement of the oxidation-reduction potential of groundwater), major ions, minor ions, and all constituents of concern to Operable Unit 4. Perched groundwater samples obtained from the slant borings were not characterized for pH, Eh, and alkalinity; these limitations are addressed when model results are discussed (Appendix E.2). The groundwater data sets can be found in Section 4.0.

Leachate data are available from several sources:

- Liquor drained from the K-65 raffinate waste in Silos 1 and 2 and collected from the decant sump tank below the silos (Tables 4-13)
- Extraction Procedure Toxic extract derived from metal-oxide waste in Silo 3 (Table 4-8)
- TCLP extract derived from K-65 raffinate in Silos 1 and 2 (Tables 4-9 and 4-11)

Analytical data for the leachate data sets are most complete for the liquor drained from Silos 1 and 2, but pH, Eh, alkalinity, actinium, polonium, protactinium, and thorium measurements are missing. The Extraction Procedure Toxicity (EP Tox) extract was analyzed for arsenic, barium, cadmium, chromium, lead, selenium, silver, and mercury. TCLP extract was analyzed for 23 metals and the radionuclides lead-210, polonium-210, radium-226, actinium-227, radium-228, thorium 228, thorium-230, protactinium-231, thorium-232, uranium-234, uranium-235/236, and uranium-238. The TCLP data for radionuclides are available for six samples from Silos 1 and 2, and for a single extract sample derived from Silo 3 waste. There are no general chemistry or major element data for the EP Tox and TCLP data sets. Limitations associated with the missing data are outlined when model results are discussed (Appendix E.2). Leachate data sets can be found in Section 4.0.

E.3.3 DEVELOPMENT OF THE CONCEPTUAL MODEL

In the geochemical assessment of leachate formation, the events leading to the failure of the silos and exposure of the waste to precipitation are not considered. It is assumed that such failure does occur, and the waste is available for chemical reactions with falling precipitation followed by migration of leachate into underlying glacial deposits where further reactions take place. The conceptual scenario used to model the release of contaminants from Operable Unit 4 waste silos is illustrated in Figure 5-1. Rainwater infiltrates the silo and reacts with inorganic waste solids to form a waste leachate, referred to as Leachate A. Subsequently, Leachate A migrates into the underlying glacial overburden and reacts with the naturally occurring minerals to form a modified leachate, referred to as Leachate B. Leachate B is used to constrain the initial contaminant concentrations for the groundwater fate and transport model (ODAST model in Appendix E.2).

The conceptual model highlights two distinct leachate compositions to reflect the difference in the physical and chemical properties of the waste pile and the underlying glacial overburden. K-65 raffinate and metal-oxide waste will react with water to form solutions with pH near or greater than 8. Measurements of pH for water saturated K-65 raffinate waste range from 7.8 to 9.8. Metal-oxide waste, though presently dry, will react with water to form an alkaline solution (e.g., $CaO + H_2O \leftrightarrow Ca^{+2} + 2OH^-$). The metal-oxide waste/water mixture may reach an equilibrium with portlandite ($Ca[OH]_2$) near a pH of 12 if sufficient lime is present to react with water to form calcium and hydroxide ion followed by precipitation of portlandite ($CaO + H_2O \leftrightarrow Ca^{+2} + 2OH^- \leftrightarrow Ca[OH]_2$). Leachates formed from waste/water reactions are referred to as Leachate A.

As long as Leachate A remains in contact with the solid waste phases, the solution will retain its high pH property. However, when Leachate A migrates into the underlying glacial overburden, which is dominated by carbonate minerals, the solution chemistry of Leachate A will change to reflect the physical and chemical conditions of its new surrounding. Perched groundwater in the glacial overburden contain abundant bicarbonate ion (350 to 500 mg/L; Table 15-1 of FEMP Groundwater Report draft of December 1990), and it is expected that pore water will have a chemical composition similar to the perched groundwater. As Leachate A migrates into the glacial overburden it will mix with pore water, resulting in a pH decrease and possible mineral precipitation (e.g., $Ca^{+2} + OH^- + HCO_3^- <-> CaCO_3 + H_2O$). In this reaction, calcium and hydroxide ions provided by Leachate A are free to react with bicarbonate ion in the pore water to form calcite and water. Such a reaction is likely because the perched groundwater, and by inference the pore water, is calculated to be saturated with respect to calcite. This type of reaction, and many others, will modify Leachate A as it migrates into the glacial overburden, and this modified leachate is referred to as Leachate B. Therefore, the conceptual model is set up to account for the distinct chemical reactions that occur in the different environments.

E.3.4 METHODOLOGY FOR ESTIMATING LEACHATES A AND B

The methodology used to estimate radionuclide and hazardous metal concentrations in Leachate A and B is outlined with the flow chart in Figure 5-4. Leachate A is best estimated by recovering and analyzing in situ leachate, as approximated by the composition of liquor in the decant sump (Tables 4-30 and 4-31). If in situ leachate is characterized for all constituents of concern, it is used to estimate Leachate A and attention is turned to formation of Leachate B. When in situ leachate is not characterized for all constituents of concern or in situ leachate data are unavailable (e.g., Silo 3), the concentration of constituents in Leachate A may be constrained by using EP Tox or TCLP data. However, EP Tox and TCLP data may overestimate the concentration of constituents in Leachate A because these data are derived using acetic acid as the leaching fluid. Acetic acid produces uncharacteristically low pH conditions (i.e., lower than acid rain) and partially degrades to the acetate ion, which forms metal complexes in solution and enhances the solubility of metal solid phases. This results in high estimates of contaminant concentrations when inorganic waste is leached with acetic acid.

Therefore, if EP Tox or TCLP data are used, the constituent concentration obtained from these leaching tests is screened to determine if it would result in depletion of the constituent inventory from the waste in a period of less than 70 years (see 70-year rule discussed below). When the inventory is not depleted in 70 years, the EP Tox and TCLP data are used to estimate constituent concentrations in Leachate A. However, if the constituent inventory is depleted in less than 70 years by using the EP Tox or TCLP data, these data are rejected and mineral solubility calculations are investigated to estimate the constituent concentration in Leachate A.

Mineral solubility calculations can be performed to estimate the concentration of constituents in Leachate A when in situ, EP Tox, or TCLP data are lacking or inappropriate. The concept of mineral solubility may be illustrated by placing the mineral cerussite ($PbCO_3$) into distilled water at 25°C and a pressure of 1 atmosphere. Under these conditions, the equilibrium lead concentration in solution is 1.1 mg/L, which is referred to as the solubility limit for lead in distilled water contacting cerussite at 25°C and 1 atmosphere. Turning to Figure 5-4, it is seen that mineral solubility calculations require data on the waste mineralogy to calculate the contaminant concentrations in Leachate A. In general, the mineralogy of the waste is unknown, and an elemental analysis of the waste can be used to form mineral phases that are thought to be present based on process knowledge or waste disposal records. Mineral solubility calculations are then carried out with the known or assumed mineral phases by using a computer code to simulate the reactions between rainwater and the waste minerals.

When mineral solubility calculations are performed, rainwater acts as the leachant and it is assumed to equilibrate with the waste minerals instantaneously. This assumption is a requirement of the mathematical model because kinetic data on the waste minerals are unavailable to assess the time needed for dissolution of mineral phases to occur. As the leachant approaches thermodynamic equilibrium with the waste solids, waste minerals dissolve to increase the solute mass (i.e., total dissolved solids, or TDS, increases) and minerals that become saturated are allowed to precipitate. These reactions continue until the leachate reaches thermodynamic equilibrium with the waste solids (i.e., constituents in the leachate reach a steady-state concentration), at which point it is referred to as Leachate A.

A final method for estimating the composition of Leachate A is by applying the EPA 70-year rule (EPA 1988). The EPA 70-year rule calculates the concentration of a contaminant in Leachate A by assuming that the total mass of the contaminant in the waste inventory will be depleted (completely leached out by percolating water) at the end of 70 years (a time period approximately equal to the life of a human being). Data required for this calculation include the total mass, or inventory, of the contaminant in the waste, and the volume of water that percolates through the waste in a 70-year period. The contaminant inventory is divided by the volume of water to obtain a concentration term in units of milligrams per liter. This method is likely to result in contaminant concentrations that grossly overestimate natural leaching conditions for all but the most soluble elements (e.g., cesium, strontium, technetium).

After all constituent concentrations in Leachate A have been constrained, the second reaction step is modeled to estimate the constituent concentrations in Leachate B (Figure 5-4). As noted above, reactions between Leachate A and pore water and/or minerals in the glacial overburden can result in changes in solution pH and major-ion concentrations with concomitant mineral precipitation. These reactions may be favorable for lowering contaminant concentrations in Leachate A. For example, the lead concentration in TCLP extract derived from the K-65 raffinate ranges from 117 to 841 mg/L.

These very high lead concentrations are not observed in groundwater containing appreciable bicarbonate because the cerussite ($PbCO_3$) solubility product is exceeded and the lead concentration is lowered as cerussite precipitates. The modeling of Leachate B accounts for this type of scenario. Therefore, if a contaminant concentration is lowered by chemical reactions in the glacial overburden, the lower concentration is used to estimate the composition of Leachate B. If a contaminant concentration is unaffected by chemical reactions in the glacial overburden, its Leachate B concentration is assumed to be identical to Leachate A. This last assumption results in a Leachate B concentration on the high side because dilution of Leachate A and adsorption of constituents of concern are not considered in the geochemical model (dilution and adsorption are considered in the fate and transport model).

In summary, site-specific data are used to estimate Leachate A compositions when they are available and appropriate. Leachate A compositions are generally estimated using a combination of in situ, EP Tox, and TCLP data supplemented with mineral solubility calculations and the EPA 70-year rule. Constraining Leachate A compositions with in situ leachate, EP Tox, and TCLP data, and the computational methods outlined above, provides the most defensible estimates of contaminant concentrations in Leachate A by using available site-specific data on Operable Unit 4 waste. Leachate A is reacted with pore water and minerals in the glacial overburden to take credit for chemical reactions that will lower some constituents of concern. The modification of Leachate A by these reactions produces Leachate B. Contaminant concentrations in Leachate B are used as the initial contaminant concentrations in the groundwater fate and transport model.

E.3.5 APPLICATION OF THE METHODOLOGY AND MODEL RESULTS

Operable Unit 4 comprises Silos 1 and 2 (K-65 waste), and Silo 3 (metal-oxide waste). Silos 1 and 2 house wet raffinate produced from the extraction of uranium from Belgian Congo ore, while Silo 3 contains a dry, granular, metal-oxide waste produced by evaporation of liquid waste streams. Each waste type is distinct in its physical and chemical properties, implying that each waste type will produce a leachate of distinct composition. For the Silos 1 and 2, the pore fluid in the raffinate contains most of the mobile contaminants, and the interaction of percolating rainfall with this pore fluid will produce a leachate distinct from that arising from the interaction of rainwater with dry metal-oxide waste in Silo 3. This section will summarize the site-specific data that are available to estimate the composition of leachate that may migrate from the silos. The methodology for estimating the composition of leachate was discussed above.

In applying the best available date to the estimation of Operable Unit 4 waste leachate, Leachate A is estimated by using data from several levels. For Silos 1 and 2, process liquor in contact with the waste can be considered representative of in situ leachate. However, Silo 3 contains dry waste, and in situ leachate is unavailable. TCLP data for 23 metals and 12 radionuclides are available for Silos 1 and 2. Extraction Procedure Toxicity (EP Tox) data for seven metals and TCLP data for 12

radionuclides are available for Silo 3. As dictated by the prescribed methodology (Figure 5-4), the TCLP results are screened to determine if their use would result in depletion of the contaminant inventory in less than 70 years. At this point, available leachate data have been used and constituent concentrations that remain unconstrained are estimated with mineral solubility calculations or the 70-year rule.

Mineral solubility calculations are investigated first by assessing the available information on waste characterization. For example, elemental analyses of the metal-oxide waste in Silo 3 and process knowledge are used to estimate the waste minerals that may be present. As the name of the waste implies, many metals in the waste have been converted to oxide compounds during the evaporation of liquid waste streams (e.g., BeO, NiO). Other metals will tend to react with the sulfate that is present in the waste stream to form sulfate minerals (e.g., $BaSO_4$). In this way, the mineralogy of the waste is estimated, and the mineral solubility calculations are carried out with the assumed mineral phases. Constituents that do not reach a solubility limit are carried down to the 70-year rule calculation. After finishing the solubility and 70-year calculations, all contaminant concentrations in Leachate A will be constrained by in situ leachate, TCLP or EP Tox data, mineral solubility calculations, or the EPA 70-year rule.

Modeling results for Leachate A are summarized in Tables E.3-1 and E.3-2. These tables contain the parameter of interest, the assumed waste phase for applicable solubility calculations, the selected constituent concentration for Leachate A, and the constraint on the chosen contaminant concentration. For Silos 1 and 2 (Table E.3-1), most constituents are constrained by TCLP data rather than the in situ liquor recovered from the decant sump. TCLP data were chosen over the in situ liquor for all constituents because the liquor obtained from the decant sump was pumped into a tank truck that had not been decontaminated prior to samples being split and sent off for analysis. All constituents of concern in Silos 1 and 2 have their Leachate A concentrations constrained by TCLP data (Table E.3-1).

In Table E.3-2, the constituents of concern in Silo 3 have their Leachate A concentrations constrained by TCLP and EP Tox data, mineral solubility calculations, or the 70-year rule.

The second reaction-step used to estimate the composition of Leachate B is summarized in Figure 5-4. Leachate A is modified by dissolution of minerals in the glacial overburden and precipitation of secondary mineral phases. Secondary minerals represent phases that are stable in the presence of Leachate A and glacial overburden, but they are not present in glacial overburden initially. Minerals in the glacial overburden underlying the waste units have been characterized (Solebello 1991), and the results are summarized in Table E.3-3. When the reactions between Leachate A and glacial-overburden minerals achieve thermodynamic equilibrium, the modified leachate is referred to as Leachate B. Contaminant input parameters and results for Leachate B are summarized in Tables E.3-4

TABLE E.3-1

SILOS 1 AND 2
RESULTS FOR LEACHATE A

Parameter or Element	Assumed Waste Phase	Leachate A CConcentration(ppm)[a]	Constraint[b]
pH	NA	9.3 SU	NA
Eh	NA	286 mV	NA
Actinium	NM	0.691×10^{-7}	TCLP
Antimony	NM	0.950×10^{-1}	TCLP
Arsenic	NM	0.120×10^{-1}	TCLP
Barium	NM	0.153×10^{1}	TCLP
Beryllium	NM	0.300×10^{-2}	TCLP
Boron	NM	0.359×10^{0}	TCLP
Cadmium	NM	0.190×10^{-1}	TCLP
Chromium	NM	0.800×10^{-1}	TCLP
Cobalt	NM	0.226×10^{1}	TCLP
Copper	NM	0.651×10^{0}	TCLP
Lead	NM	0.501×10^{3}	TCLP
Manganese	NM	0.389×10^{0}	TCLP
Mercury	NM	0.200×10^{-3}	TCLP
Molybdenum	NM	0.670×10^{-1}	TCLP
Nickel	NM	0.329×10^{1}	TCLP
Protactinium	NM	0.615×10^{-4}	TCLP
Polonium	NM	0.181×10^{-7}	TCLP
Radium	NM	0.567×10^{-4}	TCLP
Selenium	NM	0.100×10^{0}	TCLP
Silver	NM	0.520×10^{-1}	TCLP
Thorium	NM	0.510×10^{-1}	TCLP
Thallium	NM	0.600×10^{2}	TCLP
Uranium	NM	0.484×10^{1}	TCLP
Vanadium	NM	0.330×10^{-1}	TCLP
Zinc	NM	0.199×10^{0}	TCLP

[a] Element concentrations in milligrams per liter, or parts per million (ppm); pH in standard units (SU); and Eh in millivolts (mV).
[b] Constraint on reported concentration is by Toxicity Characteristic Leaching Procedure (TCLP).
NA = not applicable.
NM = Mineral solubility was not modeled due to the availability of TCLP data.

TABLE E.3-2

SILO 3
RESULTS FOR LEACHATE A

Parameter or Element	Assumed Waste Phase	Leachate A Concentration (mg/L)[a]	Constraint[b]
pH	NA	10.5 SU	NA
Eh	NA	103 mV	NA
Actinium	NM	0.766×10^{-10}	TCLP
Arsenic	NM	0.417×10^{2}	EP Tox
Beryllium	BeO	0.749×10^{-1}	BeO
Cadmium	NM	0.633×10^{1}	EP Tox
Chromium	NM	0.119×10^{2}	EP Tox
Cobalt	nm	0.634×10^{2}	70-year rule
Copper	CuO	0.365×10^{-4}	CuO
Lead	NM	0.101×10^{1}	EP Tox
Manganese	MnO	0.653×10^{-2}	Mn_3O_4
Mercury	NM	0.300×10^{-2}	EP Tox
Nickel	NiO	0.704×10^{-2}	NiO
Protactinium	NM	0.137×10^{-4}	TCLP
Radium	NM	0.248×10^{-5}	TCLP
Selenium	NM	0.117×10^{2}	EP Tox
Silver	NM	0.320×10^{-1}	EP Tox
Thorium	NM	0.909×10^{-2}	TCLP
Thallium	nm	0.124×10^{1}	70-year rule
Uranium	NM	0.256×10^{0}	TCLP
Vanadium	nm	0.770×10^{2}	70-year rule
Zinc	ZnO	0.622×10^{-1}	ZnO

[a] Element concentrations in milligrams per liter, or parts per million (ppm); pH in standard units (SU); and Eh in millivolts (mV).

[b] Constraint on reported concentration is by EP Toxicity Leaching Procedure (EP Tox, Toxicity Characteristic Leaching Procedure TCLP), EPA 70-year rule, or by solubility with respect to the indicated mineral phase.

NA = not applicable.

nm = mineral solubility was not modeled due to lack of thermodynamic data for the constituent or mineral solubility result is greater than 70-year result.

NM = mineral solubility was not modeled due to the availability of TCLP data.

TABLE E.3-3

MINERALOGY OF GLACIAL OVERBURDEN[a]

Mineral	Modal Percent
Dolomite	trace to 71
Quartz	3 to 73
Calcite	trace to 18
Feldspar	trace to 26
Muscovite	3 to 72
Chlorite	4 to 21
Smectite	< 5

[a] Data taken from Table III of Solebello (1991).

TABLE E.3-4

SILOS 1 AND 2
RESULTS FOR LEACHATE B

Parameter or Element	Concentration (mg/L)a	Constraint[b]
pH	7.1 SU	NA
Eh	409 mV	NA
Actinium	0.132×10^{-05}	Leachate A
Antimony	0.950×10^{-01}	Leachate A
Arsenic	0.120×10^{-01}	Leachate A
Barium	0.233×10^{-02}	$BaSO_4$
Beryllium	0.352×10^{-03}	BeO
Boron	0.359×10^{00}	Leachate A
Cadmium	0.190×10^{-01}	Leachate A
Chromium	0.152×10^{-03}	CrO_2
Cobalt	$0.226 \times 10^{+01}$	Leachate A
Copper	$0.651 \times 10^{+00}$	Leachate A
Lead	0.470×10^{-02}	$PbCO_3$
Manganese	0.872×10^{-02}	$MnCO_3$[c]
Mercury	0.198×10^{-05}	Hg_2Cl_2
Molybdenum	0.670×10^{-01}	Leachate A
Nickel	$0.329 \times 10^{+01}$	Leachate A
Protactinium	0.121×10^{-02}	Leachate A
Polonium	0.744×10^{-06}	Leachate A
Radium	0.504×10^{-04}	Leachate A
Selenium	$0.100 \times 10^{+00}$	Leachate A
Silver	0.371×10^{-01}	AgCl
Thorium	0.217×10^{-08}	Leachate A
Thallium	0.600×10^{-02}	Leachate A
Uranium	$0.418 \times 10^{+01}$	Leachate A
Vanadium	0.330×10^{-01}	Leachate A
Zinc	0.118×10^{-01}	$ZnCO_3$[c]

[a] Element concentrations in milligrams per liter (mg/L), pH in standard units (SU), and Eh in millivolts (mV).
[b] Constraint on reported concentration is by Leachate A or by solubility with respect to the indicated mineral phase.
[c] $MnCO_3$ and $ZnCO_3$ are part of solid solution series with calcite.
NA = not applicable.

and E.3-5. These tables contain results for constituents of concern only, although major leachate constituents (e.g., Ca^{+2}, SO_4^{-2}, etc.) were modeled also. Contaminants in Leachate B are constrained by TCLP or EP Tox data, mineral solubility, or the EPA 70-year rule.

In accordance with the conceptual scenario stated above, contaminant concentrations reported for Leachate B will be lower than Leachate A when dissolution/precipitation reactions between Leachate A and glacial-overburden minerals result in a pH for Leachate B that corresponds to a solubility minimum for the mineral controlling the contaminant of concern. For example, beryllium oxide (BeO) is more soluble at pH values above nine than below nine. Therefore, beryllium concentrations in Leachate A will be greater than Leachate B when pH values in Leachate A are greater than nine and in Leachate B less than nine (Tables E.3-2 and E.3-5). Conversely, contaminants in Leachate A that are controlled by mineral solubility or TCLP values cannot increase their concentration in Leachate B by reaction with glacial-overburden minerals because waste elements are assumed to be absent in the glacial overburden. Therefore, contaminant concentrations in Leachate A are estimates of maximum values, and these values may only be lowered by reaction with glacial-overburden minerals.

E.3.6 DISCUSSION OF RESULTS AND OBSERVED DATA

The inorganic constituents of concern for Operable Unit 4 Silos are listed in Tables E.3-4 and E.3-5. Groundwater, leachate, or TCLP data exist for all 25 elements listed in Table E.3-4. For metal-oxide waste in Silo 3, TCLP and EP Tox data exist for 12 of the 20 inorganic constituents of concern. Elements for which Silo 3 leachate data are lacking include beryllium, cobalt, copper, manganese, nickel, thallium, vanadium, and zinc. The mineral solubility calculations and 70-year concentrations presented in Table E.3-2 reflect the lack of site-specific leachate data for these Silo 3 elements. Twenty of the 25 inorganic constituents of concern are compared to observed data and discussed in this light; the exceptions being actinium, antimony, boron, polonium, and protactinium. These five constituents have only a single data reference (e.g., boron and antimony concentrations in TCLP extract from K-65 raffinate in Silos 1 and 2) and comparisons to other data sets are not possible. Summary figures are presented for the remaining 20 elements, and these illustrate the observed concentration range of the constituent in:

- Perched groundwater obtained from background wells
- Perched groundwater obtained from the slant borings emplaced below Silos 1 and 2
- Liquor obtained from the decant sump below Silos 1 and 2
- TCLP extract derived from the K-65 raffinate in Silos 1 and 2
- TCLP (one sample) and EP Tox extract derived from metal-oxide waste in Silo 3

TABLE E.3-5

SILO 3
RESULTS FOR LEACHATE B

Parameter or Element	Concentration (mg/L)[a]	Constraint[b]
pH	7.0 SU	NA
Eh	427 mV	NA
Actinium	0.242×10^{-06}	Leachate A
Arsenic	$0.417 \times 10^{+02}$	Leachate A
Beryllium	0.854×10^{-03}	BeO
Cadmium	$0.633 \times 10^{+01}$	Leachate A
Chromium	0.166×10^{-03}	CrO_2
Cobalt	$0.634 \times 10^{+02}$	Leachate A
Copper	0.365×10^{-04}	Leachate A
Lead	0.135×10^{-01}	$PbCO_3$
Manganese	0.672×10^{-02}	$MnCO^{3c}$
Mercury	0.300×10^{-02}	Leachate A
Nickel	0.704×10^{-02}	Leachate A
Protactinium	0.435×10^{-03}	Leachate A
Radium	0.161×10^{-02}	Leachate A
Selenium	$0.117 \times 10^{+02}$	Leachate A
Silver	0.320×10^{-01}	Leachate A
Thorium	0.213×10^{-08}	Leachate A
Thallium	$0.124 \times 10^{+01}$	Leachate A
Uranium	0.226×10^{-04}	Leachate A
Vanadium	$0.770 \times 10^{+02}$	Leachate A
Zinc	0.619×10^{-01}	$ZnCO_3$[c]

[a] Element concentrations in milligrams/liter (mg/L), pH in standard units (SU), and Eh in millivolts (mV).
[b] Constraint on reported concentration is by Leachate A or by solubility with respect to the indicated mineral phase.
[c] $MnCO_3$ and $ZnCO_3$ are part of solid solution series with calcite.
NA = not applicable

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The figures also contain theoretical solubility limits for the indicated solid phases at 25°C and 1 atmosphere in groundwater from a background well and liquor derived from the decant sump tank. These solutions (i.e., background groundwater and sump liquor) represent boundary conditions for contaminant transport in fluid medium. Finally, the figures contain the modeling result reported in Tables E.3-4 and E.3-5.

Barium (Ba) and radium (Ra) data are discussed together because Ba^{+2} and Ra^{+2} ions have similar geochemical behavior in the aqueous environment when sulfate ion is present. Barium and radium concentrations in solution are dependent on the concentration of sulfate ion (Figure E.3-1). The solubility curves shown in Figure E.3-1 are for the pure $BaSO_4$ and $RaSO_4$ endmembers, as thermodynamic data are unavailable for predicting the solubility of a $Ba_{1-x}Ra_xSO_4$ solid solution. In the natural environment, some small mole fraction of radium always occurs in the barite ($Ba_{1-x}Ra_xSO_4$) structure (Deer et al. 1966), and the solubility of natural barite containing radium will be less than the pure salts shown in Figure E.3-1. A pure $RaSO_4$ salt has not been found in the natural environment because radium concentrations in natural waters are kept below the $RaSO_4$ saturation point by solid solution formation and adsorption (Langmuir and Riese 1985).

In Figure E.3-2, the observed barium concentrations in perched groundwater, liquor from the decant sump, and TCLP and EP Tox extract lie between 0.001 and 10 mg/L. Theoretical solubility limits are shown for barytocalcite ($CaBa[CO_3]_2$) and barite ($BaSO_4$) in perched groundwater from background well 1024, and for barite in liquor obtained from the decant sump tank. The modeling result for Silos 1 and 2 lies near the theoretical solubility limit for barite in decant sump liquor (Note: barium is not a constituent of concern for Silo 3 waste). In this case, the model result for barium is lower than all observed data, but may overlap with groundwater obtained from background wells if the analytical detection limit for barium was lower. The result for Leachate B lies near the barite solubility limit in sump liquor, rather than the barite solubility limit in perched groundwater, because the waste in Silos 1 and 2 contains sulfate ion in concentrations similar to sump liquor, rather than perched groundwater. As discussed above, Leachate A (i.e., the waste leachate) controls the release of constituents to the glacial overburden, and it is the high concentration of sulfate ion in Leachate A, not the sulfate ion in perched groundwater, that controls the barium concentration in the Leachate B result. The theoretical solubility limit for barium in perched groundwater equilibrated with barite agrees well with the observed barium concentration in sump liquor and background perched groundwater, and overlaps with the lower end of the ranges observed for perched groundwater under Silos 1 and 2, and EP Tox extract derived from Silo 3. It is noteworthy that all observed barium concentration ranges in groundwater and decant sump liquor lie between the theoretical solubility limits for barytocalcite and barite in perched groundwater. This suggests that the observed barium concentrations fall in a quasi steady-state zone controlled by the dissolution of barium from carbonate minerals and the precipitation of barite. Barium is a common trace element in calcite and dolomite (Deer et al. 1966), and these minerals are major constituents in the glacial overburden. Therefore, there is a source for barium in

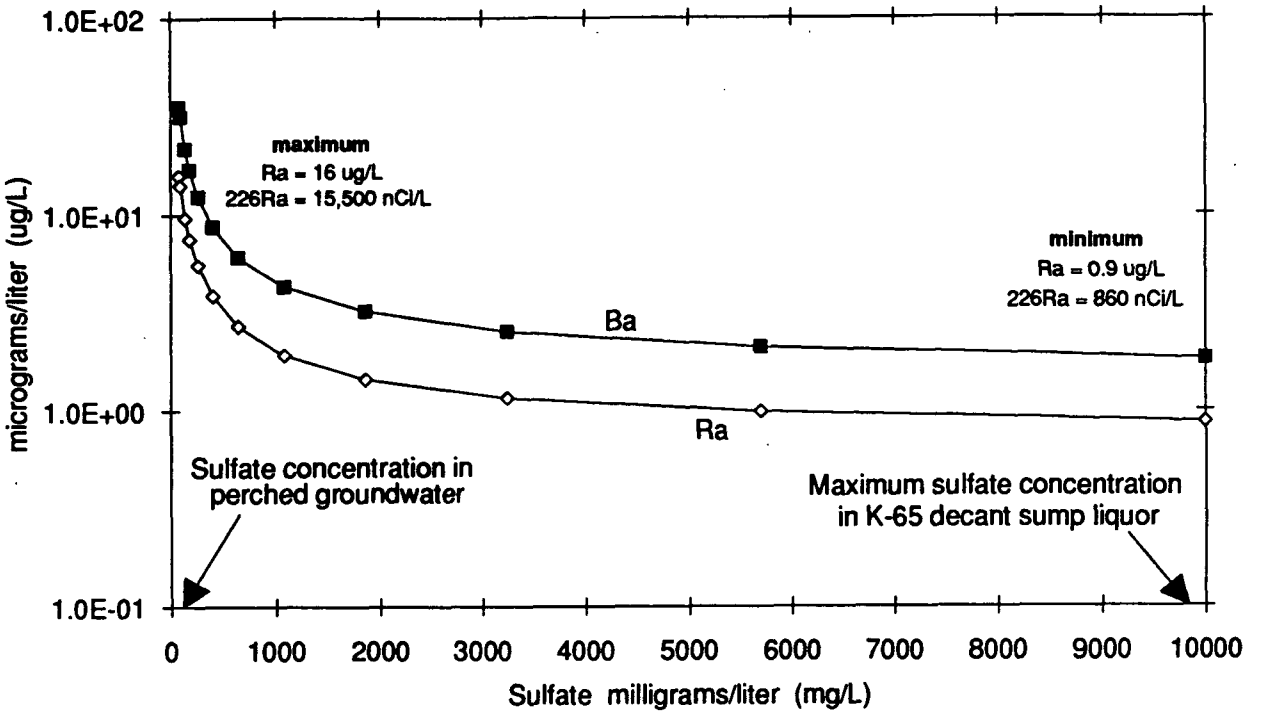
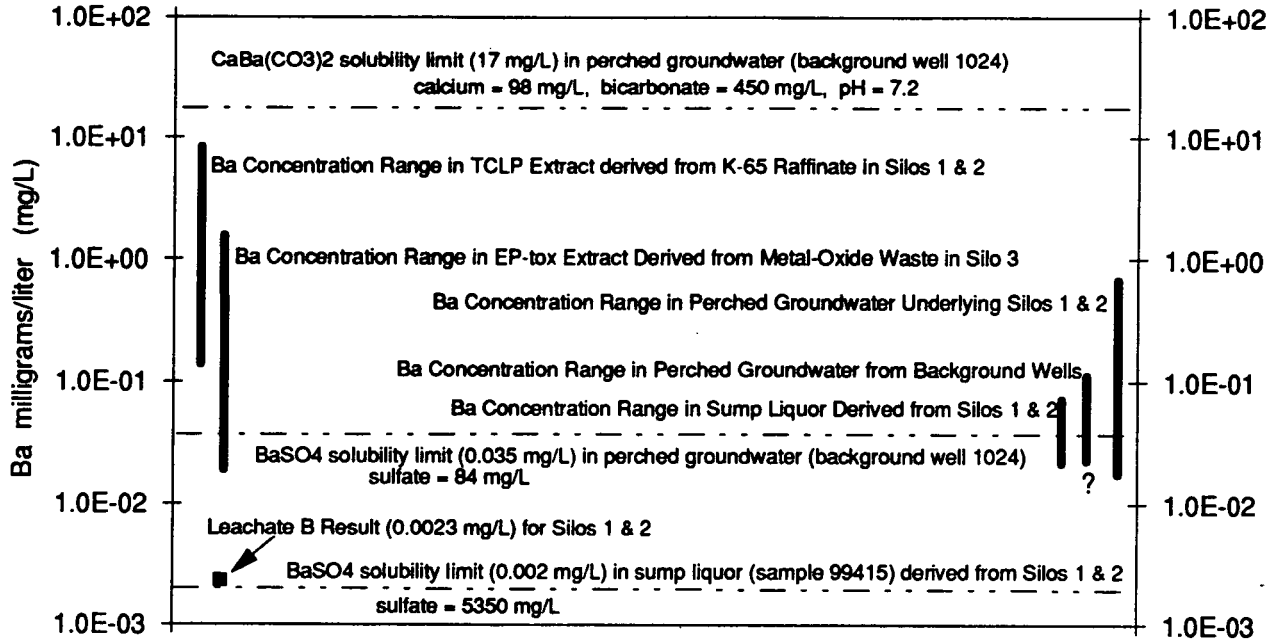


FIGURE E.3-1

$BaSO_4$ AND $RaSO_4$ SOLUBILITY AS A FUNCTION OF SULFATE CONCENTRATION



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2; and 5) EP-tox extract derived from the metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B result (filled square) for Silos 1 & 2 is constrained by $BaSO_4$ solubility. Barium is not a constituent of concern for Silo 3.

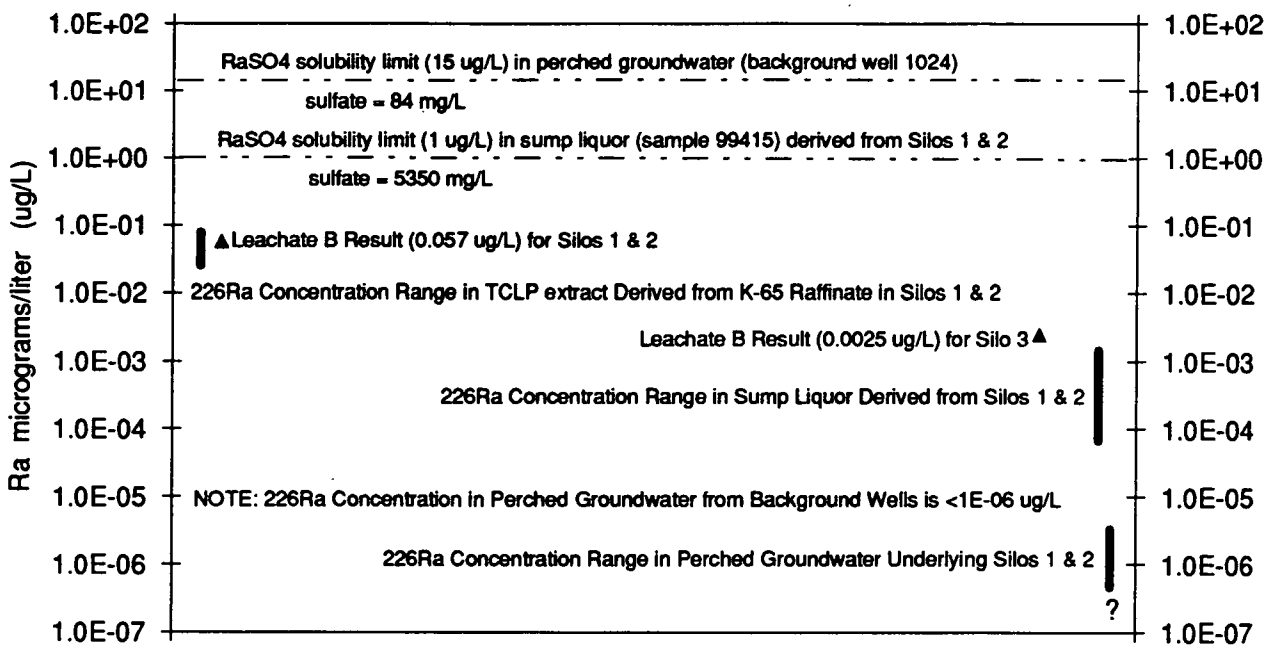
FIGURE E.3-2

BARIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B

the glacial overburden that has not been accounted for in the model because site-specific data on the concentration of barium in the carbonate minerals are unavailable.

Radium data are available for TCLP extract, sump liquor, and perched groundwater obtained from background wells and the slant borings below Silos 1 and 2 (Figure E.3-3). Concentrations of radium in these environments range from less than 1E-06 to 9E-02 µg/L. All observed radium concentrations are below the theoretical solubility limits for $RaSO_4$ in perched groundwater and decant sump liquor. The results for Leachate B indicate radium concentrations are constrained by the mean TCLP data for Silos 1 and 2, and by a single TCLP value for Silo 3. As noted above, theoretical predictions are well above the observed range of radium concentrations in decant sump liquor, TCLP extract, and perched groundwater because the pure $RaSO_4$ salt is modeled rather than a solid solution. Concentration data for barium and radium in K-65 raffinate and in decant sump liquor (Table 4-13) show the average Ba/Ra value to be 4.9×10^4 and 8.2×10^4, respectively. These ratios are very similar, and they suggest that the release of barium and radium from the K-65 raffinate in Silos 1 and 2 is controlled by solubility of a $Ba_{1-x}Ra_xSO_4$ salt.

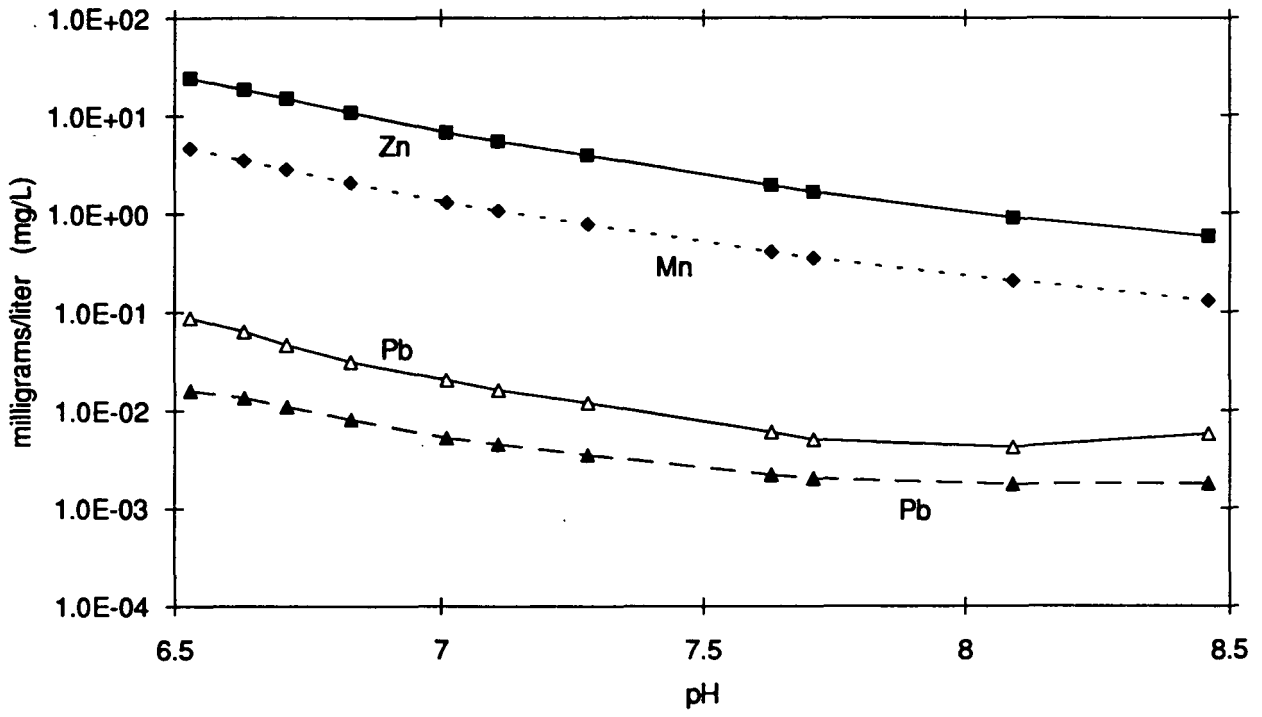
Manganese (Mn), zinc (Zn), and lead (Pb) data are discussed together because Mn^{+2}, Zn^{+2}, and Pb^{+2} ions have similar geochemical behavior in the aqueous environment when bicarbonate ion is present. Manganese, zinc, and lead concentrations in solution are dependent on the concentration of bicarbonate ion and pH (Figure E.3-4). The solubility curves shown in Figure E.3-4 are for pure $MnCO_3$ (rhodochrosite), $ZnCO_3$ (smithsonite), and $PbCO_3$ (cerussite), but substitution of manganese and zinc for calcium in calcite ($CaCO_3$) would lower the manganese and zinc concentration curves by one to two orders of magnitude (see Figures E.3-5 and E.3-6). Other metals that can readily substitute for calcium in the calcite structure include magnesium and iron. A general formula for impure calcite is $Ca_{1-(w+x+y+z)}Mg_wMn_xFe_yZn_zCO_3$. Lead does not easily substitute for calcium in the calcite structure due to the size of the Pb^{+2} ion, but limited substitution of lead, barium, and cobalt is possible (Deer et al. 1966). Figure E.3-5 summarizes data and calculations for manganese. Observed manganese concentrations in perched groundwater range from 0.003 to 6.25 mg/L, a range that overlaps with TCLP and sump liquor data. Theoretical solubility limits for $MnCO_3$ and a calcium, magnesium, and manganese carbonate intersect the ranges observed for TCLP data and perched groundwater under Silos 1 and 2, TCLP data, and perched groundwater from background wells, respectively. Solubility limits for manganese carbonate in decant sump liquor are not shown because there are no analytical data on pH and bicarbonate ion for the liquor. The model results predict manganese concentrations to be controlled by solid solution in calcite, and results fall in the lower range of observed concentration for manganese in perched groundwater from background wells. This suggests that manganese concentrations in perched groundwater are also controlled by solubility of a manganese bearing carbonate phase (e.g., dolomite or calcite). Results for Leachate B are lower than the theoretical solubility limit for manganese bearing carbonate in perched groundwater from background well 1024 because the bicarbonate concentration in Leachate B (about 600 mg/L) is higher. Figure E.3-4 illustrates the decrease in metal ion concentration when bicarbonate ion is increased.



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2 and metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled triangles) for Silos 1 & 2 and Silo 3 are constrained by the mean TCLP value and a single TCLP analysis, respectively.

FIGURE E.3-3

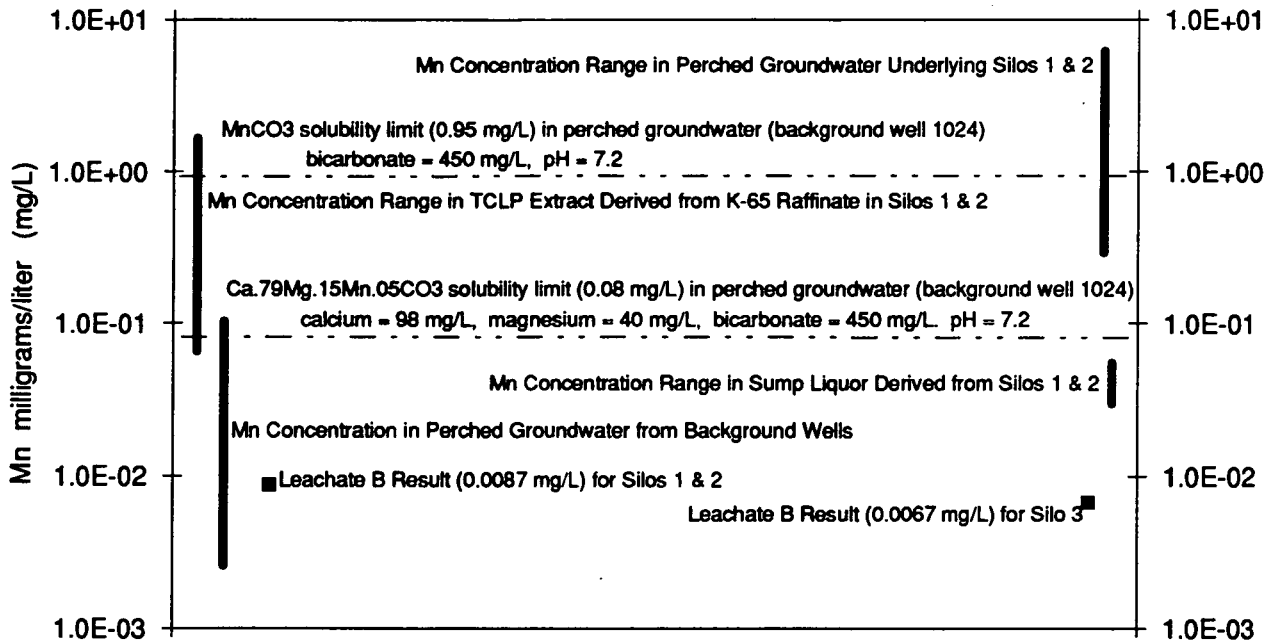
RADIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B



$MnCO_3$, $ZnCO_3$, and $PbCO_3$ solubility in perched groundwater. Solid symbols correspond to a bicarbonate concentration of 450 mg/L at pH = 6.5. Open symbols for lead indicate the increase in lead concentration when the initial bicarbonate concentration is dropped to 75 mg/L.

FIGURE E.3-4

MANGANESE, ZINC, AND LEAD CONCENTRATIONS AS A FUNCTION OF BICARBONATE ION CONCENTRATION AND pH



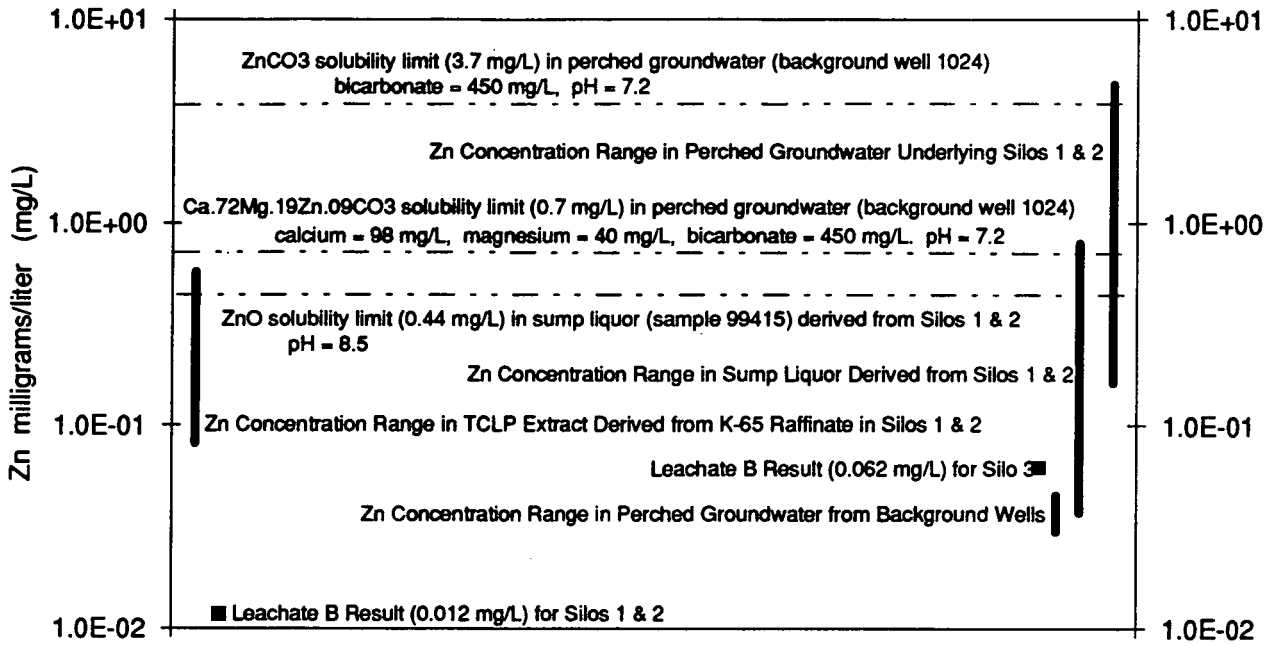
Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled squares) for Silos 1 & 2 and Silo 3 are constrained by $MnCO_3$ solubility in a carbonate solid solution.

FIGURE E.3-5

MANGANESE CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B

In Figure E.3-6, observed zinc data and solubility calculations are similar to results for manganese. Zinc concentrations in perched groundwater range from 0.032 to 4.9 mg/L, with higher concentrations being associated with perched groundwater under Silos 1 and 2. Observed concentration ranges for TCLP extract and sump liquor fall within the range defined by perched groundwater. Theoretical solubility limits are shown for $ZnCO_3$, a calcium, magnesium, and zinc carbonate, and zincite (ZnO). While the carbonates are the expected stable solid in perched groundwater, zincite may be stable in the K-65 raffinate and metal-oxide waste due to higher pH and low bicarbonate concentrations. Like $ZnCO_3$, ZnO solubility is a function of pH (Figure E.3-7), and the predicted zinc concentration range over the pH interval of 8 to 10 (the range for liquor in contact with K-65 raffinate in Silos 1 and 2) is in good agreement with observed zinc concentrations in sump liquor derived from Silos 1 and 2, suggesting ZnO controls the release of zinc to the liquor in Silos 1 and 2. The model results predict zinc concentrations to be controlled by solid solution in calcite, and results bracket the range of observed concentration for zinc in perched groundwater from background wells. This suggests that zinc concentrations in perched groundwater are also controlled by the solubility of a zinc bearing carbonate phase (e.g., dolomite or calcite). Results for Leachate B are lower than the theoretical solubility limit for zinc bearing carbonate in perched groundwater from background well 1024 because the bicarbonate concentration in Leachate B (about 600 mg/L) is higher. Figure E.3-4 illustrates the decrease in metal ion concentration when bicarbonate ion is increased.

Observed data, solubility calculations, and model results for lead are given in Figure E.3-8. Lead concentrations in perched groundwater range from less than 0.002 to 0.08 mg/L, and in decant sump liquor from 0.132 to 0.602 mg/L. EP Tox extract shows lead concentrations overlapping with the perched groundwater and decant sump liquor, but TCLP extract data indicate very high lead concentrations (117 to 841 mg/L). The high lead concentrations in TCLP extract may be due to complexation of lead by acetate ion and/or a more soluble lead solid in K-65 raffinate (e.g., $PbSO_4$) relative to metal-oxide waste (e.g., PbO). Theoretical solubility limits for $PbSO_4$ in sump liquor and $PbCO_3$ in perched groundwater bracket the observed lead concentrations for all data sets except TCLP data. In particular, the sump liquor lies near the $PbSO_4$ solubility boundary, and perched groundwater under Silos 1 and 2 extends below sump liquor to the $PbCO_3$ solubility boundary. These observations are consistent with lead concentrations in liquor from Silos 1 and 2 being controlled by $PbSO_4$ solubility. As the lead enters the bicarbonate environment present in perched groundwater, $PbCO_3$ becomes the controlling solid phase for lead concentrations. Alternatively, dilution of sump liquor by perched groundwater will also lower the lead concentration. Results for Leachate B predict lead is controlled by the solubility of $PbCO_3$ near the upper concentration level observed for lead in perched groundwater from background wells and the predicted solubility boundary for $PbCO_3$ in perched groundwater from background well 1024. This is consistent with lead concentrations in perched groundwater from background wells being controlled by the solubility of cerussite ($PbCO_3$).
Figure E.3-9 summarizes data and model results for cadmium. Cadmium concentrations in perched groundwater range from less than 0.002 to 0.025 mg/L, and this range overlaps with observed data for



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled squares) for Silos 1 & 2 and Silo 3 are constrained by $ZnCO_3$ solubility in a carbonate solid solution.

FIGURE E.3-6

ZINC CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B

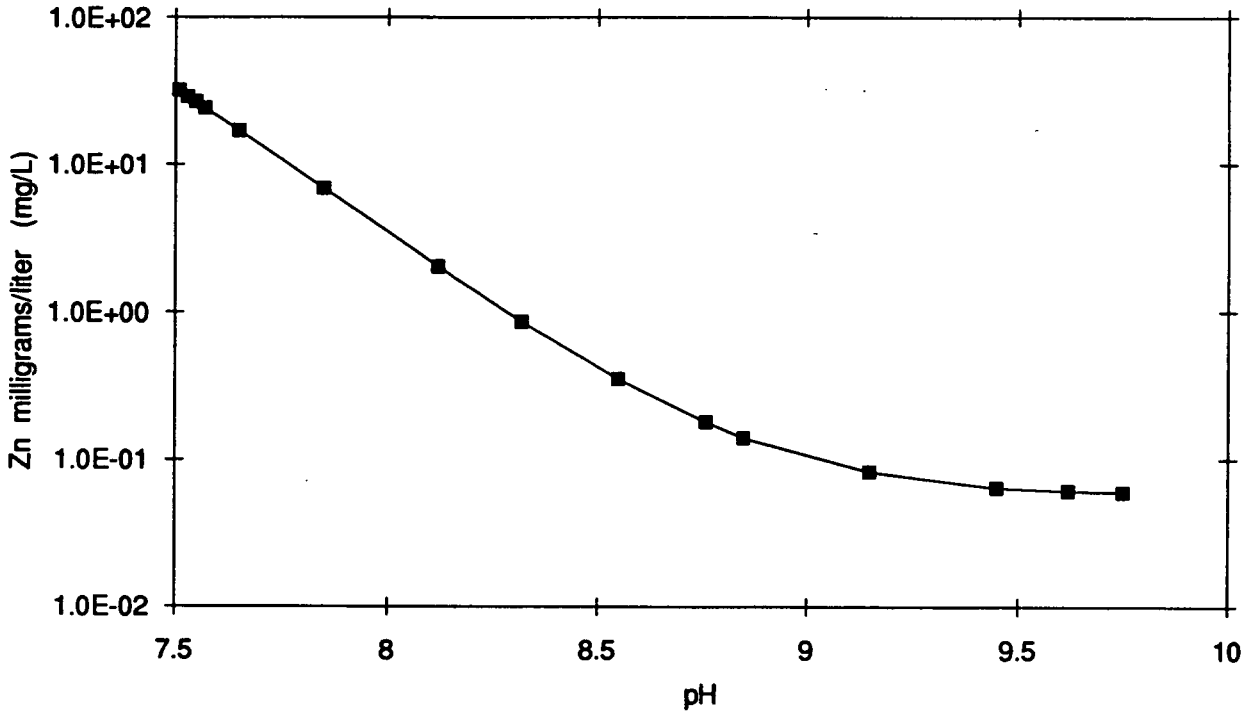
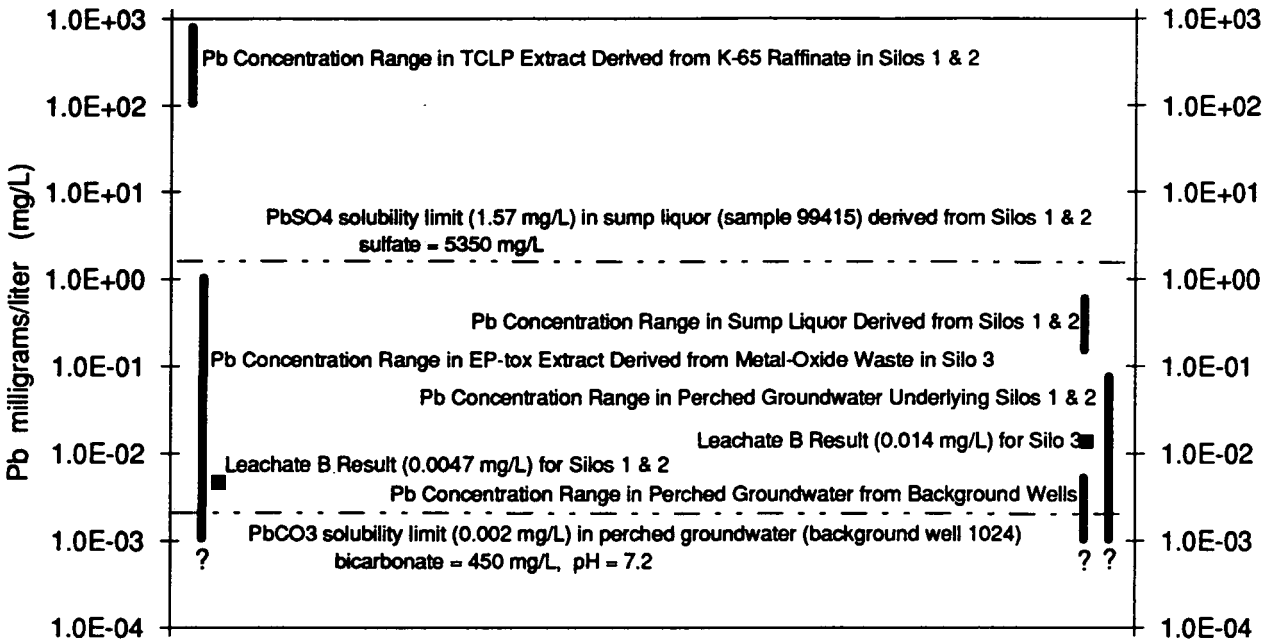


FIGURE E.3-7

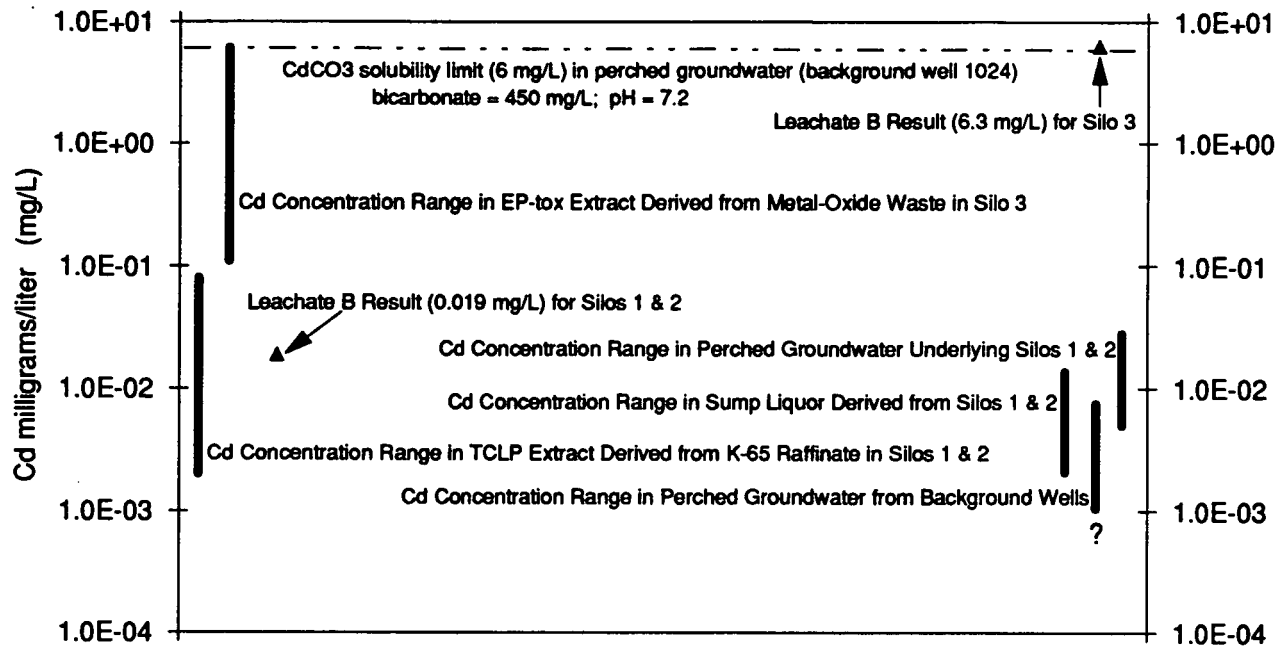
ZnO SOLUBILITY IN SILO 1 AND 2 DECANT SUMP LIQUOR AS A FUNCTION OF pH



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2; and 5) EP-tox extract derived from metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled squares) for Silos 1 & 2 and Silo 3 are constrained by $PbCO_3$ solubility.

FIGURE E.3-8

LEAD CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2; and 5) EP-tox extract derived from metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled triangles) for Silos 1 & 2 and Silo 3 are constrained by the mean TCLP value and maximum EP-tox value, respectively.

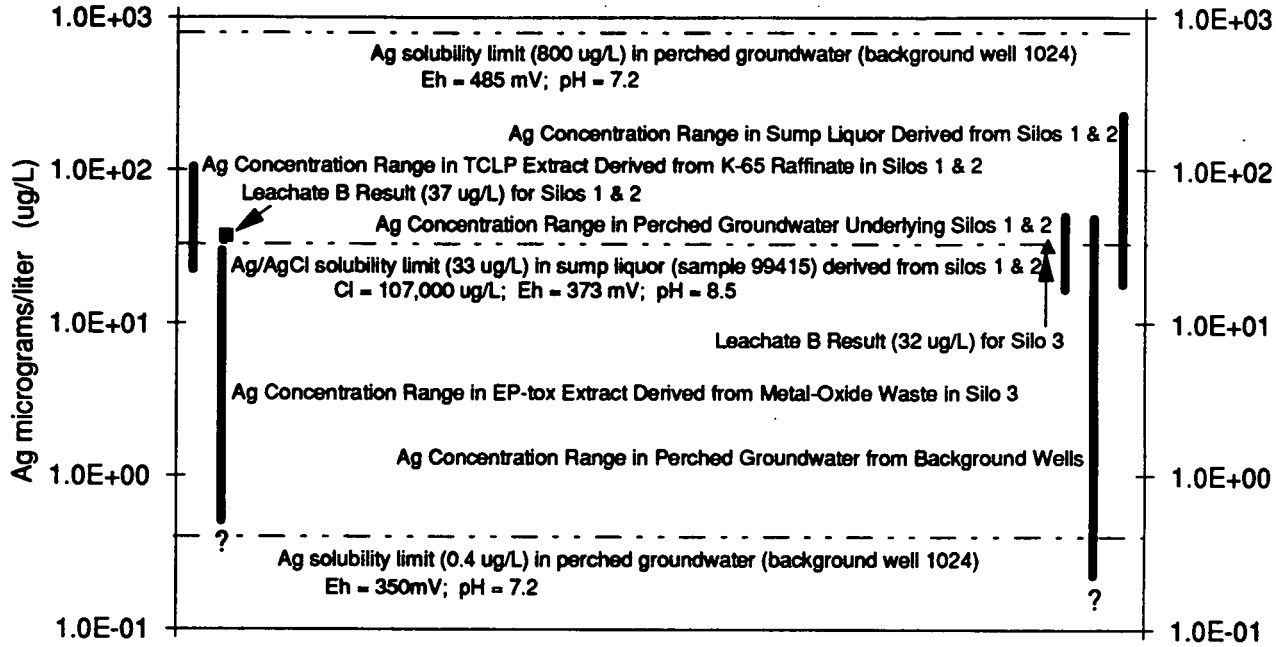
FIGURE E.3-9

CADMIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B

sump liquor and TCLP extract. EP Tox extract has cadmium concentrations that range from 0.1 to 6 mg/L. Results for Leachate B reflect the mean TCLP value for Silos 1 and 2, and the maximum EP Tox value for Silo 3. The maximum EP Tox value was used over a mean value because the EP Tox data set had only one-third the number of analyses relative to TCLP data for Silos 1 and 2. Within the observed range of cadmium concentrations, only $CdCO_3$ is predicted to reach a solubility limit. However, $CdCO_3$ is unlikely to form in the natural environment because cadmium concentrations are kept below the pure salt saturation point by adsorption and/or substitution in the structure of lead minerals (Deer et al., 1966).

Silver (Ag) and mercury (Hg) data are discussed together because they have similar geochemical behavior in the aqueous environment. These elements tend to be present in their native element state as a solid (Ag) and a liquid (Hg), but both will form chloride solids under oxidizing conditions when a moderate concentration of chloride ion (e.g., 100 mg/L Cl^-) is present (Brookins, 1988).

Observed data and theoretical solubility limits for silver are summarized in Figure E.3-10. Silver concentrations in perched groundwater range from less than 0.5 to 49 µg/L, and this range overlaps with EP Tox data. TCLP data show silver concentrations peaking at 100 µg/L, and sump liquor as high as 200 µg/L. Theoretical solubility boundaries for Ag in perched groundwater indicate the sensitivity of the aqueous silver concentration to an increase in Eh (compare the Ag solubility limit of 800 µg/L at an Eh of 450 millivolts to the limit of 0.4 µg/L at an Eh of 350 mV). Eh is a measurement of the oxidation potential of groundwater. The oxidation potential is dependent on the oxygen activity in groundwater, which is equal to the fugacity of oxygen in the groundwater environment. Assuming ideal behavior for oxygen gas, the fugacity is equal to the partial pressure of oxygen. As the partial pressure of oxygen in the groundwater increases, the activity of oxygen in groundwater increases and Eh values increase. Native silver has a higher solubility at higher Eh values because the metal is oxidized to form the Ag^+ ion. For perched groundwater with low chloride concentration (less than 10 mg/L), silver concentrations controlled by silver solubility will be a function of the oxygen activity in groundwater, which could explain the two order of magnitude range in silver concentrations for perched groundwater from background wells. In sump liquor obtained from Silos 1 and 2, the solubility boundary for Ag and AgCl occurs when Eh = 373 millivolts, pH = 8.5, and chloride = 107 mg/L (i.e., under these conditions both solids are equally saturated in the sump liquor). This boundary intersects the silver concentration range of all observed data. For the sump liquor data, silver concentrations above this solubility boundary may be interpreted to be controlled by AgCl solubility at Eh greater than 373 millivolts, while below this boundary silver concentration may be controlled by Ag solubility at Eh less than 373 millivolts. Leachate B results for silver are controlled by AgCl solubility for Silos 1 and 2, and by the EP Tox maximum for Silo 3, and these results are in agreement with observed data in perched groundwater and sump liquor.



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2; and 5) EP-tox extract derived from metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B result for Silos 1 & 2 (filled square) is constrained by AgCl solubility, and for Silo 3 (filled triangle) by the maximum EP-tox value.

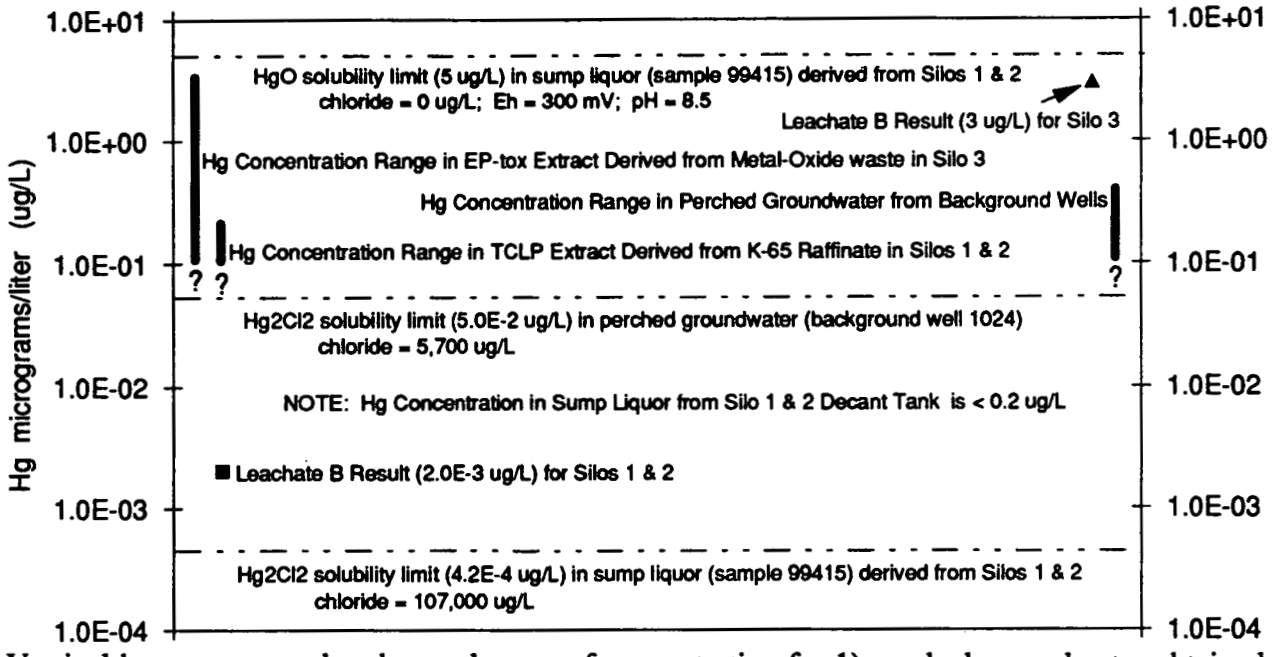
FIGURE E.3-10

SILVER CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B

Mercury data, solubility calculations, and Leachate B results are summarized in Figure E.3-11. Mercury concentrations in perched groundwater from background wells (data unavailable for perched groundwater under Silos 1 and 2) range from less than 0.2 to 0.4 µg/L. TCLP data are restricted to mercury levels of 0.2 µg/L or less, though EP Tox results for metal-oxide waste go as high as 3 µg/L. Sump liquor data show all analyses to have mercury concentrations of less than 0.2 µg/L. Theoretical solubility limits for boundary conditions in sump liquor and perched groundwater indicate mercury concentrations as high as 5 µg/L (HgO solubility) and as low as 0.05 µg/L (Hg_2Cl_2 solubility), respectively. Note that the HgO solubility in sump liquor was modeled with chloride equal to zero to simulate possible conditions in the metal-oxide waste, and a boundary also appears for Hg_2Cl_2 at 0.0004 µg/L mercury. A theoretical solubility boundary for liquid mercury, or quicksilver, is not indicated on Figure E.3-11 because this boundary occurs in perched groundwater (pH = 7.2, Eh = 350 millivolts and 25°C) at a mercury concentration of 1.6×10^{-17} µg/L. Solubility boundaries for Hg_2Cl_2 and liquid mercury support observations for mercury in sump liquor (i.e., less than 0.2 µg/L), but not in the aqueous environment of the glacial overburden. However, analytical results for mercury in perched groundwater are very near the detection limit (0.2 µg/L) of the analytical method, and large errors may be associated with the reported concentration of 0.3 µg/L. Leachate B results indicate mercury concentration is controlled by the solubility of Hg_2Cl_2 for Silos 1 and 2, and by the maximum EP Tox result for Silo 3. The Leachate B result for Silos 1 and 2 lies above the theoretical boundary for Hg_2Cl_2 in sump liquor because the modeled Leachate B concentration had a lower chloride concentration (32,000 µg/L). For Silo 3, Leachate B is constrained by the maximum EP Tox value, which lies close to the HgO solubility boundary for chloride-free sump liquor. This implies that metal-oxide waste could release mercury in the low µg/L range under oxidizing conditions and the absence of chloride. However, if mercury is released from Silo 3 at the predicted concentration of 5 µg/L, the lower Eh and presence of chloride in the perched groundwater environment is likely to cause precipitation of Hg_2Cl_2, or liquid mercury. This scenario is in agreement with the majority of observations in perched groundwater and sump liquor, and the theoretical solubility boundaries for Hg_2Cl_2 and liquid mercury.

Chromium (Cr), copper (Cu), beryllium (Be), nickel (Ni), thorium (Th), and uranium (U) are predicted to form oxide compounds in most of the waste and groundwater environments. In the groundwater environment, Eh values have been measured in the range of 100 to 450 millivolts over a pH range of 7 to 7.5 (FEMP Groundwater Report, Dec 1990). Over this Eh and pH range, chromium and copper may exist as Cr^{+3}, Cr^{+4}, Cu^{+}, and Cu^{+2} ions, which results in a variety of oxide solids to consider in solubility calculations. The summary diagrams for chromium and copper will be discussed first, followed by beryllium, nickel, thorium, and uranium.

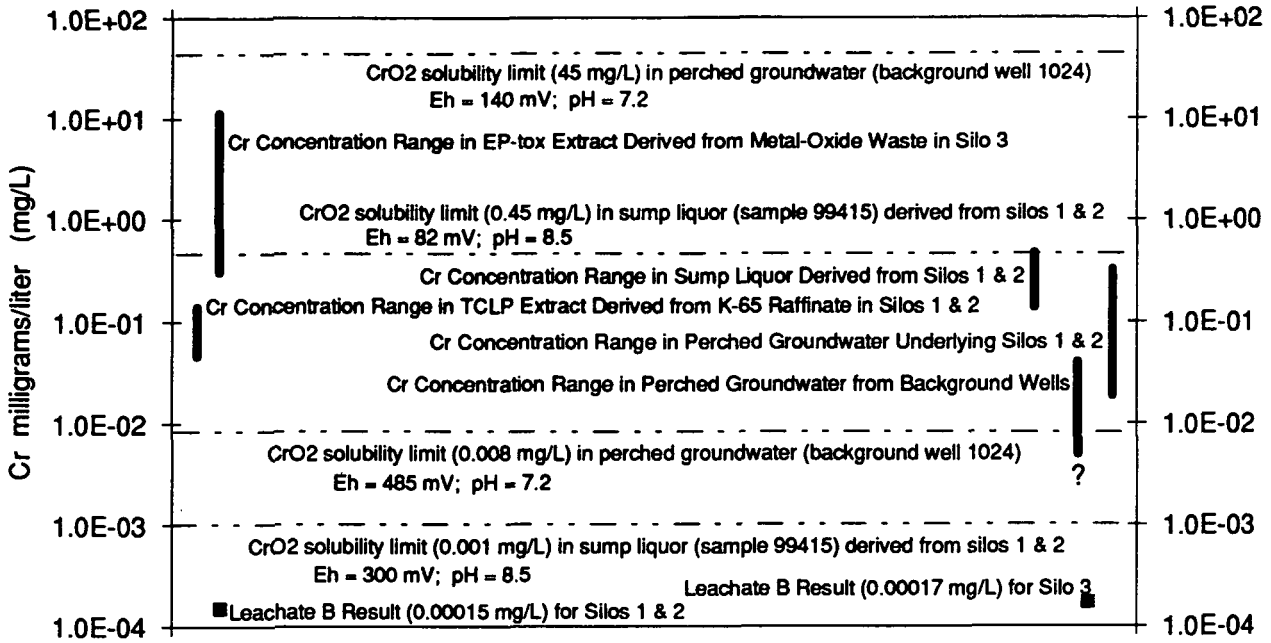
Figure E.3-12 summarizes the observed data, solubility calculations, and Leachate B results for chromium. Chromium concentrations in perched groundwater range from less than 0.01 to 0.38



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) sump liquor obtained from the decant tank below Silos 1 & 2; 3) TCLP extract derived from K-65 raffinate in Silos 1 & 2; and 4) EP-tox extract derived from metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B result for Silos 1 & 2 (filled square) is constrained by Hg_2Cl_2 solubility, and for Silo 3 (filled triangle) by the maximum EP-tox value.

FIGURE E.3-11

MERCURY CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B



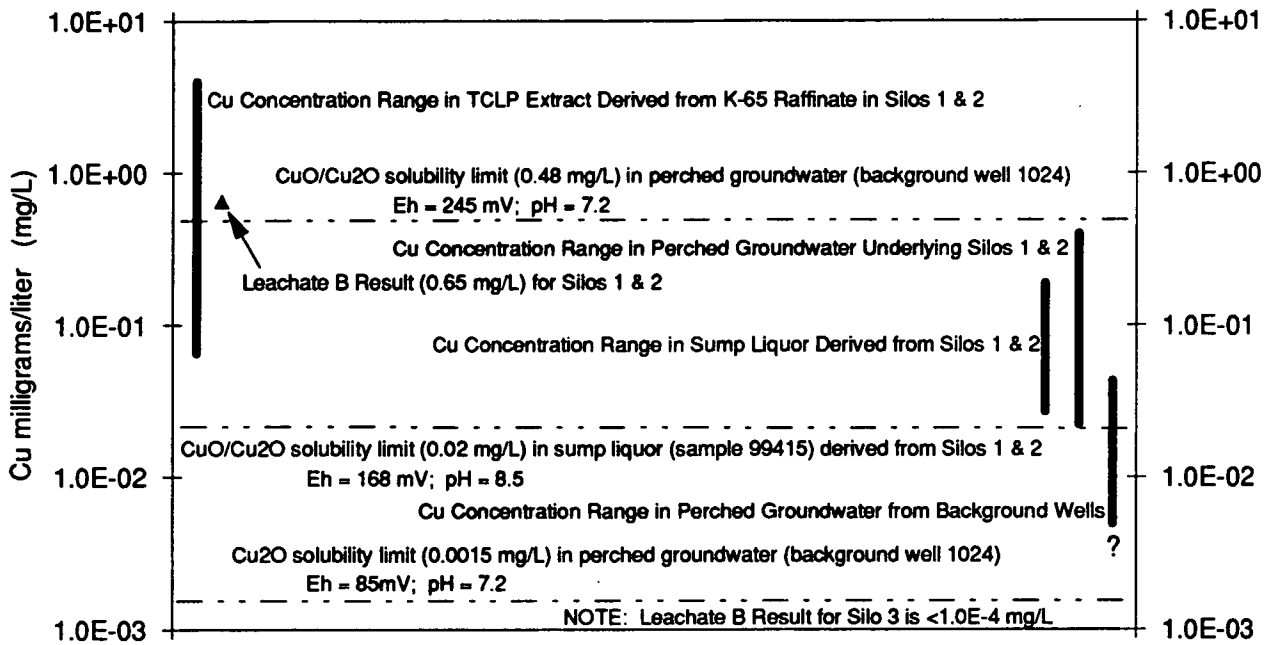
Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2; and 5) EP-tox extract derived from metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled squares) for Silos 1 & 2 and Silo 3 are constrained by CrO_2 solubility.

FIGURE E.3-12

CHROMIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B

milligrams/liter (mg/L), and this range overlaps with TCLP data and most results for chromium in sump liquor. Data derived from EP Tox extract indicates chromium levels as high as 12 mg/L. Theoretical solubility boundaries for CrO_2 in perched groundwater agree with observed values in perched groundwater from background wells when Eh is 485 millivolts, but as Eh falls to 140 millivolts the chromium concentration rises by nearly four orders of magnitude. The rise in chromium concentration as Eh decreases is attributed to reducing the Cr^{+4} ion in equilibrium with CrO_2 to Cr^{+3}, which increases the solubility of CrO_2. Solubility boundaries for CrO_2 in sump liquor are consistent with observed chromium values in sump liquor when Eh is 82 millivolts, but at Eh of 300 millivolts the solubility of CrO_2 decreases to 0.001 mg/L. Based on the overlap of solubility boundaries with observed data fields, oxygen activity in perched groundwater and sump liquor is predicted to be, respectively, oxidizing and transitional (i.e., between oxidizing and reducing). Leachate B results predict chromium concentration to be constrained by solubility with CrO_2, yet the results lie below the CrO_2 solubility boundary in sump liquor at Eh = 300 millivolts and pH = 8.5. This difference arises because the model predicts higher pH and Eh values (about 400 millivolts at pH 9.2) in Leachate B relative to the values assumed for the decant sump liquor.

Observed data and solubility calculations for copper are summarized in Figure E.3-13. Copper concentrations in perched groundwater range from less than 0.01 to 0.39 mg/L, with higher values occurring in groundwater below Silos 1 and 2. The range of copper values in sump liquor falls within the range observed for perched groundwater under Silos 1 and 2. Copper concentrations in TCLP extract go as high as 3.9 mg/L. Theoretical solubility boundaries for CuO and Cu_2O in perched groundwater are shown at Eh of 245 millivolts and Eh of 85 millivolts. The solubility limit at 0.48 mg/L copper is with respect to CuO and Cu_2O, that is both solids are equally saturated in perched groundwater at Eh = 245 millivolts and pH = 7.2. Below an Eh of 245 millivolts, Cu_2O is the most stable phase in perched groundwater with pH = 7.2, and a Cu_2O solubility boundary at Eh = 85 millivolts occurs at a copper concentration of 0.0015 mg/L. Note that this lower boundary is consistent with groundwater copper concentrations reported as below a detection level of 0.01 mg/L, and the range in perched groundwater concentrations can be interpreted as variation in the activity of oxygen in groundwater contacting Cu_2O. That is, increasing the activity of oxygen in groundwater would raise the lower Cu_2O solubility boundary into the field of observed groundwater concentrations, and this occurs due to the oxidation of Cu^{+} to Cu^{+2}. The solubility boundary for saturation of CuO and Cu_2O in sump liquor occurs at a copper concentration of 0.02 mg/L, and this boundary is at the lower end of the observed range for sump liquor and perched groundwater under Silos 1 and 2. If CuO or Cu_2O controls the copper concentration in sump liquor, then moving the calculated solubility boundary into the sump liquor range requires an increase in Eh or a decrease in pH. The solubility of both copper oxides is dependent on pH (Figure E.3-14), and a lowering of pH will have a greater effect on the copper concentration relative to an increase in Eh. Raising Eh above 168 millivolts, at pH = 8.5, will not produce the strong variance observed for copper ion in equilibrium with Cu_2O, as



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B result for Silos 1 & 2 (filled triangle) is constrained by the mean TCLP value, and for Silo 3 by CuO solubility (below the lowest concentration on the y-axis).

FIGURE E.3-13

COPPER CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B

noted above for perched groundwater. The strong Eh dependence is not observed for CuO because it is the stable phase above an Eh of 168 millivolts, and the Cu^{+2} ion will not be oxidized to a higher state in naturally occurring waters. Leachate B results indicate that copper is constrained by the mean TCLP value for Silos 1 and 2, and by Cu_2O solubility for Silo 3. The TCLP value is near the predicted solubility limit for CuO/Cu_2O in perched groundwater at pH = 7.2, and saturation with respect to one of these phases was not reached because the Leachate B result for Silos 1 and 2 has a slightly lower pH of 7.1. For Silo 3, a pH of 10.5 is predicted for Leachate B, and this results in a very low copper concentration when Cu_2O is the stable solid phase (Figure E.3-14).

Figure E.3-15 summarizes the observed data and predicted results for beryllium. Beryllium concentrations in perched groundwater underlying Silos 1 and 2, sump liquor, and TCLP extract all fall in the range of less than 1 to 10 µg/L. Note that all beryllium concentrations in groundwater from background wells are reported as less than 1 µg/L. Theoretical solubility boundaries for bromellite (BeO) are given for perched groundwater at pH 7.2 and sump liquor at pH of 10 and 8.5. The solubility of BeO is a function of pH with a minimum beryllium concentration occurring at a pH of about 8 (Figure E.3-16). The predicted solubility limit for BeO in perched groundwater is consistent with beryllium concentrations of less than 1 µg/L in groundwater from background wells. Observed beryllium values in perched groundwater under Silos 1 and 2, and sump liquor can be explained if the pH of these waters is between 8.5 and 10 or less than 8 (Figure E.3-16). Unfortunately, pH measurements are not available for these waters to test this hypothesis. Leachate B results for beryllium agree with observed values in perched groundwater and sump liquor. The Leachate B results lie above the predicted solubility limit of BeO in groundwater at pH of 7.2 because the pH of Leachate B is 7.1 for Silos 1 and 2, and 7 for Silo 3.

Observed concentrations and Leachate B results for nickel are summarized in Figure E.3-17 with solubility boundaries for NiO in sump liquor. Nickel concentrations in perched groundwater range from less than 0.02 to 0.37 mg/L, which encloses the range of values reported in sump liquor samples. TCLP extract data ranges from 1.32 to 5.8 mg/L nickel. The solubility boundaries for NiO in sump liquor are calculated at pH of 8.9 and 10, as NiO becomes increasingly unstable (i.e., more soluble) below a pH of 9. Solubility boundaries for nickel solids in contact with perched groundwater are not shown because the boundaries lie at nickel concentration values well above all observed data ranges in Figure E.3-17. The nickel concentrations in sump liquor are consistent with solubility control by NiO if the pH of the liquor is between 9 and 10. However, perched groundwater from background wells have pH between 7 and 7.5, and the nickel concentrations in these waters are likely to be controlled by adsorption. Although pH measurements are unavailable for perched groundwater, a similar conclusion is drawn for the perched groundwater under Silos 1 and 2 because pH above 8.5 has not been observed in any perched groundwater sampled across the site. Leachate B results indicate nickel

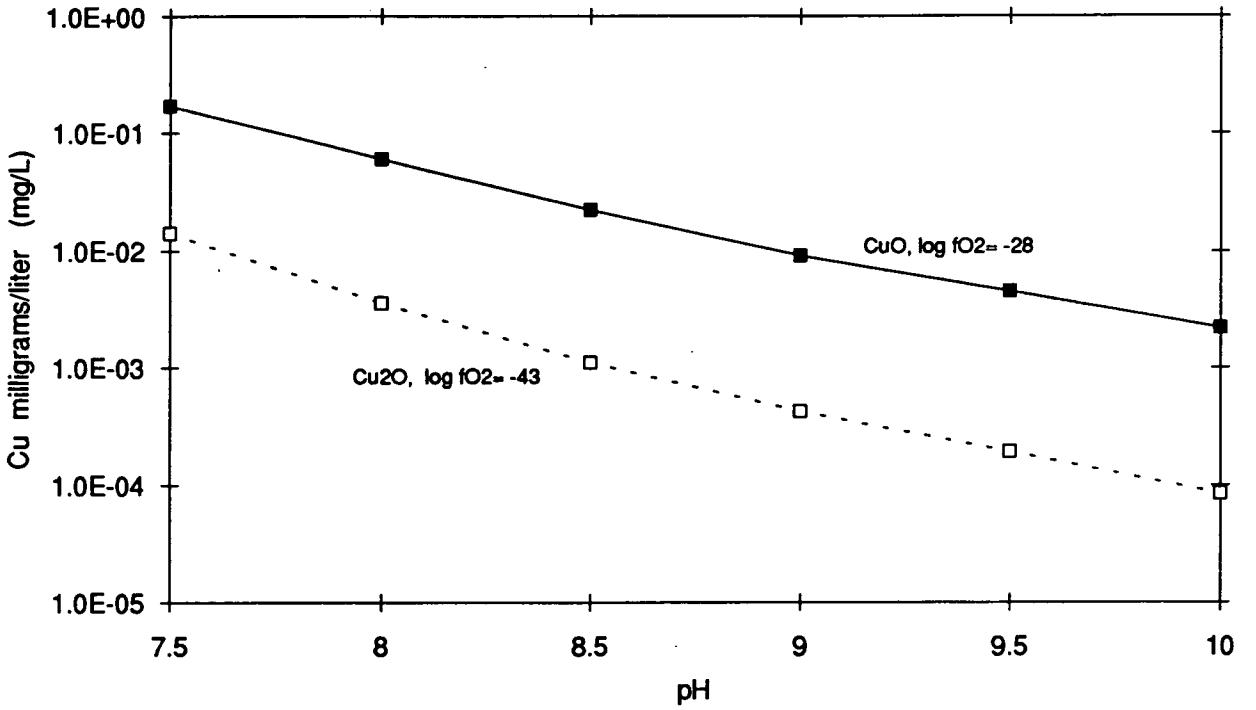
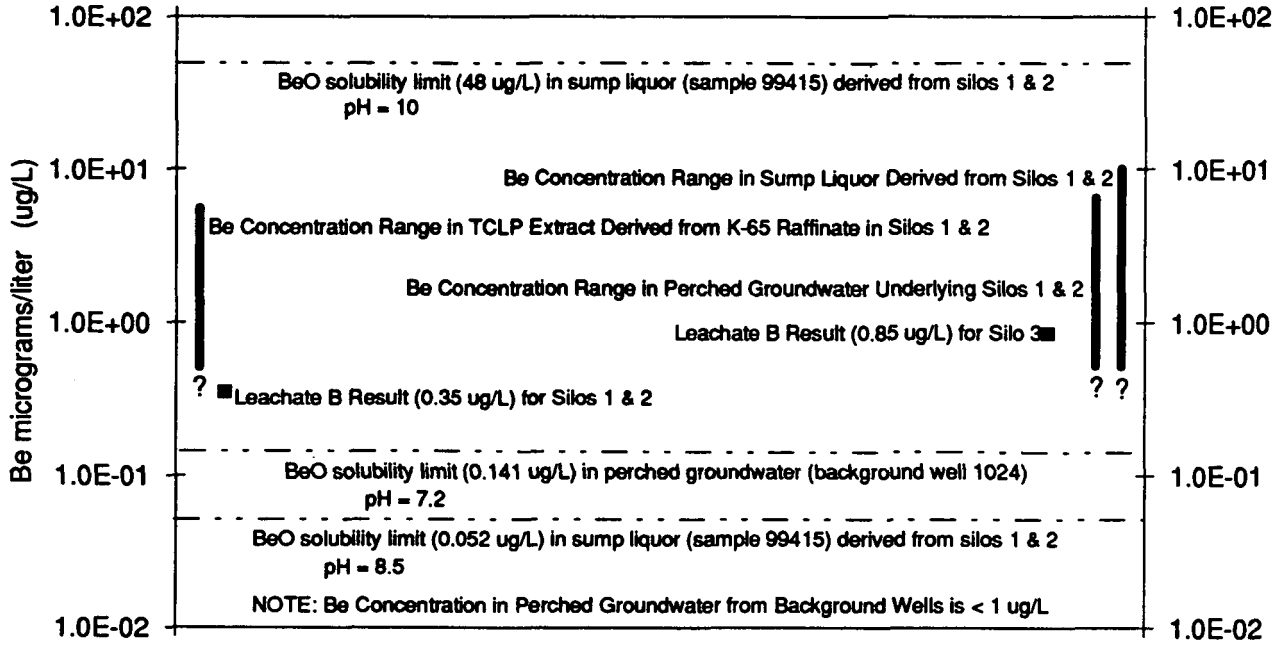


FIGURE E.3-14

CuO AND Cu_2O SOLUBILITY IN SILO 1 AND 2 DECANT SUMP LIQUOR AS A FUNCTION OF OXYGEN FUGACITY (fO_2) AND pH



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled squares) for Silos 1 and 2 and Silo 3 are constrained by BeO solubility.

FIGURE E.3-15

BERYLLIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B

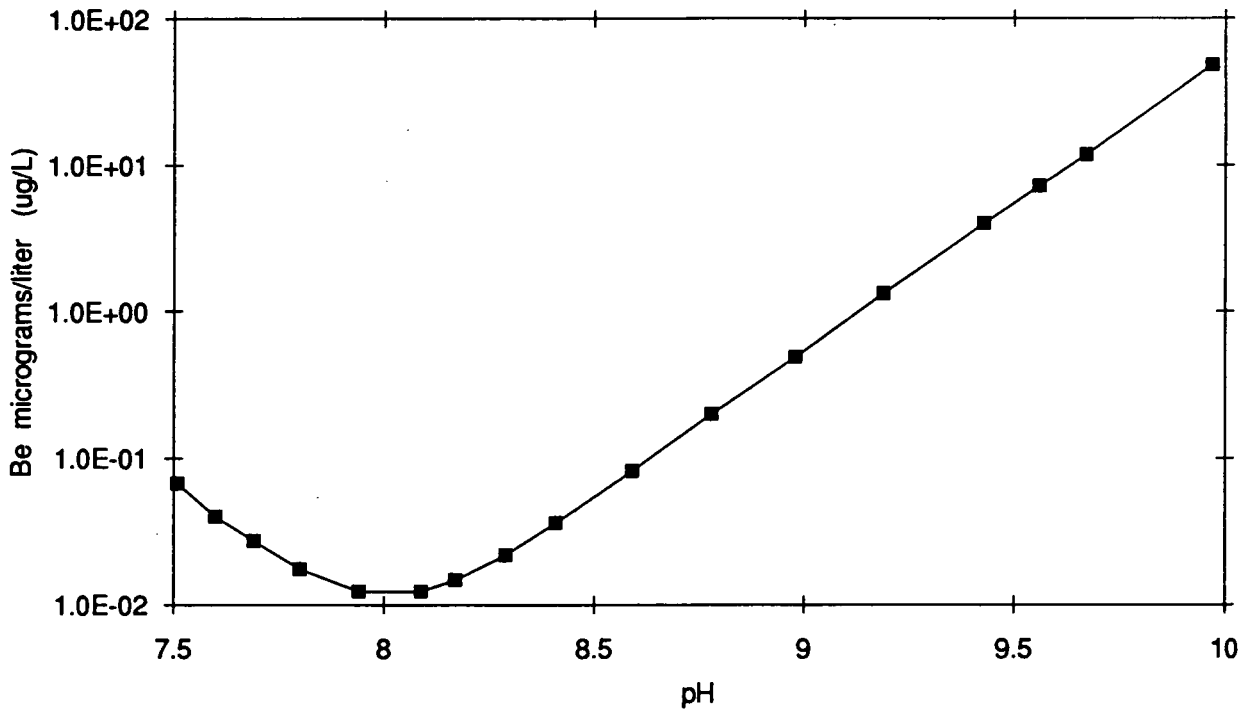
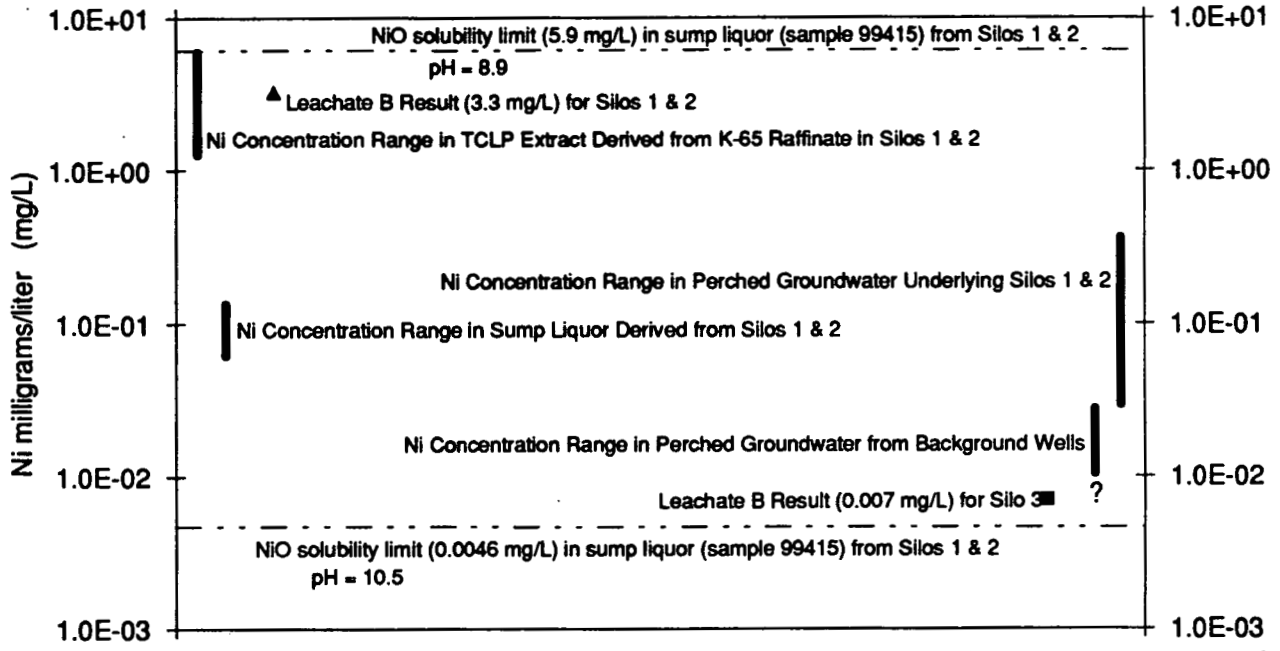


FIGURE E.3-16

BeO SOLUBILITY IN SILO 1 AND 2 DECANT SUMP LIQUOR AS A FUNCTION OF pH



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B result for Silos 1 & 2 (filled triangle) is constrained by the mean TCLP value, and for Silo 3 (filled square) by NiO solubility.

FIGURE E.3-17

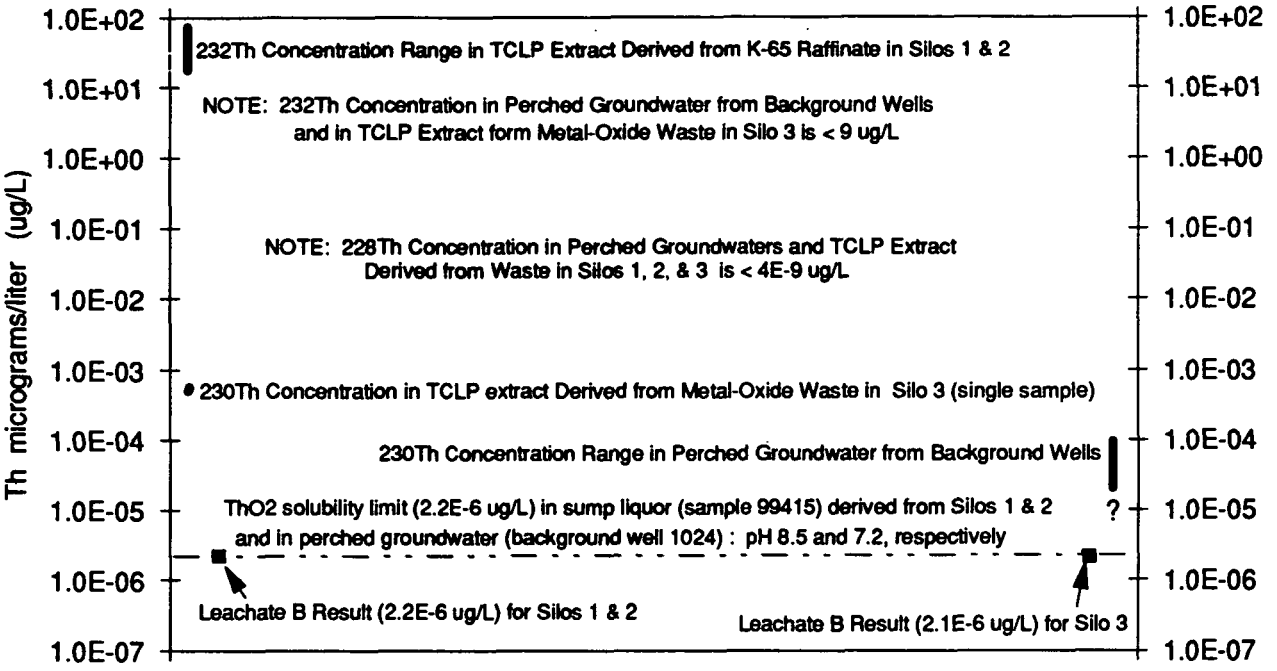
NICKEL CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B

concentrations are constrained by the mean TCLP value for Silos 1 and 2, and by NiO solubility for Silo 3. The Leachate B result for Silo 3 falls near the NiO solubility boundary for sump liquor at pH = 10.5, as the modeled Leachate B pH is also 10.5.

Figure E.3-18 summarizes observed data and solubility calculations for thorium. Observed thorium isotope concentrations in perched groundwater are less than 4 x 10^{-9} µg/L for Th-228, less than 4 x 10^{-5} to 1 x 10^{-4} µg/L for Th-230, and less than 9 µg/L for Th-232. TCLP data for Th-232 show very high concentrations from 17 to 76.5 µg/L, consistent with an extract with pH below 4 and high concentration of sulfate ion. Thorium is known to be mobilized from uranium mill tailings when pH is below 4, and sulfate ion is available for complexation (Brookins 1988). A single TCLP extract analysis from Silo 3 waste has Th-232 less than 9 µg/L and ^{230}Th at 5 x 10^{-4} µg/L. The theoretical solubility boundary for ThO_2 lies at 2.2 x 10^{-6} µg/L thorium, and this boundary lies between observed groundwater values for Th-228 and Th-230. Because the solubility boundary is identical for ThO_2 in sump liquor and perched groundwater, and given Leachate B results at pH 9.3 and 10.5 also fall on this boundary, it is noted that ThO_2 solubility is independent of pH over the range of 7 to 10.5. This conclusion is consistent with observations of thorium concentrations in groundwater across the FEMP site. As noted above, thorium mobility in water is generally restricted to drainage from uranium mill tailings, where pH is less than 4 and sulfate ion is present to complex the thorium as $ThSO_4^{+2}$ (Brookins 1988).

Uranium data and solubility calculations are presented in Figure E.3-19. Observed uranium concentrations in perched groundwater range from less than 0.001 to 0.44 mg/L and in sump liquor range from less than 24 to 77 mg/L. TCLP extract derived from waste in Silos 1 and 2 has uranium values that range from 0.76 to 12 mg/L, and the single analysis for Silo 3 is 0.26 mg/L. Theoretical solubility boundaries for $CaUO_4$ in sump liquor at pH 8.5 and 10 bracket the observed range of uranium in sump liquor, suggesting uranium in sump liquor may be controlled by $CaUO_4$ over the pH interval of 8.5 to 10. A solubility boundary for $(UO_2)_2SiO_4{:}2H_2O$ (soddyite) in perched groundwater at pH 7.2 lies near the maximum uranium concentration observed for perched groundwater under Silos 1 and 2, and also cuts the field of uranium values observed for TCLP extract. Although soddyite is known to occur in low temperature uranium ore deposits, nucleation and precipitation of silicate minerals under low temperature conditions generally takes thousands to millions of years (Lasaga and Kirkpatrick 1981). Therefore, it is unlikely that soddyite will form in the time frame of concern to the FEMP risk assessment. Leachate B results indicate uranium concentrations are constrained by the mean TCLP value for Silos 1 and 2, and by the single TCLP analysis for Silo 3.

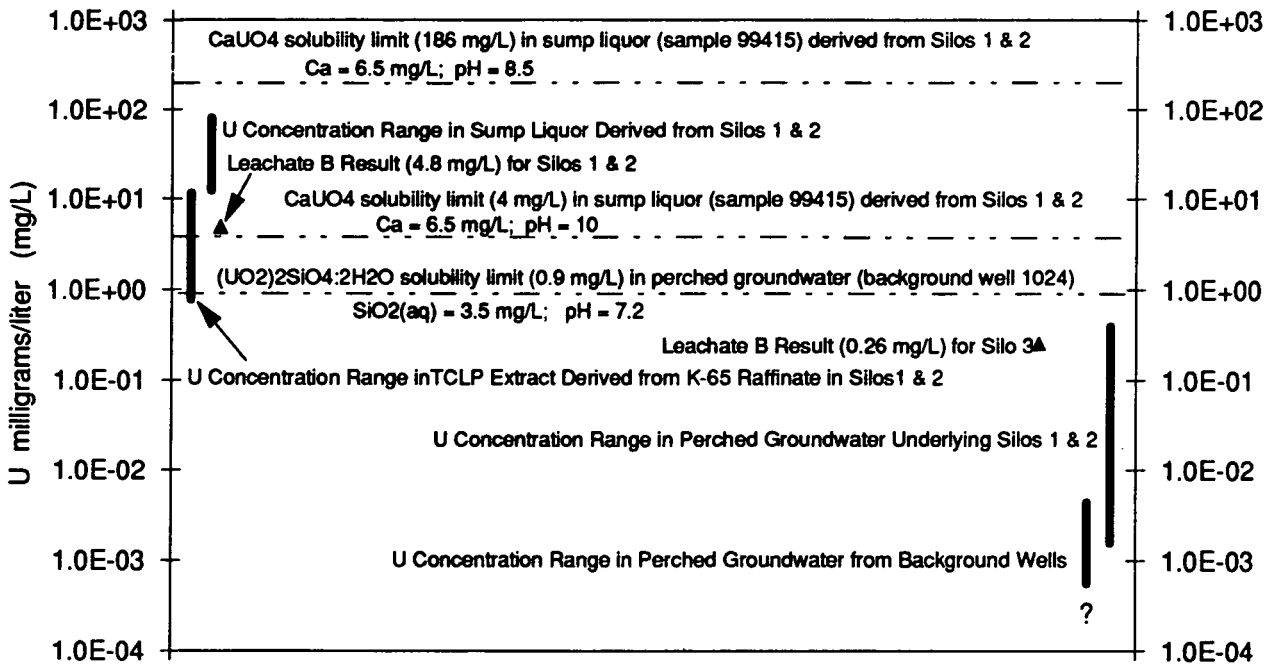
The remaining constituents of concern for which there are comparable site-specific data sets are vanadium (V), cobalt (Co), arsenic (As), selenium (Se), molybdenum (Mo), and thallium (Tl). However, solubility calculations were not carried out for these elements because:



Vertical bars represent the observed range of concentration for individual isotopes in perched groundwater obtained from background wells or TCLP extract. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled squares) for Silos 1 & 2 and Silo 3 are constrained by ThO_2 solubility.

FIGURE E.3-18

THORIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, TCLP EXTRACT, AND LEACHATE B



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. Horizontal dashed lines indicate theoretical solubility limits for the indicated phase at 25°C and 1 atmosphere, given the dependent solute concentrations when appropriate. The Leachate B results (filled triangles) for Silos 1 & 2 and Silo 3 are constrained by the mean TCLP value and a single TCLP analysis, respectively.

FIGURE E.3-19

URANIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B

- Thermodynamic data for solid solution phases (e.g., As in Fe_2O_3 or other iron oxyhydroxide minerals, Co in $CaCO_3$, etc.) are not available.

- The pure endmember minerals of these elements form soluble solids (e.g., As_2O_3, $CoCO_3$) and calculated solubility limits for these pure endmembers exceed observed concentrations by several orders of magnitude.

- Most of the listed elements have their concentrations in groundwater controlled by substitution in host mineral structures or by adsorption.

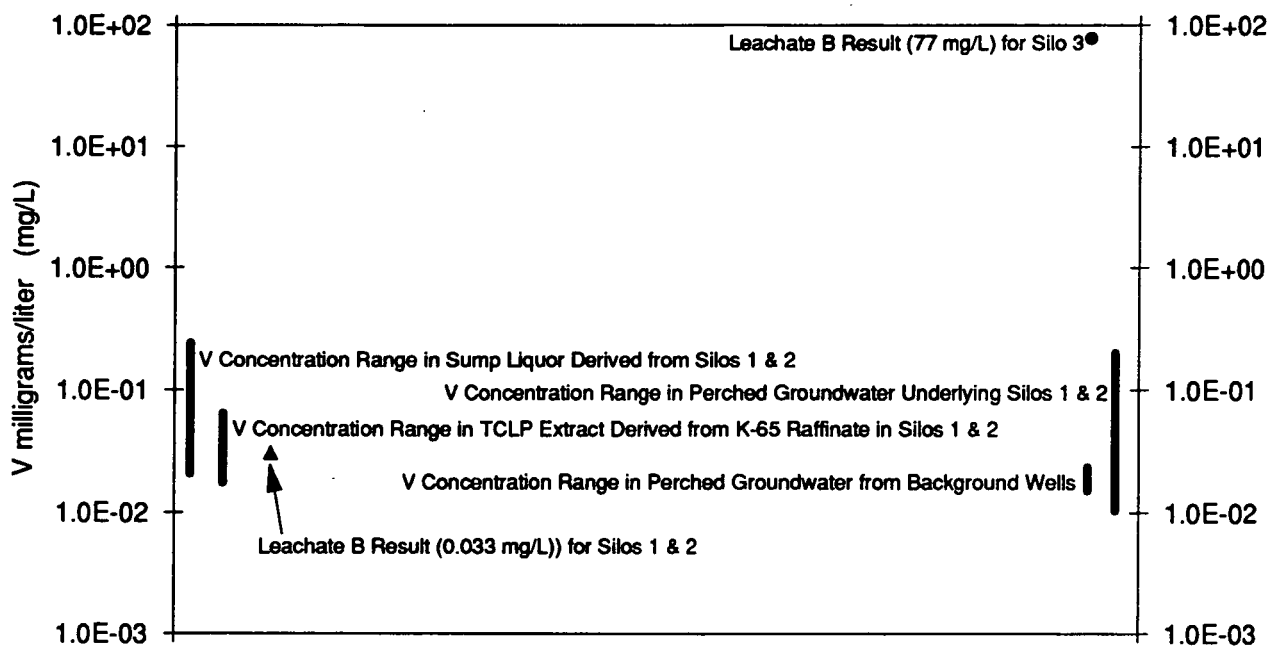
Figure E.3-20 summarizes observed data and Leachate B results for vanadium. Vanadium concentrations in perched groundwater range from 0.01 to 0.2 mg/L, which overlaps with concentrations reported for sump liquor and TCLP extract. Leachate B results for vanadium are constrained by the mean TCLP value for Silos 1 and 2, and by the 70-year rule for Silo 3. There are no site-specific data for vanadium concentrations in leachate generated from Silo 3 waste.

Observed data and Leachate B results for cobalt are summarized in Figure E.3-21. Cobalt concentrations in perched groundwater below Silos 1 and 2 and sump liquor range from less than 0.01 to 0.1 mg/L, and rise to 0.72 to 6.2 mg/L in TCLP extract derived from waste in Silos 1 and 2. Perched groundwater obtained from background wells has no detectable cobalt at a level of 0.02 mg/L. Leachate B results for cobalt are constrained by the mean TCLP value for Silos 1 and 2, and by the 70-year rule for Silo 3. There are no site-specific data for cobalt concentrations in leachate generated from Silo 3 waste.

Figure E.3-22 summarizes observed data and Leachate B results for arsenic. Arsenic concentrations in perched groundwater range from less than 0.002 to 0.057 mg/L, and up to 0.68 mg/L in sump liquor. TCLP extract data show cobalt ranging from less than 0.002 to 0.1 ppm, and EP Tox extract rises to 41.5 mg/L arsenic. Leachate B results are constrained by the mean TCLP value for Silos 1 and 2 and by the maximum EP Tox value for Silo 3.

Selenium data and Leachate B results are given in Figure E.3-23. Selenium concentrations in perched groundwater below Silos 1 and 2 range from less than 0.002 to 0.1 mg/L, rising to 6 mg/L in sump liquor. Perched groundwater obtained from background wells has no detectable selenium at a level of 0.002 mg/L. TCLP extract data indicate selenium levels of 0.015 to 0.14 mg/L, and in EP Tox extract levels of 0.9 to 11.7. Leachate B results are constrained by the mean TCLP value for Silos 1 and 2, and by the maximum EP Tox value for Silo 3.

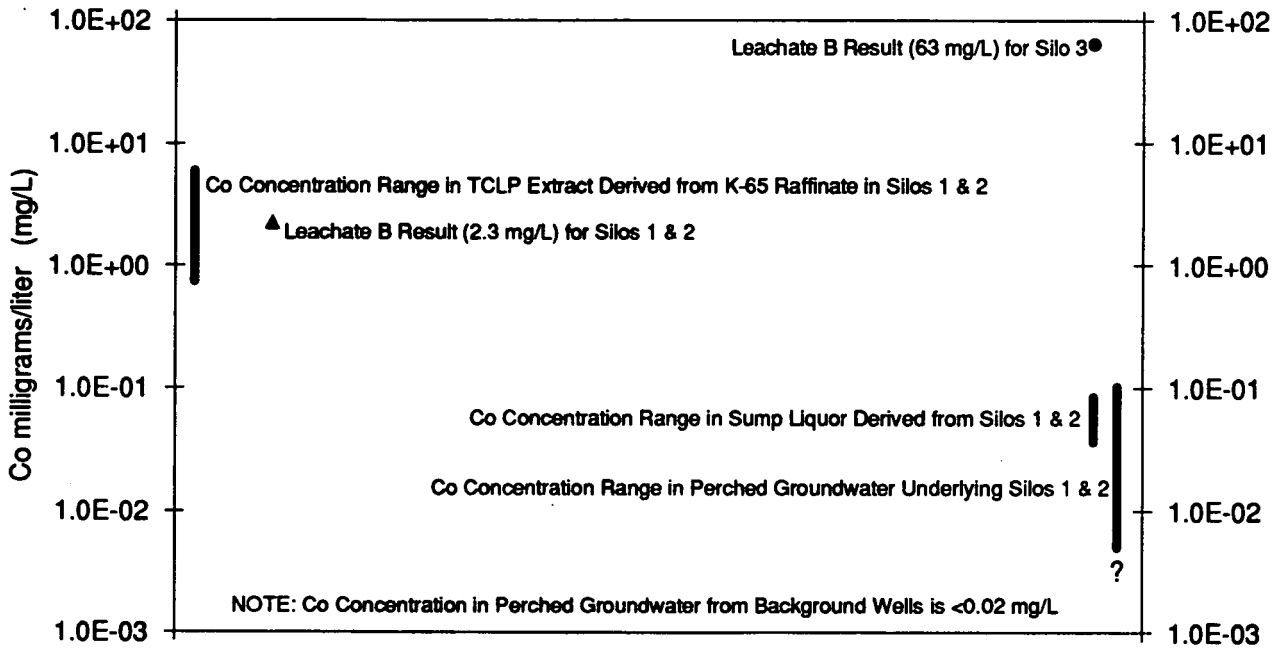
Molybdenum data and the Leachate B result for Silos 1 and 2 (Mo is not a constituent of concern for Silo 3) are summarized in Figure E.3-24. Molybdenum concentrations in perched groundwater under Silos 1 and 2 range from 0.021 to 0.26 mg/L, and this range extends up to 7.7 mg/L in sump liquor.



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. The Leachate B result for Silos 1 & 2 (filled triangle) is constrained by the mean TCLP value, and for Silo 3 (filled circle) by the 70-year rule.

FIGURE E.3-20

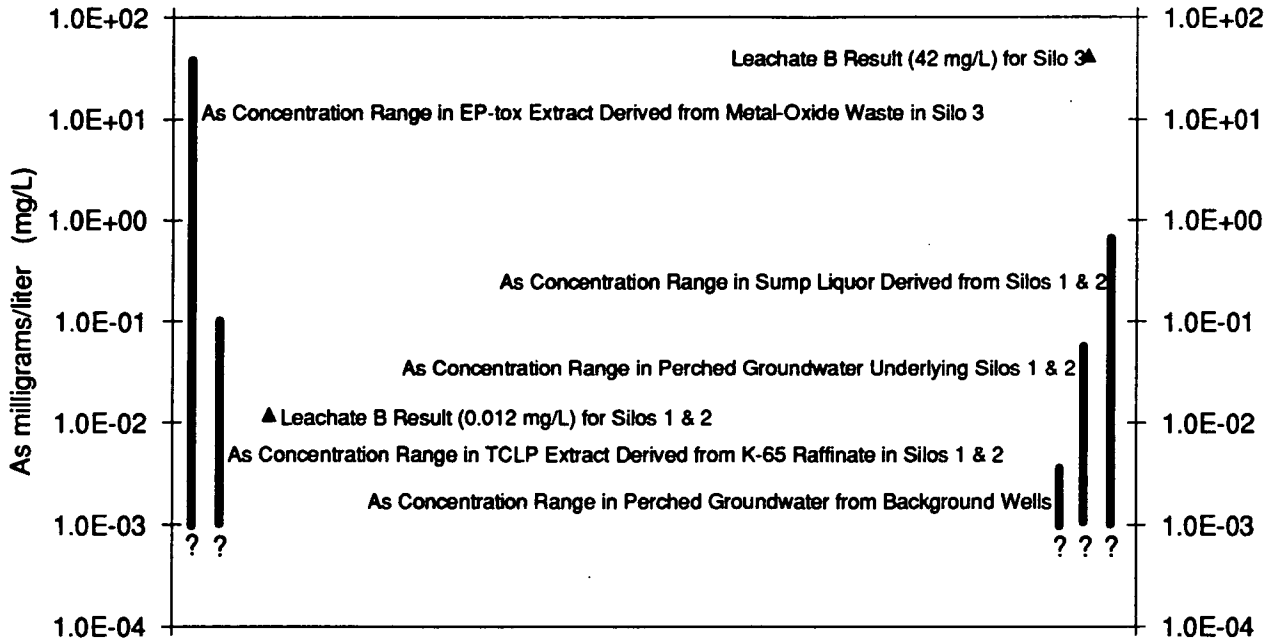
VANADIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. The Leachate B result for Silos 1 & 2 (filled triangle) is constrained by the mean TCLP value, and for Silo 3 (filled circle) by the 70-year rule.

FIGURE E.3-21

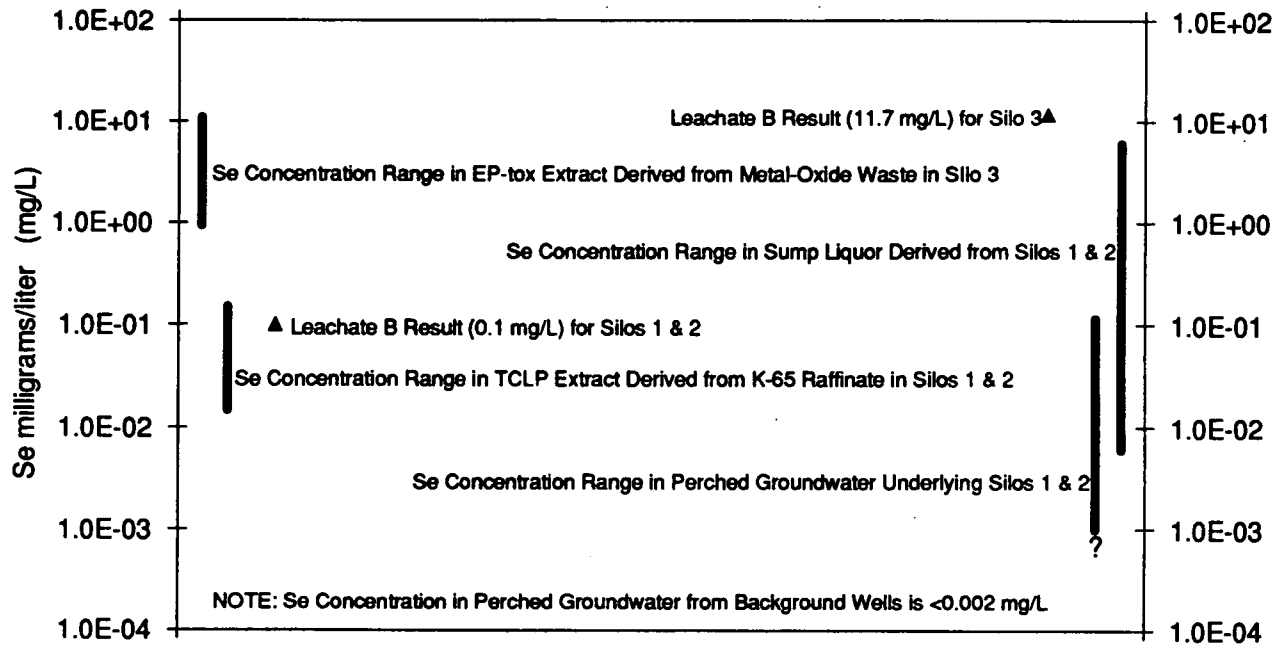
COBALT CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2; and 5) EP-tox extract derived from metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. The Leachate B results (filled triangles) are constrained by the mean TCLP value for Silos 1 & 2 and by the maximum EP-tox value for Silo 3.

FIGURE E.3-22

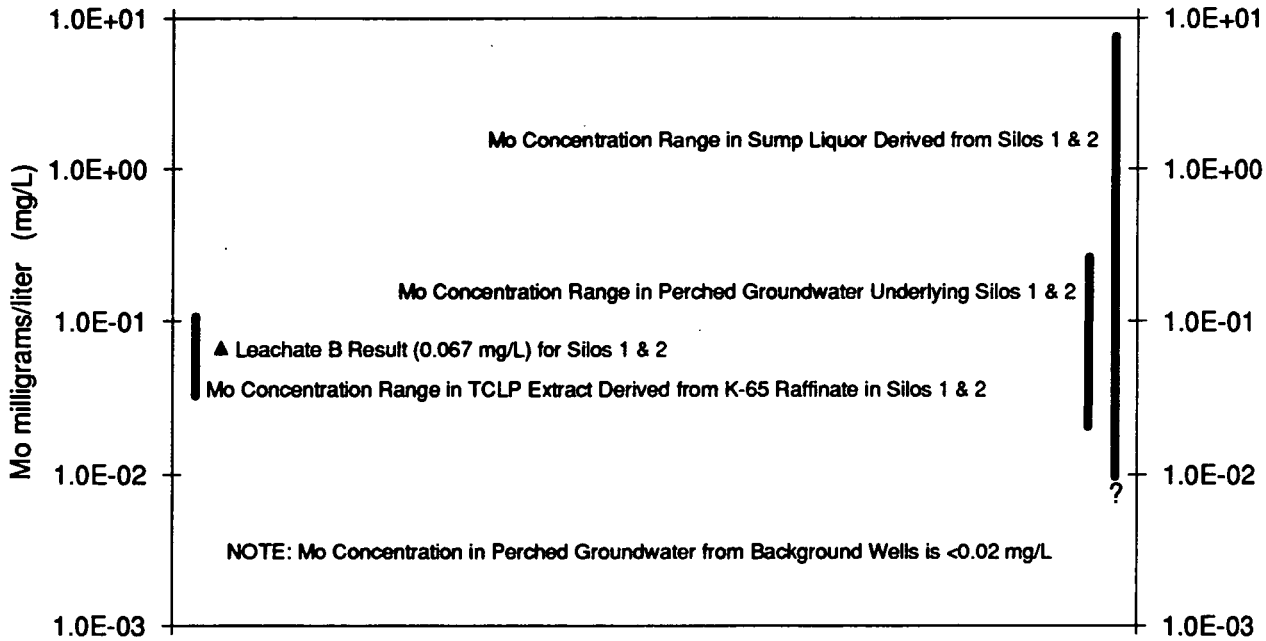
ARSENIC CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2; and 5) EP-tox extract derived from metal-oxide waste in Silo 3. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. The Leachate B results (filled triangles) are constrained by the mean TCLP value for Silos 1 & 2 and by the maximum EP-tox value for Silo 3.

FIGURE E.3-23

SELENIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, EP-TOX EXTRACT, AND LEACHATE B



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) perched groundwater below Silos 1 & 2; 3) sump liquor obtained from the decant tank below Silos 1 & 2; and 4) TCLP extract derived from K-65 raffinate in Silos 1 & 2. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. The Leachate B result for Silos 1 & 2 (filled triangle) is constrained by the mean TCLP value. Molybdenum is not a constituent of concern for Silo 3.

FIGURE E.3-24

MOLYBDENUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, TCLP EXTRACT, AND LEACHATE B

Perched groundwater data from background wells are all less than 0.02 mg/L molybdenum. TCLP extract data show molybdenum concentrations of 0.034 to 0.11 mg/L, and the Leachate B result is the mean TCLP value.

Figure E.3-25 summarizes observed data and Leachate B results for thallium. Thallium concentrations in perched groundwater are less than 0.001 mg/L. Sump liquor and TCLP extract contain thallium in levels of less than 0.001 to 0.002 mg/L and less than 0.001 to 0.029 mg/L, respectively. Leachate B results for thallium are constrained by the mean TCLP value for Silos 1 and 2, and by the 70-year rule for Silo 3. There are no site-specific data for thallium concentrations in leachate derived from Silo 3 waste.

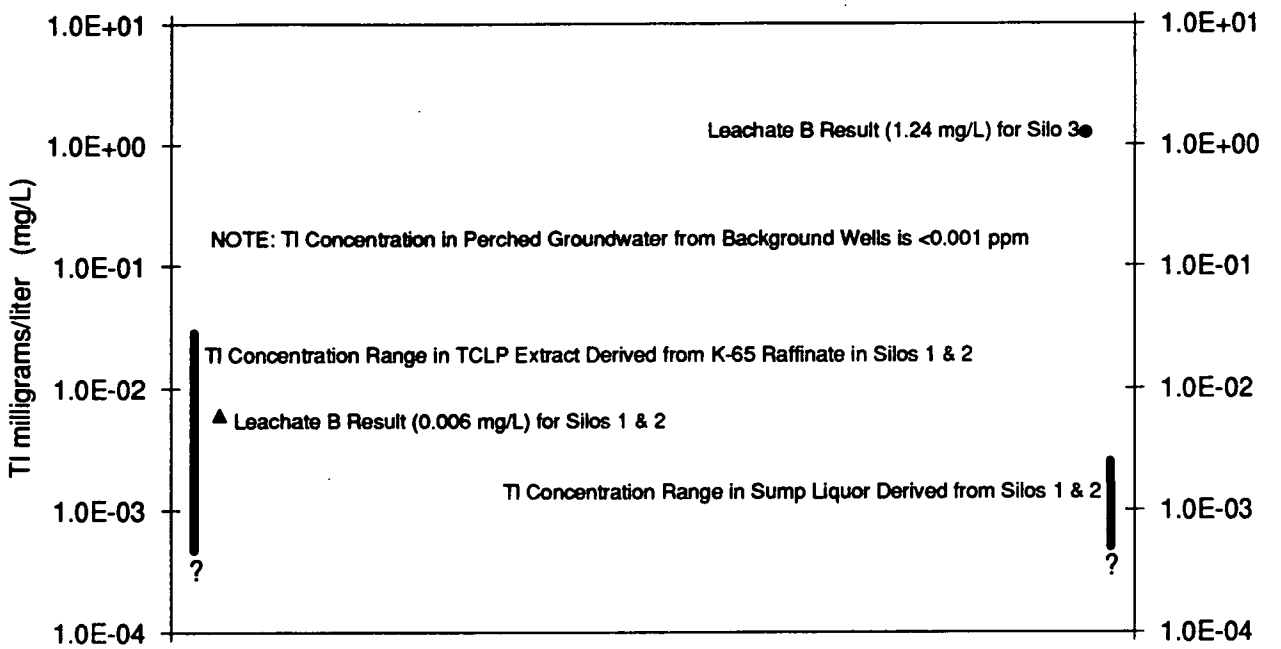
E.3.7 EQ3/6 GEOCHEMICAL COMPUTER CODE

E.3.7.1 Code Background

Mineral solubility calculations were performed with the EQ3/6 geochemical computer code. EQ3/6 was developed at Lawrence Livermore National Laboratory (Wolery 1983; Wolery and Daveler 1989) for predicting the behavior of metals, radionuclides, and other contaminants in the natural environment. The EQ3/6 computer code is an industry-standard geochemical model that performs solubility and speciation (aqueous form) calculations and reaction-path modeling. These calculations involve the simultaneous solution of equations describing the mass balance of each component, mass action expressions for solubility equilibrium, oxidation/reduction reactions, and electrical balance constraint. Activity coefficients of aqueous species are approximated with the B-dot set of equations, which are valid up to the ionic strength of seawater.

The EQ3/6 code accesses a data base containing the thermodynamic properties of 78 elements, 862 aqueous species, 886 minerals, and 76 gases. This data base includes 57 aqueous uranium species and 160 uranium-bearing minerals, constituting the most complete data base available for modeling the behavior of uranium in natural waters. EQ3/6 has been validated using standard geochemistry problems, such as the speciation of seawater (Nordstrom 1979), basalt/seawater interactions (Bowers et al. 1985), and numerous comparisons with experimentally determined mineral solubilities (Jackson 1988). Benchmark comparisons with the results of similar codes (e.g., PHREEQE) have been performed by INTERA (1983), Nordstrom (1979), Kincaid and Morey (1984), and Kerrisk (1981).

EQ3 is the portion of the code that calculates the initial aqueous species distribution with user provided concentration data and computes the saturation indices of pertinent minerals. The saturation index is defined as SI = log (Q/K), where Q = the ion activity product and K = equilibrium constant. A SI of greater than zero, zero, and less than zero corresponds to a mineral that is supersaturated, saturated, and undersaturated, respectively. After computing the speciation model, EQ3 computes a mass balance for each chemical element and charge balance, and writes this information in a pickup



Vertical bars represent the observed range of concentration for 1) perched groundwater obtained from background wells; 2) sump liquor obtained from the decant tank below Silos 1 & 2; and 3) TCLP extract derived from K-65 raffinate in Silos 1 & 2. A question mark below the vertical bars indicates that the lower end of the range is unknown, and the lower range shown is one-half the value of the lowest reported detection limit. The Leachate B result for Silos 1 & 2 (filled triangle) is constrained by the mean TCLP value, and for Silo 3 (filled circle) by the 70-year rule.

FIGURE E.3-25

THALLIUM CONCENTRATIONS IN PERCHED GROUNDWATERS, DECANT SUMP LIQUOR, AND LEACHATE B

file that is used as an input file by EQ6. EQ3 differs from EQ6 in that EQ3 identifies minerals that are supersaturated and undersaturated, but EQ3 cannot precipitate and dissolve the pertinent minerals.

The EQ6 portion of the code performs all the calculations of EQ3 and reaction-path calculations. Reaction-path (chemical evolution) modeling simulates a sequence of thermodynamic equilibrium problems in reacting systems consisting of water and minerals or other solids. The reacting system may consist of water (rainwater, groundwater, surface water, etc.) that migrates through, and equilibrates with, waste solids and natural minerals in compositionally distinct horizons (e.g., rainwater reacts with Operable Unit 4 waste to form Leachate A followed by migration and reaction with underlying glacial overburden minerals to form Leachate B). The chemical evolution of the reacting system is driven by dissolution and precipitation of minerals or solids and/or by changes in temperature and pressure. Along each step of the reaction path, the EQ6 code computes the precipitation and dissolution of minerals based on mass action expressions for solubility equilibrium with water. Thus, EQ6 differs from EQ3 by allowing supersaturated minerals (SI > 0) to precipitate from solution and undersaturated minerals (SI < 0) to dissolve.

E.3.7.2 Limitations and Assumptions of Mineral Solubility Calculations

The EQ3/6 geochemical code estimates contaminant concentrations by calculating mineral solubilities in water/solid systems. These calculations have the following limitations and assumptions:

- A limited number of organic constituents can be modeled, and this can lead to low estimates of leachate concentrations for some inorganic constituents if organic complexation occurs with constituents not present in the data base (e.g., lead complexed with acetate ion).
- Mineral phases are assumed to represent the actual solid phases in the waste material.
- Dissolution and precipitation kinetics are instantaneous, and this can lead to estimates of concentrations that are too high or too low.
- Adsorption processes are not evaluated with the EQ3/6 model.
- Modeled concentrations are site-specific solubility limits, and in most cases these concentrations are the highest concentrations which can exist in solution.
- Rainwater is assumed to enter the silos to act as the leaching fluid.

The first four bullets identify limitations and assumptions that introduce the greatest uncertainty in the calculated leachate concentration, and these merit further discussion. For example, a solution containing trace amounts of acetate ion (an organic complex not present in the EQ3/6 thermodynamic data base) will contain a greater concentration of lead relative to a solution with no acetate ion. Therefore, metal concentrations in TCLP extract are likely to be greater than predicted solubility limits because the acetic acid degrades into acetate ion. With respect to the second bullet, if a contaminant

is present in a metastable, amorphous form rather than a crystalline solid (i.e., mineral), using a mineral phase for the solid will usually lead to low estimates of the contaminant concentration. This occurs because crystalline phases generally contain shorter and stronger element bonds relative to amorphous solids, and this leads to a lower solubility for the crystalline phase. In contrast to the statement of bullet three, dissolution of crystalline solids is rarely instantaneous or complete in the natural environment (e.g., feldspar), except for some highly soluble salts (e.g., NaCl), and this can lead to high estimates of contaminant concentrations. Assuming instantaneous precipitation of mineral phases can lead to low estimates of element concentrations if the mineral is difficult to nucleate and crystallize in the natural environment (e.g., dolomite). Finally, the calculated solubility concentrations may be too high when compared with observed element concentrations in groundwater because adsorption reactions are not considered. Adsorption reactions can substantially lower some contaminant concentrations below the calculated solubility limit (e.g., Cs^{+}).

E.3.7.3 Uncertainty in Thermodynamic Data used in Mineral Solubility Calculations

To assess the uncertainty of thermodynamic data present in the EQ3/6 data base, analytical data on groundwater from background well 1024 and sump liquor from the decant sump below Silos 1 and 2 were entered into EQ3/6 and MINTEQA2 (Allison et al. 1991) to compare the predicted saturation states of minerals and aqueous specie distribution. Results are summarized in Tables E.3-6 through E.3-9. The discussion below focuses on results for perched groundwater (Tables E.3-6 and E.3-7) because a comparison to decant sump liquor from Silos 1 and 2 (Tables E.3-8 and E.3-9) indicates the uncertainty is not a function of solution type.

Table E.3-6 presents the input data for perched groundwater from background well 1024, a list of minerals, and a comparison of saturation indices for the minerals. The saturation index is defined as the logarithm of the activity product of the ions forming the solid (e.g., Ca^{+2} and CO_3^{-2}) minus the logarithm of the mineral solubility product, or in mathematical form:

$$SI = \log (Q/K)$$

where SI is the saturation index, Q is the activity product of the ions, and K is the solubility product of the mineral. When the saturation index value is zero, the mineral is in equilibrium (i.e., Q = K) with the solution. Saturation indices below and above zero correspond to undersaturated and supersaturated states, respectively. An undersaturated mineral will undergo dissolution and a supersaturated mineral may precipitate. In general, the saturation indices for minerals formed from principal components (e.g., Ca^{+2}, Mg^{+2}, CO_3^{-2}, SO_4^{-2}, etc.) in groundwater agree quite well (i.e., within 0.5 SI). These minerals include calcite, gypsum, and magnesite. The saturation indices of minerals formed from trace metals (e.g., Ba, Pb, Ni, etc.) are quite variable. That is they can compare quite well, as for barite, rhodochrosite, rutherfordine, schoepite, tenorite, and witherite, or compare very poorly, as for anglesite, bunsenite, cerussite, litharge, malachite, and otavite. For lead bearing

TABLE E.3-6

COMPARISON OF MINERAL SATURATION INDICIES IN PERCHED GROUNDWATER FROM WELL 1024

Input Data (mg/L)		Saturation Index[b]	
PGW 1024[a]	Mineral	MINTEQA2	EQ3/6
pH = 7.2	anglesite ($PbSO_4$)	-2.45	-4.11
Eh = 350 mV	anhydrite ($CaSO_4$)	-1.97	-1.67
Ag = 3.81E-03	barite ($BaSO_4$)	0.427	0.412
Ba = 9.28E-02	bunsenite (NiO)	-4.89	-6.08
Ca = 9.83E+01	calcite ($CaCO_3$)	0.093	0.090
Cd = 3.25E-03	$CaUO_4$	-5.71	NP
Cr = 4.05E-02	cerussite ($PbCO_3$)	1.18	-0.837
Cu = 8.88E-03	chlorargyrite (AgCl)	-1.32	-1.31
K = 1.67E+00	CrO_2	1.66	NP
Mg = 4.00E+01	cuprite (Cu_2O)	-7.31	NP
Mn = 1.05E-01	dolomite ($Mg_{.5}Ca_{.5}CO_3$)	1.15	-0.054
Na = 1.52E+01	fluorite (CaF_2)	-1.36	-0.454
Ni = 5.93E-02	gypsum ($CaSO_4{:}2H_2O$)	-1.69	-1.35
Pb = 3.25E-02	litharge (PbO)	-5.70	-7.34
U = 8.82E-04	magnesite ($MgCO_3$)	-0.638	-0.638
Cl = 5.70E+00	malachite ($Cu_2CO_3(OH)_2$)	-3.77	-2.87
F = 1.02E+00	manganite (MnOOH)	-4.42	NP
HCO_3 = 4.25E+02	$Ni(OH)_2$	-5.14	-3.04
NO_3 = 5.00E-02	$NiCO_3$	-4.90	-6.32
PO_4 = 2.50E-01	otavite ($CdCO_3$)	-3.29	0.206
SO_4 = 8.43E+01	rhodochrosite ($MnCO_3$)	-0.976	-1.09
T = 15°C	rutherfordine (UO_2CO_3)	-5.91	-6.06
	schoepite ($UO_3{:}2H_2O$)	-5.57	-6.32
	tenorite (CuO)	-2.00	-1.89
	witherite ($BaCO_3$)	-3.09	-3.26

[a] Average groundwater composition of samples taken from well 1024.
[b] Saturation index is defined as the log of the activity product minus the log of the solubility product, or log(Q/K). Values of greater than zero, zero, and less than zero indicate, respectively, supersaturated, saturated, and undersaturated conditions for the indicated solid phase in perched groundwater.
NP = solid is not present in the thermodynamic data base of the indicated code.

TABLE E.3-7

COMPARISON OF AQUEOUS SPECIE DISTRIBUTION IN PERCHED GROUNDWATER FROM WELL 1024

Element	Specie	EQ3/6 Molal Percent[a]	MINTEQA2 Molal Percent[a]
Silver	Ag^{+}	75.4	77.4
	$AgCl^{o}$	24.0	21.6
	$AgCl_2^{-}$	0.5	0.4
	$AgSO_4^{-}$	NP	0.6
Barium	Ba^{+2}	97.0	100
	$BaHCO_3^{+}$	2.9	NP
Calcium	Ca^{+2}	92.3	92.2
	$CaCO_3^{o}$	0.3	0.1
	$CaHCO_3^{+}$	4.0	2.7
	$CaSO_4^{o}$	3.3	4.8
Cadmium	Cd^{+2}	100	50.9
	$CdCO_3^{o}$	NP	26.1
	$CdHCO_3^{+}$	NP	18.5
	$CdSO_4^{o}$	NP	3.8
	$CdCl^{+}$	NP	0.5
Chlorine	Cl^{-}	99.9	99.9
Chromium	$Cr(OH)_2^{+}$	84.2	NP
	$Cr(OH)_3^{o}$	15.7	NP
	CrO_4^{-2}	0.0	87.7
	$HCrO_4^{-}$	0.0	12.1
	$NaCrO_4^{-}$	NP	0.2
Copper	$CuCO_3^{o}$	91.3	64.6
	Cu^{+2}	5.0	5.9
	$CuOH^{+}$	3.0	0.7
	$Cu(CO_3)_2^{-2}$	0.7	0.4
	$CuCO_3(OH)_2^{-2}$	0.2	NP
	$Cu(OH)_2^{o}$	NP	19.6
	$CuHCO_3^{+}$	NP	8.5
	$CuSO_4^{o}$	NP	0.3

TABLE E.3-7
(Continued)

Element	Specie	EQ3/6 Molal Percent[a]	MINTEQA2 Molal Percent[a]
Fluorine	F^-	97.3	94.5
	MgF^+	2.0	4.6
	CaF^+	0.7	0.9
Carbon	HCO_3^-	84.8	87.8
	$H_2CO_3^o$	12.5	10.0
	$CaHCO_3^+$	1.4	1.0
	$MgHCO_3^+$	0.9	0.9
	$CaCO_3^o$	0.1	0.1
Phosphorous	$MgP_2O_7^{-2}$	96.6	NP
	$CaP_2O_7^{-2}$	3.4	NP
	HPO_4^{-2}	0.0	38.0
	$H_2PO_4^-$	0.0	29.2
	$CaHPO_4^o$	0.0	15.7
	$MgHPO_4^o$	0.0	14.3
	$CaH_2PO_4^+$	0.0	0.9
	$MgH_2PO_4^+$	0.0	0.7
	$CaPO_4^-$	0.0	0.5
	$MgPO_4^-$	0.0	0.5
Potassium	K^+	99.7	99.7
	KSO_4^-	0.3	0.3
Magnesium	Mg^{+2}	90.4	91.2
	$MgSO_4^o$	5.4	4.2
	$MgHCO_3^+$	3.9	3.9
	$MgCO_3^o$	0.2	0.2
	MgF^+	0.1	0.1
Manganese	Mn^{+2}	86.4	90.7
	$MnCO_3^o$	5.8	NP
	$MnSO_4^o$	5.1	4.0
	$MnHCO_3^+$	2.6	5.2
Sodium	Na^+	98.9	99.6
	$NaHCO_3^o$	0.8	0.2

TABLE E.3-7
(Continued)

Element	Specie	EQ3/6 Molal Percent[a]	MINTEQA2 Molal Percent[a]
	$NaSO_4^-$	0.3	0.2
Nickel	Ni^{+2}	96.4	6.0
	$NiSO_4^o$	3.6	0.3
	$NiCO_3^o$	NP	90.4
	$NiHCO_3^+$	NP	2.5
	$Ni(CO_3)_2^{-2}$	NP	0.8
Nitrogen	N_3^-	99.7	NP
	HN_3^o	0.1	NP
	NO_3^-	0.0	100
Lead	Pb^{+2}	88.7	2.5
	$PbOH^+$	11.0	0.6
	$PbCl^+$	0.2	
	$PbCO_3^o$	NP	89.6
	$PbHCO_3^+$	NP	5.8
	$Pb(CO_3)_2^{-2}$	NP	1.1
	$PbSO_4^o$	NP	0.4
Sulfur	SO_4^{-2}	80.4	78.6
	$MgSO_4^o$	10.2	7.8
	$CaSO_4^o$	9.2	13.4
Uranium	$UO_2(CO_3)_3^{-4}$	52.3	21.7
	$UO_2(CO_3)_2^{-2}$	46.7	34.5
	$UO_2(HPO_4)_2^{-2}$	NP	42.7
	$UO_2CO_3^o$	0.5	1.0
	$UO_2(OH)_2^o$	0.4	NP

[a] Molal percent based on total moles of the indicated element per kilogram of water.
NP = specie is not present in the thermodynamic data base of the indicated code.

TABLE E.3-8

COMPARISON OF MINERAL SATURATION INDICIES IN DECANT SUMP LIQUOR FROM SILOS 1 AND 2

Input Data DSL 99415[b]	Mineral	Saturation Index[a] EQ3/6	Saturation Index[a] MINTEQA2
pH = 8.5[c]	anglesite ($PbSO_4$)	-0.825	-3.00
Eh = 300 mV[c]	anhydrite ($CaSO_4$)	-2.12	-1.86
Ag = 1.84E-01	barite ($BaSO_4$)	0.969	0.986
Ba = 2.18E-02	bunsenite (NiO)	-2.76	-4.62
Ca = 6.51E+00	calcite ($CaCO_3$)	-0.424	-0.491
Cd = 1.19E-02	$CaUO_4$	-2.06	NP
Cr = 3.11E-01	cerussite ($PbCO_3$)	2.44	-0.101
Cu = 8.78E-02	chlorargyrite (AgCl)	0.782	0.834
K = 2.83E+01	cristobalite (SiO_2)	0.934	1.13
Mg = 4.19E+01	CrO_2	2.59	NP
Mn = 2.93E-02	dolomite ($Mg_{.5}Ca_{.5}CO_3$)	0.163	-0.992
Na = 3.36E+03	fluorite (CaF_2)	-0.536	0.301
Ni = 6.47E-02	gypsum ($CaSO_4{:}2H_2O$)	-1.85	-1.55
Pb = 2.13E-01	litharge (PbO)	-2.96	-5.14
U = 3.3E+01[d]	magnesite ($MgCO_3$)	-1.10	-0.995
Cl = 1.07E+02	malachite ($Cu_2CO_3(OH)_2$)	-0.446	-0.998
F = 2.00E+01	manganite (MnOOH)	-2.56	NP
HCO_3 = 3.5E+02[c]	$Ni(OH)_2$	-3.02	-1.59
NO_3 = 7.91E+02	$NiCO_3$	-4.24	-6.33
PO_4 = 8.34E+00	otavite ($CdCO_3$)	-1.94	1.09
SO_4 = 5.35E+03	rhodochrosite ($MnCO_3$)	-1.01	-1.01
SiO_2 = 1.47E+02	rutherfordine (UO_2CO_3)	-4.69	-4.45
T = 15°C	schoepite ($UO_3{:}2H_2O$)	-2.88	-3.26
	silver (Ag)	2.07	2.23
	SiO_2 (amorphous)	0.141	0.209
	soddyite ($(UO_2)_2SiO_4{:}2H_2O$)	1.43	NP
	tenorite (CuO)	0.403	-0.221
	uranophane ($Ca(UO_2)_2(SiO_3)_2(OH)_2$)	-5.65	-5.34
	witherite ($BaCO_3$)	-2.91	-3.07

[a] Saturation index is defined as the log of the activity product minus the log of the solubility product, or $\log(a_p/K_{sp})$. Values of greater than zero, zero, and less than zero indicate, respectively, supersaturated, saturated, and undersaturated conditions for the indicated solid phase in perched groundwater.
[b] Composition of decant sump liquor reported for sample 99415 (Table 4-31 of OU4 RI, draft of Oct 92).
[c] Estimated values for pH, Eh, and bicarbonate; based on pH of waste/liquid in Silos 1 and 2 and assuming adequate bicarbonate is available to saturate the solution with dolomite (EQ3/6 run).
[d] Average uranium value from monthly decant sump analyses over the period 8/89 to 4/90.
NP = solid is not present in the thermodynamic database of the indicated code.

TABLE E.3-9

COMPARISON OF AQUEOUS SPECIE DISTRIBUTION IN DECANT SUMP LIQUOR FROM SILOS 1 AND 2

ELEMENT	AQUEOUS SPECIE	EQ3/6 Molal Percent[a]	MINTEQA2 Molal Percent[a]
Silver	Ag^{+}	15.9	16.6
	$AgCl^{o}$	61.9	58.8
	$AgCl_2^{-}$	21.7	20.1
	$AgCO_3^{-}$	0.4	NP
	$AgCl_3^{-2}$	0.1	0.1
	$AgSO_4^{-}$	NP	4.3
Barium	Ba^{+2}	98.3	100
	$BaHCO_3^{+}$	1.2	NP
	$BaCO_3^{o}$	0.4	NP
Calcium	Ca^{+2}	62.0	54.8
	$CaCO_3^{o}$	1.5	0.8
	$CaHCO_3^{+}$	1.1	0.7
	$CaSO_4^{o}$	34.5	43.4
	$CaP_2O_7^{-2}$	0.6	NP
	CaF^{+}	0.1	0.1
	$CaHPO_4^{o}$	0.0	0.1
	$CaPO_4^{-}$	0.0	0.1
Cadmium	Cd^{+2}	100	15.8
	$CdCO_3^{o}$	NP	51.6
	$CdHCO_3^{+}$	NP	2.3
	$CdSO_4^{o}$	NP	18.1
	$Cd(SO_4)_2^{-2}$	NP	10.3
	$CdCl^{+}$	NP	1.4
	$CdNO_3^{+}$	NP	0.2
	$CdOHCl^{o}$	NP	0.1
	$Cd(OH)^{+}$	NP	0.1
Chlorine	Cl^{-}	98.8	99.9
	$NaCl^{o}$	1.1	0.0
Chromium	$Cr(OH)_2^{+}$	2.1	NP
	$Cr(OH)_3^{o}$	6.4	0.0
	CrO_4^{-2}	89.0	82.2
	CrO_4^{-3}	2.0	NP
	$HCrO_4^{-}$	0.4	0.3
	$NaCrO_4^{-}$	NP	17.3
	$KCrO_4^{-}$	NP	0.1
Copper	$CuCO_3^{o}$	77.1	10.0
	Cu^{+2}	0.6	0.2
	$CuOH^{+}$	4.6	0.2
	$Cu(CO_3)_2^{-2}$	17.5	1.9
	$CuCO_3(OH)_2^{-2}$	0.2	NP
	$Cu(OH)_2^{o}$	NP	87.6
	$CuHCO_3^{+}$	NP	0.0
	$CuSO_4^{o}$	NP	0.1
Fluorine	F^{-}	99.3	98.7
	NaF^{o}	0.7	1.2

TABLE E.3-9
(Continued)

ELEMENT	AQUEOUS SPECIE	EQ3/6 Molal Percent[a]	MINTEQA2 Molal Percent[a]
Carbon	HCO_3^-	80.2	87.1
	$NaHCO_3^o$	10.3	2.9
	$UO_2(CO_3)_3^{-4}$	6.4	5.8
	CO_3^{-2}	2.1	2.5
	$H_2CO_3^o$	0.5	0.4
	$NaCO_3^-$	0.4	1.2
Phosphorous	$MgP_2O_7^{-2}$	77.0	NP
	$NaP_2O_7^{-3}$	18.9	NP
	$CaP_2O_7^{-2}$	2.4	NP
	$Na_2P_2O_7^{-2}$	1.7	NP
	HPO_4^{-2}	0.0	71.7
	$UO_2(HPO_4)_2^{-2}$	NP	20.6
	$NaHPO_4^-$	0.0	4.8
	$H_2PO_4^-$	0.0	1.6
	$CaHPO_4^o$	0.0	0.3
	$MgHPO_4^o$	0.0	0.4
	$CaPO_4^-$	0.0	0.2
	$MgPO_4^-$	0.0	0.3
Potassium	K^+	91.4	92.2
	KSO_4^-	8.6	7.8
Magnesium	Mg^{+2}	38.4	57.3
	$MgSO_4^o$	40.3	39.8
	$MgP_2O_7^{-2}$	19.6	NP
	$MgHCO_3^+$	0.8	1.0
	$MgCO_3^o$	0.5	0.6
	MgF^+	0.3	0.9
	$Mg(H_3SiO_4)_2^o$	0.1	NP
	$MgHPO_4^o$	0.0	0.2
	$MgPO_4^-$	0.0	0.2
Manganese	Mn^{+2}	41.5	58.5
	$MnCO_3^o$	19.0	NP
	$MnSO_4^o$	38.4	39.7
	$MnHCO_3^+$	0.5	1.3
	MnF^+	0.4	0.1
	$MnOH^+$	0.2	0.1
	$MnCl^+$	0.0	0.2
Sodium	Na^+	91.8	93.5
	$NaHCO_3^o$	0.4	0.1
	$NaSO_4^-$	7.5	6.3
	$NaHSiO_3^o$	0.2	NP
	$NaH_3SiO_4^o$	0.1	NP
Nickel	Ni^{+2}	65.6	0.8
	$NiSO_4^o$	34.4	0.6
	$NiCO_3^o$	NP	78.1
	$NiHCO_3^+$	NP	0.1
	$Ni(CO_3)_2^{-2}$	NP	20.3
Nitrogen	N_3^-	100	NP
	NO_3^-	0.0	100

TABLE E.3-9
(Continued)

ELEMENT	AQUEOUS SPECIE	EQ3/6 Molal Percent[a]	MINTEQA2 Molal Percent[a]
Lead	Pb^{+2}	39.2	0.3
	$PbOH^{+}$	56.8	0.8
	PbO^{o}	3.0	NP
	$PbCl^{+}$	1.0	0.0
	$PbCO_3^{o}$	NP	70.9
	$PbHCO_3^{+}$	NP	0.3
	$Pb(CO_3)_2^{-2}$	NP	26.7
	$PbSO_4^{o}$	NP	0.8
	$Pb(SO_4)_2^{-2}$	NP	0.2
Sulfur	SO_4^{-2}	80.0	83.1
	$NaSO_4^{-}$	19.7	16.5
	$MgSO_4^{o}$	0.1	0.1
	KSO_4^{-}	0.1	0.1
	$CaSO_4^{o}$	0.1	0.1
Uranium	$UO_2(CO_3)_3^{-4}$	99.3	91.4
	$UO_2(CO_3)_2^{-2}$	0.6	1.2
	$UO_2(HPO_4)_2^{-2}$	NP	7.4

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[a] Molal percent based on total moles of the indicated element per kilogram of water.
NP = specie is not present in the thermodynamic database of the indicated code.

solids, the saturation indices are 1.6 to 2 SI units greater in the EQ3/6 results. Referring to the SI definition above and using anglesite as an example, this implies that the calculated activity product for Pb^{+2} and SO_4^{-2} is 1.7 orders of magnitude greater when calculated by EQ3/6, if the solubility product is constant for both computer codes. Alternatively, if the solubility constants used by the codes differ by 1.7 orders of magnitude, the activity product can be identical in both codes. In general, there is some small difference in the solubility product used by each code and most of the difference lies with the calculation of the activity product.

The value of the activity product is dependent on the number and type of aqueous species that are formed in solution. Table E.3-7 summarizes the speciation in perched groundwater predicted by each code. When the two codes agree with respect to the speciation of an element in solution (e.g., silver, barium, calcium, etc.), the saturation index for a mineral of that element agrees quit well (e.g., chlorargyrite, barite, calcite in Table E.3-6). However, when the predicted element speciation is grossly different (e.g., cadmium, nickel, lead), the calculated saturation index can vary by two orders of magnitude (e.g., anglesite, bunsenite, otavite in Table E.3-6). To illustrate, consider the predicted speciation for cadmium (Table E.3-7). The EQ3/6 code contains a single cadmium specie (Cd^{+2}) in contrast to the five cadmium species predicted to be present by MINTEQA2. In this case, the difference in speciation is due to the absence of four of the predicted MINTEQA2 species from the EQ3/6 thermodynamic data base. Similar differences in the predicted speciation for nickel and lead also arise due to the absence of nickel and lead carbonate species in EQ3/6. To overcome this limitation in the uncertainty analysis, thermodynamic data present in MINTEQA2 can be extracted and entered in EQ3/6.

E.4.0 SURFACE WATER RUNOFF MODELING

E.4.1 INTRODUCTION

The modeling approach is used to estimate contaminant concentrations in surface water resulting from transport by runoff from Operable Unit 4; the approach is described in this section. Modeling the contaminant transport by runoff requires characterization of the contaminants in the initial soil or water source term. Based on the runoff scenarios selected, runoff and partitioning models were used to quantify the migration of contaminants to stream sediment and surface water from erosion by runoff effluent.

During a rainfall event, soil particles are dislodged by the impact of raindrops and the flow of runoff across the soil surface. The amount of soil erosion depends on rainfall intensity, slope length, slope steepness, vegetative cover, and erosion control practices in place. Contaminants attached to the soil particles are also removed and carried into the receiving surface water. Each contaminant will be present in the runoff water in two forms: (1) adsorbed to the soil particles, and (2) dissolved in the water.

E.4.2 CONCEPTUAL MODEL

Four source term areas were selected for the model. These areas are:

- Operable Unit 4 surface soil and berm fill material (combined)
- Operable Unit 4 surface soil
- Berm fill material
- Contents of Silo 3 (assuming silo failure)

Concentrations for these source areas used in the model are presented in Table E.4-1.

Paddys Run is an intermittent stream that begins north of the site and flows southward along the western edge. Natural drainage from the site flows primarily to Paddys Run. Paddys Run flows into the Great Miami Aquifer 2.4 kilometers (km) south of the Fernald Environmental Management Project (FEMP). Some surface water drainage has been diverted away from Paddys Run into a retention basin (WEMCO 1991). The Storm Sewer Outfall Ditch flows from the retention basin into Paddys Run in the south end of the FEMP. Runoff from Operable Unit 4 was assumed to enter Paddys Run.

Surface water and sediment concentrations were modeled on an event-specific basis using the Modified Universal Soil Loss Equation (MUSLE). Because Paddys Run is an intermittent stream, event-specific concentrations should yield more realistic results of episodal contamination than an average calculated for one or several years. Paddys Run flows primarily between January and May, with estimated flows from 0.2 to 4.0 cubic ft per second. Peak flows have not been gauged (DOE 1990a). Surface water

TABLE E.4-1

SURFACE WATER RUNOFF RESULTS FOR
SURFACE SOILS, BERM FILL, AND SILO 3

	Chemical Data		Results	
Constituent	Partition Coefficient, K_D (mL/g)	Concentration in Waste Area, C_i (mg/kg)(pCi/g)[a]	Concentration in Paddys Run Surface Water, C_w (mg/L)(pCi/L)[a]	Concentration in Great Miami River Surface Water, C_w (mg/L)(pCi/L)[a]
SURFACE SOILS AND BERM FILL (COMBINED)				
Radionuclides				
Lead-210	3.00×10^{3}	3.98×10^{0}	3.1×10^{-2}	9.3×10^{-7}
Polonium-210	4.00×10^{2}	4.02×10^{0}	2.4×10^{-1}	7.0×10^{-6}
Radium-224	6.96×10^{2}	1.02×10^{0}	3.5×10^{-2}	1.0×10^{-6}
Radium-226	6.96×10^{2}	5.75×10^{0}	2.0×10^{-1}	5.8×10^{-6}
Radium-228	6.96×10^{2}	1.12×10^{0}	3.8×10^{-2}	1.1×10^{-6}
Strontium-90	1.00×10^{1}	1.31×10^{0}	3.1×10^{0}	9.1×10^{-5}
Technetium-99	1.18×10^{-1}	8.21×10^{-1}	8.8×10^{1}	2.6×10^{-3}
Thorium-230	5.80×10^{3}	4.03×10^{0}	1.6×10^{-2}	4.9×10^{-7}
Thorium-232	5.80×10^{3}	1.40×10^{0}	5.7×10^{-3}	1.7×10^{-7}
Uranium-234	1.80×10^{0}	3.17×10^{0}	3.9×10^{1}	1.2×10^{-3}
Uranium-238	1.80×10^{0}	1.20×10^{1}	1.5×10^{2}	4.4×10^{-3}
Organics				
2-Butanone	3.47×10^{-2}	6.55×10^{-3}	5.7×10^{-4}	3.4×10^{-8}
2-Hexanone	4.59×10^{-1}	5.00×10^{-3}	1.1×10^{-4}	6.2×10^{-9}
4-Methyl-2-Pentanone	2.36×10^{-1}	3.00×10^{-3}	1.1×10^{-4}	6.2×10^{-9}
Acenaphthylene	1.59×10^{2}	3.15×10^{-1}	2.3×10^{-5}	1.4×10^{-9}
Acetone	1.09×10^{-2}	5.94×10^{-2}	6.3×10^{-3}	3.7×10^{-7}
Anthracene	5.36×10^{2}	2.77×10^{-1}	6.1×10^{-6}	3.6×10^{-10}
Aroclor-1254	2.05×10^{4}	3.00×10^{-2}	1.7×10^{-8}	1.0×10^{-12}
Benzo(a)anthracene	7.66×10^{3}	4.15×10^{-1}	6.4×10^{-7}	3.8×10^{-11}
Benzo(a)pyrene	1.83×10^{4}	5.20×10^{0}	3.4×10^{-6}	2.0×10^{-10}
Benzo(b)fluoranthene	7.11×10^{4}	5.18×10^{-1}	8.7×10^{-8}	5.1×10^{-12}
Benzo(g,h,i)perylene	3.25×10^{5}	4.51×10^{-1}	1.6×10^{-8}	9.7×10^{-13}
Benzoic acid	1.42×10^{0}	5.90×10^{-2}	4.6×10^{-4}	2.7×10^{-8}
bis(2-Ethylhexyl)phthalate	3.83×10^{3}	3.77×10^{-1}	1.2×10^{-6}	6.9×10^{-11}
Chrysene	7.66×10^{3}	3.86×10^{-1}	6.0×10^{-7}	3.5×10^{-11}
Dibenzo(a,h)anthracene	1.79×10^{4}	2.87×10^{-1}	1.9×10^{-7}	1.1×10^{-11}
Di-n-butylphthalate	3.03×10^{3}	1.90×10^{-1}	7.5×10^{-7}	4.4×10^{-11}
Fluoranthene	4.09×10^{3}	4.24×10^{-1}	1.2×10^{-6}	7.2×10^{-11}

TABLE E.4-1
(Continued)

Constituent	Chemical Data: Partition Coefficient, K_D (mL/g)	Chemical Data: Concentration in Waste Area, C_i (mg/kg)(pCi/g)[a]	Results: Concentration in Paddys Run Surface Water, C_w (mg/L)(pCi/L)[a]	Results: Concentration in Great Miami River Surface Water, C_w (mg/L)(pCi/L)[a]
Ideno(1,2,3-cd)pyrene	8.75×10^{5}	4.25×10^{-1}	5.8×10^{-9}	3.4×10^{-13}
Methylene chloride	3.41×10^{-1}	2.00×10^{-2}	5.4×10^{-4}	3.2×10^{-8}
Phenol	5.52×10^{-1}	2.30×10^{-1}	4.2×10^{-3}	2.5×10^{-7}
Phenanthrene	5.55×10^{2}	3.76×10^{-1}	8.0×10^{-6}	4.7×10^{-10}
Pyrene	2.90×10^{3}	4.49×10^{-1}	1.8×10^{-6}	1.1×10^{-10}
Toluene	9.38×10^{0}	8.20×10^{-3}	1.0×10^{-5}	6.0×10^{-10}
Xylenes (total)	2.11×10^{1}	6.01×10^{-3}	3.4×10^{-6}	2.0×10^{-10}
Inorganics				
Antimony	2.50×10^{2}	2.87×10^{1}	1.4×10^{-3}	8.0×10^{-8}
Beryllium	1.30×10^{3}	8.46×10^{-1}	7.7×10^{-6}	4.6×10^{-10}
Cadmium	5.00×10^{2}	5.36×10^{0}	1.3×10^{-4}	7.5×10^{-9}
Chromium	1.50×10^{3}	2.04×10^{1}	1.6×10^{-4}	9.5×10^{-9}
Copper	1.25×10^{2}	2.10×10^{1}	2.0×10^{-3}	1.2×10^{-7}
Lead	1.36×10^{1}	1.36×10^{1}	5.4×10^{-5}	3.2×10^{-9}
Nickel	6.50×10^{2}	3.08×10^{1}	5.6×10^{-4}	3.3×10^{-8}
Silver	1.80×10^{2}	9.81×10^{0}	6.5×10^{-4}	3.8×10^{-8}
Thallium	1.50×10^{3}	3.21×10^{-1}	2.5×10^{-6}	1.5×10^{-10}
Uranium	1.80×10^{0}	3.57×10^{1}	2.2×10^{-1}	1.3×10^{-5}
BERM FILL				
Radionuclides				
Lead-210	3.00×10^{3}	3.98×10^{0}	3.1×10^{-2}	6.2×10^{-7}
Polonium-210	4.00×10^{2}	4.02×10^{0}	2.4×10^{-1}	4.7×10^{-6}
Radium-224	6.96×10^{2}	1.02×10^{0}	3.5×10^{-2}	6.9×10^{-7}
Radium-226	6.96×10^{2}	6.68×10^{0}	2.3×10^{-1}	4.5×10^{-6}
Thorium-230	5.80×10^{3}	4.78×10^{0}	2.0×10^{-2}	3.9×10^{-7}
Thorium-232	5.80×10^{3}	1.35×10^{0}	5.5×10^{-3}	1.1×10^{-7}
Uranium-234	1.80×10^{0}	3.62×10^{0}	4.5×10^{1}	8.9×10^{-4}
Uranium-238	1.80×10^{0}	4.17×10^{0}	5.2×10^{1}	1.0×10^{-3}

TABLE E.4-1
(Continued)

Constituent	Chemical Data: Partition Coefficient, K_D (mL/g)	Chemical Data: Concentration in Waste Area, C_i (mg/kg)(pCi/g)[a]	Results: Concentration in Paddys Run Surface Water, C_w (mg/L)(pCi/L)[a]	Results: Concentration in Great Miami River Surface Water, C_w (mg/L)(pCi/L)[a]
Organics				
2-Butanone	3.47×10^{-2}	1.10×10^{-2}	6.4×10^{-4}	3.8×10^{-8}
Acetone	1.09×10^{-2}	6.40×10^{-2}	4.5×10^{-3}	2.7×10^{-7}
Di-n-butylphthalate	3.03×10^{3}	4.80×10^{-2}	1.3×10^{-7}	7.4×10^{-12}
Phenol	5.52×10^{1}	1.10×10^{-1}	1.3×10^{-3}	7.9×10^{-8}
Toluene	9.38×10^{0}	1.51×10^{-1}	1.3×10^{-4}	7.4×10^{-9}
Xylenes (total)	2.11×10^{1}	4.16×10^{-2}	1.6×10^{-5}	9.2×10^{-10}
Inorganics				
Antimony	2.50×10^{2}	2.49×10^{1}	7.9×10^{-4}	4.7×10^{-8}
Beryllium	1.30×10^{3}	8.50×10^{1}	5.2×10^{-6}	3.1×10^{-10}
Cadmium	5.00×10^{2}	4.20×10^{0}	6.7×10^{-5}	3.9×10^{-9}
Chromium	1.50×10^{3}	2.84×10^{1}	1.5×10^{-4}	8.8×10^{-9}
Copper	1.25×10^{2}	2.38×10^{1}	1.5×10^{-3}	8.9×10^{-8}
Molybdenum	9.00×10^{1}	1.33×10^{1}	1.2×10^{-3}	6.9×10^{-8}
Silver	1.80×10^{2}	1.44×10^{1}	6.4×10^{-4}	3.7×10^{-8}
Thallium	1.50×10^{3}	7.10×10^{-1}	3.8×10^{-6}	2.2×10^{-10}
Uranium	1.80×10^{0}	1.24×10^{1}	5.2×10^{-2}	3.1×10^{-6}
SURFACE SOILS				
Radionuclides				
Radium-226	6.96×10^{2}	2.18×10^{0}	1.5×10^{-1}	2.2×10^{-6}
Radium-228	6.96×10^{2}	1.26×10^{0}	8.5×10^{-2}	1.3×10^{-6}
Strontium-90	1.00×10^{1}	1.80×10^{0}	8.4×10^{0}	1.3×10^{-4}
Technetium-99	1.18×10^{-1}	9.29×10^{-1}	2.0×10^{2}	3.0×10^{-3}
Thorium-230	5.80×10^{3}	4.80×10^{0}	3.9×10^{-2}	5.8×10^{-7}
Uranium-234	1.80×10^{0}	3.40×10^{0}	8.5×10^{1}	1.3×10^{-3}
Uranium-238	1.80×10^{0}	1.23×10^{1}	3.1×10^{2}	4.5×10^{-3}
Organics				
2-Butanone	3.47×10^{-2}	5.99×10^{-3}	5.2×10^{-4}	3.1×10^{-8}
2-Hexanone	4.59×10^{-1}	5.00×10^{-3}	1.1×10^{-4}	6.2×10^{-9}
4-Methyl-2-Pentanone	2.36×10^{-1}	3.00×10^{-3}	1.1×10^{-4}	6.2×10^{-9}
Acenaphthylene	1.59×10^{2}	3.83×10^{-1}	2.9×10^{-5}	1.7×10^{-9}
Acetone	1.09×10^{-2}	6.29×10^{-2}	6.7×10^{-3}	3.9×10^{-7}

TABLE E.4-1
(Continued)

	Chemical Data		Results	
Constituent	Partition Coefficient, K_D (mL/g)	Concentration in Waste Area, C_i (mg/kg)(pCi/g)[a]	Concentration in Paddys Run Surface Water, C_w (mg/L)(pCi/L)[a]	Concentration in Great Miami River Surface Water, C_w (mg/L)(pCi/L)[a]
Anthracene	5.36×10^{2}	3.18×10^{-1}	7.1×10^{-6}	4.2×10^{-10}
Aroclor-1254	2.05×10^{4}	3.00×10^{-2}	1.7×10^{-8}	1.0×10^{-12}
Benzo(a)anthracene	7.66×10^{3}	5.74×10^{-1}	8.9×10^{-7}	5.2×10^{-11}
Benzo(a)pyrene	1.83×10^{4}	5.20×10^{0}	3.4×10^{-6}	2.0×10^{-10}
Benzo(b)fluoranthene	7.11×10^{4}	7.77×10^{-1}	1.3×10^{-7}	7.6×10^{-12}
Benzo(g,h,i)perylene	3.25×10^{5}	6.37×10^{-1}	2.3×10^{-8}	1.4×10^{-12}
Benzoic acid	1.42×10^{0}	5.90×10^{-2}	4.6×10^{-4}	2.7×10^{-8}
bis(2-Ethylhexyl)phthalate	3.83×10^{3}	4.99×10^{-1}	1.5×10^{-6}	9.1×10^{-11}
Chrysene	7.66×10^{3}	5.18×10^{-1}	8.0×10^{-7}	4.7×10^{-11}
Dibenzo(a,h) anthracene	1.79×10^{4}	3.35×10^{-1}	2.2×10^{-7}	1.3×10^{-11}
Di-n-butylphthalate	3.03×10^{3}	1.90×10^{-1}	7.5×10^{-7}	4.4×10^{-11}
Fluoranthene	4.09×10^{3}	5.99×10^{-1}	1.7×10^{-6}	1.0×10^{-10}
Ideno(1,2,3-cd)pyrene	8.75×10^{5}	5.85×10^{-1}	7.9×10^{-9}	4.7×10^{-13}
Methylene chloride	3.41×10^{-1}	2.04×10^{-2}	5.5×10^{-4}	3.2×10^{-8}
Phenol	5.52×10^{-1}	2.30×10^{-1}	4.2×10^{-3}	2.5×10^{-7}
Phenanthrene	5.55×10^{2}	4.92×10^{-1}	1.1×10^{-5}	6.2×10^{-10}
Pyrene	2.90×10^{3}	6.50×10^{-1}	2.7×10^{-6}	1.6×10^{-10}
Toluene	9.38×10^{0}	1.00×10^{-3}	1.3×10^{-6}	7.4×10^{-11}
Inorganics				
Antimony	2.50×10^{2}	3.01×10^{1}	1.4×10^{-3}	8.4×10^{-8}
Beryllium	1.30×10^{3}	8.66×10^{-1}	7.9×10^{-6}	4.7×10^{-10}
Cadmium	5.00×10^{2}	5.68×10^{0}	1.4×10^{-4}	7.9×10^{-9}
Chromium	1.50×10^{3}	1.86×10^{1}	1.5×10^{-4}	8.7×10^{-9}
Copper	1.25×10^{2}	2.08×10^{1}	2.0×10^{-3}	1.2×10^{-7}
Lead	3.00×10^{3}	1.48×10^{1}	5.9×10^{-5}	3.5×10^{-9}
Manganese	1.80×10^{2}	6.65×10^{2}	4.4×10^{-2}	2.6×10^{-6}
Nickel	6.50×10^{2}	3.20×10^{1}	5.8×10^{-4}	3.4×10^{-8}
Silver	1.80×10^{2}	9.15×10^{0}	6.0×10^{-4}	3.6×10^{-8}
Thallium	1.50×10^{3}	2.89×10^{-1}	2.3×10^{-6}	1.3×10^{-10}
Uranium	1.80×10^{0}	3.67×10^{1}	2.3×10^{-1}	1.4×10^{-5}

TABLE E.4-1
(Continued)

Constituent	Chemical Data: Partition Coefficient, K_D (mL/g)	Chemical Data: Concentration in Waste Area, C_i (mg/kg)(pCi/g)[a]	Results: Concentration in Paddys Run Surface Water, C_w (mg/L)(pCi/L)[a]	Results: Concentration in Great Miami River Surface Water, C_w (mg/L)(pCi/L)[a]
SILO 3				
Radionuclides				
Actinium-227	2.40×10^{3}	7.93×10^{2}	7.8×10^{0}	1.1×10^{-4}
Protactinium-231	2.70×10^{-3}	9.31×10^{2}	8.2×10^{0}	1.2×10^{-4}
Lead-210	3.00×10^{3}	4.73×10^{3}	3.7×10^{1}	5.4×10^{-4}
Radium-224	6.96×10^{2}	3.67×10^{2}	1.3×10^{1}	1.8×10^{-4}
Radium-226	6.96×10^{2}	3.87×10^{3}	1.3×10^{2}	1.9×10^{-3}
Radium-228	6.96×10^{2}	4.06×10^{2}	1.4×10^{1}	2.0×10^{-4}
Thorium-228	5.80×10^{3}	1.34×10^{3}	5.5×10^{0}	7.9×10^{-5}
Thorium-230	5.80×10^{3}	5.69×10^{4}	2.3×10^{2}	3.4×10^{-3}
Thorium-232	5.80×10^{3}	9.85×10^{2}	4.0×10^{0}	5.8×10^{-5}
Uranium-234	1.80×10^{0}	1.94×10^{3}	2.5×10^{4}	3.6×10^{-1}
Uranium-235/236	1.80×10^{0}	1.17×10^{2}	1.5×10^{3}	2.2×10^{-2}
Uranium-238	1.80×10^{0}	1.78×10^{3}	2.3×10^{4}	3.3×10^{-1}
Inorganics				
Antimony	2.50×10^{2}	5.50×10^{0}	1.3×10^{-4}	7.6×10^{-9}
Arsenic	2.00×10^{2}	3.17×10^{3}	9.3×10^{-2}	5.4×10^{-6}
Barium	1.14×10^{3}	2.58×10^{2}	1.3×10^{-3}	7.8×10^{-8}
Beryllium	1.30×10^{3}	2.91×10^{1}	1.3×10^{-4}	7.7×10^{-9}
Cadmium	5.00×10^{2}	9.41×10^{1}	1.1×10^{-3}	6.5×10^{-8}
Chromium	1.50×10^{3}	3.95×10^{2}	1.5×10^{-3}	9.1×10^{-8}
Cobalt	5.50×10^{2}	2.87×10^{3}	3.1×10^{-2}	1.8×10^{-6}
Copper	1.25×10^{2}	3.34×10^{3}	1.6×10^{-1}	9.2×10^{-6}
Lead	3.00×10^{3}	2.38×10^{3}	4.6×10^{-3}	2.7×10^{-7}
Manganese	1.80×10^{2}	5.16×10^{3}	1.7×10^{-1}	9.9×10^{-6}
Mercury	1.00×10^{1}	6.90×10^{-1}	4.0×10^{-4}	2.4×10^{-8}
Nickel	6.50×10^{2}	4.29×10^{3}	3.9×10^{-2}	2.3×10^{-6}
Selenium	7.40×10^{2}	2.29×10^{2}	1.8×10^{-3}	1.1×10^{-7}
Silver	1.80×10^{2}	1.84×10^{1}	6.0×10^{-4}	3.5×10^{-8}
Thallium	1.50×10^{3}	5.61×10^{1}	2.2×10^{-4}	1.3×10^{-8}
Vanadium	1.00×10^{3}	3.49×10^{3}	2.0×10^{-2}	1.2×10^{-6}

TABLE E.4-1
(Continued)

	Chemical Data		Results	
Constituent	Partition Coefficient, K_D (mL/g)	Concentration in Waste Area, C_i (mg/kg)(pCi/g)[a]	Concentration in Paddys Run Surface Water, C_w (mg/L)(pCi/L)[a]	Concentration in Great Miami River Surface Water, C_w (mg/L)(pCi/L)[a]
Zinc	2.40×10^{3}	5.35×10^{2}	1.3×10^{-3}	7.7×10^{-8}
Uranium	1.80×10^{0}	5.34×10^{3}	1.7×10^{1}	9.8×10^{-4}

[a]Radionuclide values presented in pCi/g or pCi/L

concentrations were estimated based on low flow rates in the receiving stream.

E.4.3 SURFACE WATER MODEL APPLICATION

E.4.3.1 Calculation of Soil Loss from Runoff

The soil loss model, MUSLE, was obtained from the U.S. Environmental Protection Agency (EPA) Superfund Exposure Assessment Manual (EPA 1988). This model calculates the total mass of soil transported by surface water in a single rainfall event using event-specific runoff volume, storm duration, and flow rate variables. Model parameters and references are presented in Table E.4-2.

Soil loss is estimated using the MUSLE:

$$Y(S)_E = (CF)[(Vr)qp)]^{0.56}(K)(LS)(C)(P) \qquad \text{(E.4-1)}$$

where

- $Y(S)_E$ = soil loss in runoff (metric tons per event)
- CF = conversion factor (11.8 for metric units)
- K = soil erodability factor (metric tons/hectares [ha]/unit R_r)
- LS = product of slope length factor and slope steepness factor (unitless)
- C = cover factor (unitless)
- P = erosion control practice factor (unitless)
- Vr = volume of runoff (m^3)
- qp = peak runoff flow rate (m^3/sec)

Intermediate parameters Vr and qp are calculated by:

$$Vr = (100)(A)(Qr) \qquad \text{(E.4-2)}$$

and

$$Qr = (Rt-0.2Sw)^2/(Rt+0.8Sw) \qquad \text{(E.4-3)}$$

and

$$Sw = (2.54)[(1000/CN)-10] \qquad \text{(E.4-4)}$$

and

$$qp = (0.028)(A)(Rt)(Qr)/(Tr)(Rt-0.2Sw) \qquad \text{(E.4-5)}$$

where

- A = contaminated area (ha)
- Qr = depth of runoff (cm)

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TABLE E.4-2

SITE-SPECIFIC INPUT PARAMETERS USED FOR SURFACE WATER RUNOFF MODEL

Parameter	Source Term Area		
	OU4 Surface Soil[a]	Berm Fill	Silo 3
LS, slope length and steepness factor (unitless)[b]	1.2	4	1.2
C, cover factor (unitless)[c]	0.042	0.042	0.45
A, contaminated area (ha)[d]	1.54	0.77	0.5
CN, SCS runoff curve number (unitless)[e]	86	86	86
Oc, available water capacity (unitless)[f]	0.15	0.15	0.15
ρ, soil bulk density (g/cm^3)[g]	1.48	1.48	2.267
K, soil erodibiity factor (ton/ha)[h]	0.26	0.26	0.26
Rt, total storm rainfall (cm)[i]	6.35	6.35	6.35
Tr, storm duration (hr)[i]	24	24	24
N, number of rainfall events per year (unitless)[j]	16	16	16

[a]This applies to the Operable Unit 4 surface soil and the Operable Unit 4 surface soil and berm fill (combined) source term areas.
[b]SEAM EPA, 1988 Figure 2-6, based on the slope length of 328 feet and steepness of 6.1 percent for soils, 14% for berms.
[c]AES, 1988 ex. 7-5, 60% grass cover assumed for the soils, 0% cover assumed for silo contents
[d]Area of soils determined from site boundary, area for Silo 3 contents estimated for cross-sectional area of 0.05ha assuming material covers 10 times that area.
[e]HELP model data for Operable Unit 4
[f]Calculated from site-specific information
[g]BD for soils based on midrange of typical values for soil type (Fincastle) (SCS Soil Survey of Hamilton and Butler Counties); BD for Silo 3 is dry density of silo material.
[h]AES, 1988, ex. 7-2 and site-specific information
[i]1-year, 24-hr storm event (Hershfield 1961)
[j]Average annual rainfall (39 inches)/Rt

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Rt = depth of rainfall (cm)
SW = soil water retention factor (cm)
CN = Soil Conservation Service (SCS) runoff curve number (unitless)
Tr = Rainfall duration (hours)

E.4.3.2 Calculation of Contaminant Partioning and Loading

Additional models are used to describe contaminant partioning between soil and water. These partioning models provide an estimate of the contaminant concentrations in surface water runoff and in the soil that is carried with the runoff and deposited in the sediments of receiving surface water bodies (Haith 1980; Mills, et al. 1982). The portion of contaminant from the eroded soil that remains with the sediment or is dissolved in the water is estimated using the following equations, respectively:

$$Ss = \{1/[1 + 0C(Kd \cdot \rho)]\}\ (Ci)(\rho)(A')(CF) \qquad \text{(E.4-6)}$$

and

$$Ms = \{1/[1 + (Kd \cdot \rho)/Oc]\}\ (Ci)(\rho)(A')(CF) \qquad \text{(E.4-7)}$$

where

Ss = available quantity of adsorbed contaminant (portion to sediments) (g)
Ms = available quantity of dissolved contaminant (portion to water) (g)
Oc = available water capacity in top cm of soil (unitless)
Kd = sorption partition coefficient (cm^3/g)
ρ = bulk soil density (g/cm^3)
Ci = concentration of contaminant in soil (mg/kg)
CF = conversion factor, 100 ($kg/mg \cdot cm^2/ha$)
A' = contaminated volume (ha-cm)

The mass of adsorbed contamination from the source area is:

$$PXi = [Y(S)_E/100\rho A']Ss \qquad \text{(E.4-8)}$$

where

PXi = sorbed substance loading per event (g)

The mass of dissolved contamination from the source area is:

$$PQi = (Qr/Rt)Ms \qquad (E.4\text{-}9)$$

where

PQi = dissolved substance loading per event (g)

The contaminant concentration in the runoff effluent is:

$$Ce = PQi/Vr \qquad (E.4\text{-}10)$$

where

Ce = concentration of contaminant in runoff (g/m^3 or mg/L)

The average runoff flow rate is:

$$Qe = Vr/Tr \qquad (E.4\text{-}11)$$

The contaminant concentration in the receiving water (Paddys Run) downstream is:

$$Cw = (Ce)(Qe)/(Qt + Qe) \qquad (E.4\text{-}12)$$

where

Cw = concentration of contaminant in surface water downstream (mg/L)
Qe = average runoff flow rate (m^3/hr)
Qt = flow rate of receiving water body downstream (m^3/hr)

The contaminant concentration in the Great Miami River is estimated by:

$$Cgmr = (Cw)(Qt)/(Qgmr + Qt) \qquad (E.4\text{-}13)$$

where

Cmgr = concentration of contaminant in the Great Miami River (mg/L)
Qgmr = flow rate of the Great Miami River (m^3/hr)

An average flow rate of 340,000 m^3/hr was used for the Great Miami River.

E.4.3.3 Model Assumptions

These models are the basis for the following assumptions:

- Constituents adsorbed to soils in runoff remain adsorbed in the stream sediments
- Constituents dissolved in runoff water remain in the water column in the receiving stream
- Concentrations measured in the soil, or Silo 3 contents, represent the upper soil layer subject to erosion

E.4.4 MODEL RESULTS

Results were calculated on a source term-specific basis. Surface water concentrations for the constituents of concern in Paddys Run and the Great Miami River are presented in Table E.4-1.

E.4.4.1 Comparison of Surface Soil to Berm Fill

Source terms for surface material within Operable Unit 4 were separated into 2 distinct source areas: Operable Unit 4 surface soil and berm fill. These areas were modeled both separately and combined in the SW runoff model.

Constituents of potential concern (COCs) in the berm fill and not in the Operable Unit 4 surface soils include:

- Lead (Pb-210)
- Polonium (Po-2120)
- Radium (Ra-224)
- Thorium (Th-232)
- Molybdenum
- Xylenes (total)

COCs in the Operable Unit 4 surface soils and not in the berm fill include:

- 2-hexanone
- 4-methyl-2-pentanone
- Acenaphthylene
- Anthracene
- Aroclor-1254
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(g,h,i)perylene
- Benzoic acid
- bis(2-Ethylhexyl)phthalate
- Chrysene
- Dibenzo(a,h)anthracene
- Fluoranthene
- Indeno(1,2,3-cd)pyrene
- Lead
- Manganese

- Methylene chloride
- Nickel
- Phenanthrene
- Pyrene
- Ra-228
- Strontium (Sr-90)
- Technetium (Tc-99)

Figure E.4-1 presents a side-by-side comparison of radionuclides modeled in Paddys Run surface water from runoff for those radionuclides common to Operable Unit 4 surface soil and berm fill. Results for Ra-226, Th-230, and U-234 are within a factor of two or three for the three different source terms. U-238 varies from 52 pCi/L in the berm fill to 310 pCi/L in the Operable Unit 4 surface soils.

Figure E.4-2 presents a side-by-side comparison of organic constituents modeled in Paddys Run from runoff for the three source terms. Toluene varies the most, from 1.3×10^{-6} mg/L in Operable Unit 4 surface soils to 1.3×10^{-4} mg/L in berm fill. Variation between source terms are within a factor of 6 or less for the other organics: 2-butanone is slightly higher in berm fill, while acetone, di-n-butylphthalate, and phenol are slightly lower in the berm fill than in Operable Unit 4 surface soils.

Figure E.4-3 presents a side-by-side comparison for inorganic constituents of potential concern modeled in Paddys Run surface water from runoff. Results for all inorganic COCs are within an order of magnitude between the three source terms. Antimony, beryllium, cadmium, copper, nickel, and uranium are slightly lower in the berm fill, silver and thallium are slightly higher in the berm fill than in Operable Unit 4 surface soils. There is no measurable difference for chromium.

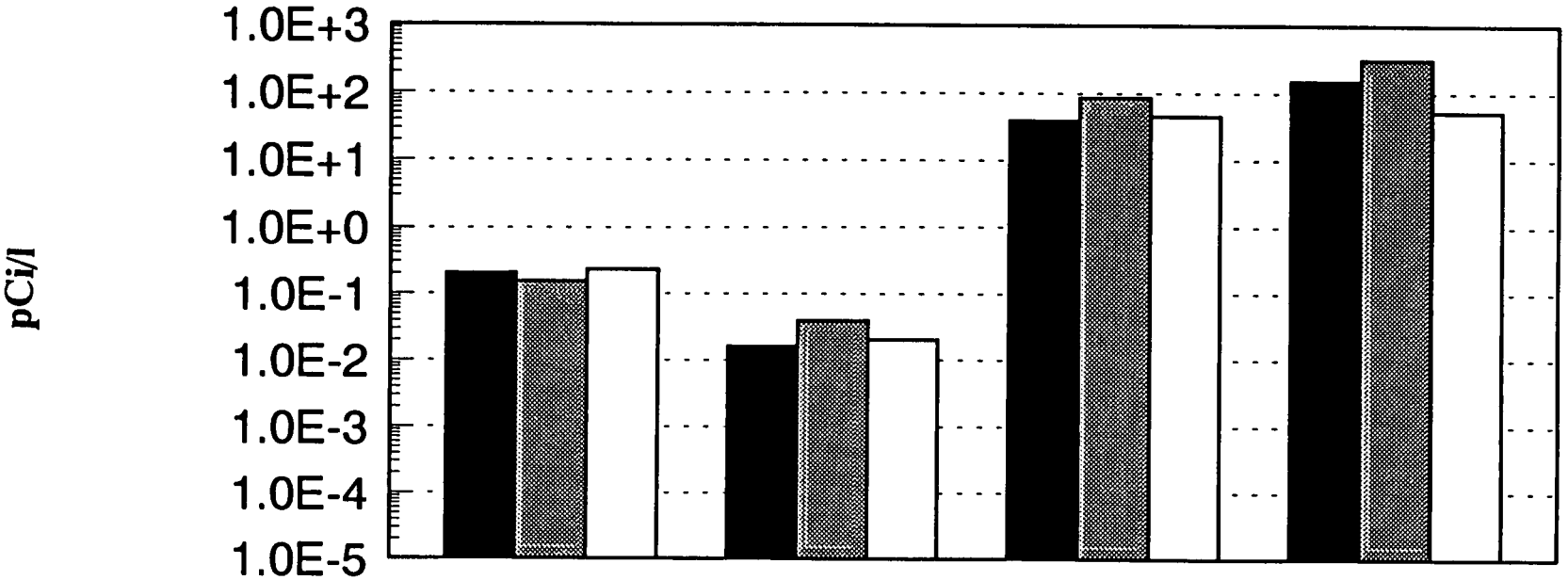
These results suggest that the variation between berm fill and Operable Unit 4 surface soil source terms are within the range of any sampling and analytical uncertainty for those constituents common to both source areas. Because there were several COCs present in one source area and not the other, the results from the combined source area (Operable Unit 4 surface soils <u>and</u> berm fill) are used in the risk assessment for surface water exposure point concentrations for runoff from soil in Operable Unit 4. This ensures that all COCs in Operable Unit 4 surface soil and berm fill are included in the risk assessment.

E.4.4.2 <u>Comparison of Modeled Results to Measured Concentrations</u>

Modeled concentrations in Paddys Run surface water are compared to measured concentrations for several constituents of potential concern in Table E.4-3. Actual surface water concentrations are expected to vary over time, depending on the current rainfall pattern. Also, a direct comparison is limited by the scope of the surface water runoff model; only soil and berm fill within the Operable

Figure E.4-1

Comparison of Radionuclides in Paddys Run From Surface Water Runoff Model

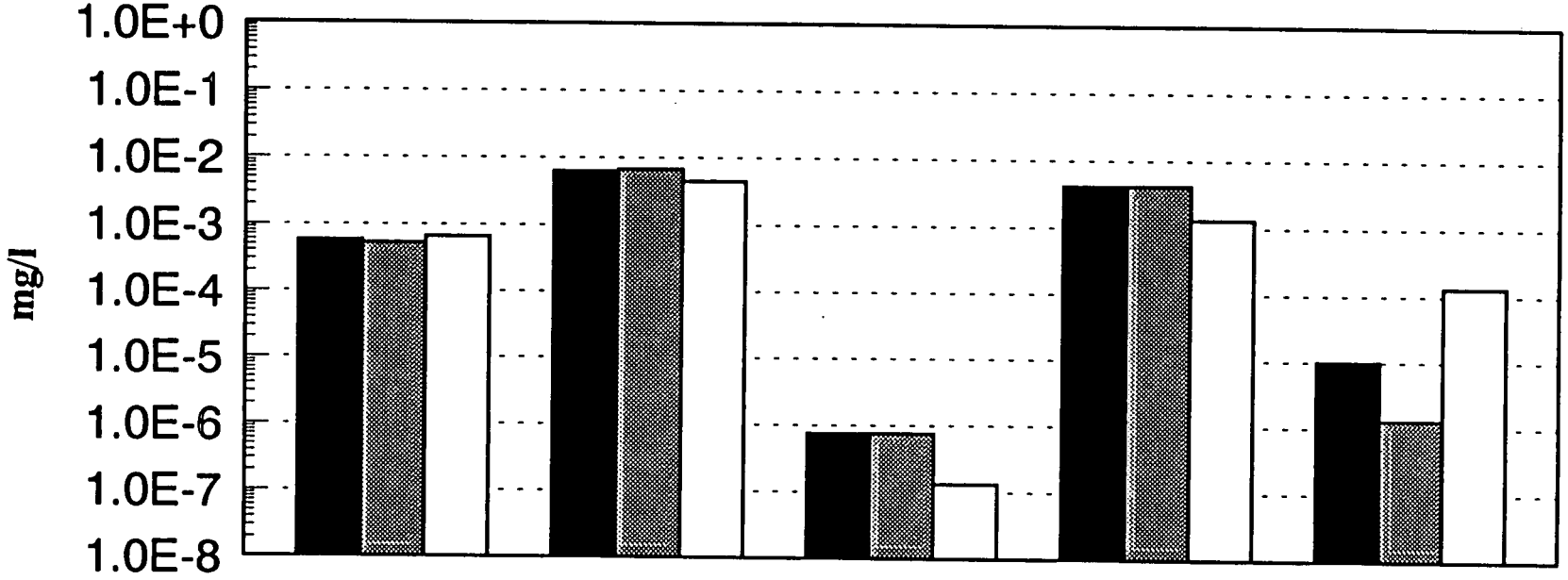


Radionuclides	Ra-226	Th-230	U-234	U-238
Combined ■	2.0E-1	1.6E-2	3.9E+1	1.5E+2
Surface Soils ▒	1.5E-1	3.9E-2	8.5E+1	3.1E+2
Berm Fill □	2.3E-1	2.0E-2	4.5E+1	5.2E+1

FEMP-OU4FEB-93FL-GRAPH-1.PRE

Figure E.4-2

Comparison of Organics in Paddys Run From Surface Water Runoff Model

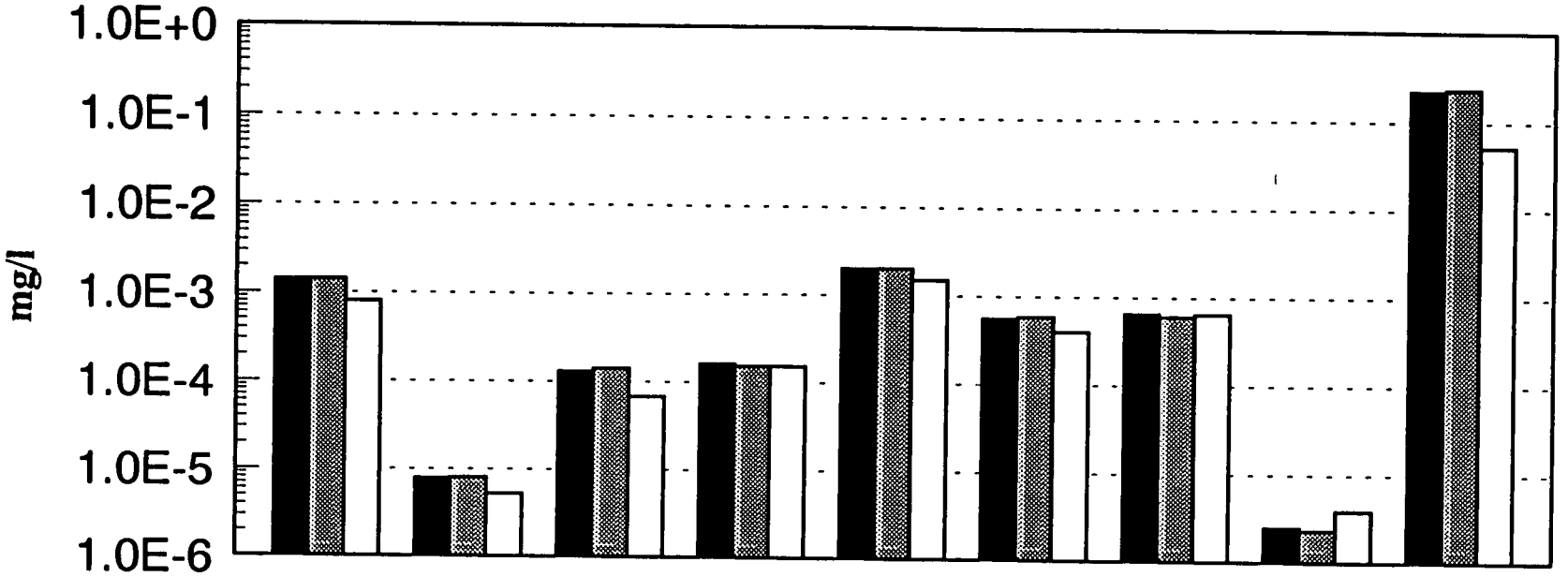


Constituent	2-Butanone	Acetone	Di-n-butyl phthalate	Phenol	Toluene
Combined ■	5.7E-4	6.3E-3	7.5E-7	4.2E-3	1.0E-5
Surface Soils ▩	5.2E-4	6.7E-3	7.5E-7	4.2E-3	1.3E-6
Berm Fill □	6.4E-4	4.5E-3	1.3E-7	1.3E-3	1.3E-4

FEMP-OU4FEB-93FL-GRAPH-1.PRE

Figure E.4-3

Comparison of Inorganics in Paddys Run From Surface Water Runoff Model



Constituent	Antimony	Beryllium	Cadmium	Chromium	Copper	Nickel	Silver	Thallium	Uranium
Combined ■	1.4E-3	7.7E-6	1.3E-4	1.6E-4	2.0E-3	5.6E-4	6.5E-4	2.5E-6	2.2E-1
Surface Soils ▩	1.4E-3	7.9E-6	1.4E-4	1.5E-4	2.0E-3	5.8E-4	6.0E-4	2.3E-6	2.3E-1
Berm Fill □	7.9E-4	5.2E-6	6.7E-5	1.5E-4	1.5E-3	4.0E-4	6.4E-4	3.8E-6	5.2E-2

FEMP-OU4FEB-93FL-GRAPH-1.PRE

TABLE E.4-3

COMPARISON OF MODELED RESULTS TO MEASURED SURFACE WATER CONCENTRATIONS

Constituent of Potential Concern[a]	Modeled Concentrations in Paddys Run[b]	Range of Measured Concentration in Paddys Run
Radionuclides (pCi/L)		
Radium-226	0.20	<1.0[c]
Thorium-230	0.016	<1.0-2.3[c]
Thorium-232	0.0057	<1.0[c]
Uranium-234	39	1.2-3.6[c]
Uranium-238	150	2.0-6.8[c]
Total Uranium	190	
1985		7.18-236[d]
1986		9.5-49[d]
1987		1.9-6.8[d]
1988		2.1-39[d]
Chemicals (µg/L)		
Cadmium	0.013	<2[e]
Chromium	0.16	<10[e]
Copper	2.0	<10[e]
Lead	0.054	7.4-9.3[e]
Nickel	0.56	<20[e]
Silver	0.65	<10[e]
Uranium	220	9-15[e]

[a]COC listed only if measured data were available for comparison
[b]Modeled from surface soil and berm fill source term
[c]From Table 4-SW, surface water sample locations W-10 and W-11
[d]Range of averages from 1985-1988 FMPC Envirnmental Monitoring Reports, surface water sample locations W-07, W-08, W-10, and W-11.
[e]ASI/IT, Geochemical Program Issues 3 and 5.

Unit 4 Study Area are accounted for, while actual concentrations in Paddys Run result from runoff from the entire stream drainage area including upstream contributions.

Measured and modeled concentrations are consistent for the following COCs: Ra-226, Th-232, cadmium, chromium, copper, nickel, and silver. In all these cases, modeled concentrations are less than the reported detection limits for surface water samples. Modeled concentrations for Th-230 and lead are approximately two orders of magnitude less than measured concentrations. Modeled concentrations for uranium are approximately one to two orders of magnitude higher than measured concentrations, with the exception of one average total uranium concentration reported at 236 pCi/L in 1985, which is very close to the modeled activity concentrations for U-234 plus U-238 at 190 pCi/L.

The fact that modeled results for several constituents are consistent with measured data indicates that the surface water runoff model is producing reasonable estimates of surface water runoff from Operable Unit 4. These measured data include modeled lead and Th-230 concentrations that are lower than measured concentrations (but within two orders of magnitude), and modeled uranium concentrations that are generally higher than measured concentrations.

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