DOE/OR/21548-065

Baseline Risk Evaluation for Exposure to Bulk Wastes at the Weldon Spring Quarry, Weldon Spring, Missouri

January 1990

U.S. Department of Energy
Oak Ridge Operations Office
Weldon Spring Site Remedial Action Project

DOE/OR/21548-065

Baseline Risk Evaluation for Exposure to Bulk Wastes at the Weldon Spring Quarry, Weldon Spring, Missouri

January 1990

prepared by

L.A. Haroun, J.M. Peterson, M.M. MacDonell, and I. Hlohowskyj

Environmental Assessment and Information Sciences Division, Argonne National Laboratory

prepared for

U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, under Contract W-31-109-Eng-38

CONTENTS

FOREWORD ix

NOTATION xi

1 INTRODUCTION 1

1.1 Site Background and Setting 1
1.2 Environmental Compliance Process for the Quarry 1
1.3 Scope of the Baseline Risk Evaluation 3
1.4 Overview of the Baseline Risk Evaluation Process 5
1.4.1 Identification of Contaminants of Concern 7
1.4.2 Exposure Evaluation 7
1.4.3 Toxicity and Risk Evaluation 7
1.4.4 Environmental Assessment 8

2 SITE CHARACTERIZATION 9

2.1 Surface Features 9
2.2 Meteorology 9
2.3 Surface Water Hydrology 10
2.4 Geology and Hydrogeology 12
2.5 Demography and Land Use 13
2.6 Ecology 14

3 IDENTIFICATION OF CONTAMINANTS OF CONCERN 19

3.1 Sources and Types of Contamination 19
3.1.1 Radioactive Contaminants 19
3.1.2 Chemical Contaminants 21
3.2 Selection of Indicator Contaminants 22
3.2.1 Preliminary List 22
3.2.2 Final Selection 35

4 EXPOSURE ASSESSMENT 41

4.1 Identification of Exposure Pathways 41
4.2 Exposure Scenarios 44
4.2.1 Impacted Area 44
4.2.2 Scenario Definition 45
4.3 Estimation of Exposure Point Concentrations 46
4.3.1 Surface Soils 46
4.3.2 Air 49
4.4 Comparison with Standards and Criteria 51
4.4.1 Radioactive Contaminants 51
4.4.2 Chemical Contaminants 52

CONTENTS (Cont'd)

4.5 Estimation of Contaminant Intakes 55
4.5.1 Passerby Scenario 55
4.5.2 Trespasser Scenario 59

5 SUMMARY TOXICITY PROFILES 67

5.1 Radiation Toxicity 67
5.2 Chemical Toxicity 68
5.2.1 Nitroaromatic Compounds 68
5.2.2 Metals 70
5.2.3 Polychlorinated Biphenyls 72
5.2.4 Polynuclear Aromatic Hydrocarbons 72

6 HEALTH RISK EVALUATION 73

6.1 Radiological Risks 73
6.2 Chemical Risks 76
6.2.1 Carcinogenic Risks 76
6.2.2 Noncarcinogenic Risks 81
6.3 Total Radiological and Chemical Risks 83
6.4 Discussion 85
6.4.1 Site Characterization Data 85
6.4.2 Selection and Use of Indicator Contaminants 86
6.4.3 Exposure Scenarios 86
6.4.4 Reference Doses and Carcinogenic Potency Factors 87
6.4.5 Summary 87

7 ENVIRONMENTAL ASSESSMENT 89

7.1 Water Resources 89
7.2 Soil Resources 90
7.3 Air Quality 90
7.4 Vegetation and Wildlife 90

8 REFERENCES 93

APPENDIX A: Methodology for Estimating Air Contaminant Concentrations 101

APPENDIX B: English/Metric - Metric/English Equivalents 107

TABLES

2.1 Threatened, Endangered, or Special Concern Species Reported from St. Charles County, Missouri, and Potentially Occurring at the Weldon Spring Quarry Area 15

3.1 History of Disposal Activities at the Weldon Spring Quarry 20

3.2 Concentrations of Radionuclides in the Quarry Bulk Wastes 21

3.3 Concentrations of Chemicals Detected in the Quarry Bulk Wastes in the 1984-1985 Characterization Study and Background Concentrations in Missouri Soils 23

3.4 Concentrations of Organic Compounds Detected in the Quarry Bulk Wastes in the 1986 Characterization Study 25

3.5 Concentrations of Nitroaromatic Compounds in Surface Soils at the Quarry 27

3.6 Scoring for Indicator Chemical Selection: Toxicity Information 33

3.7 Preliminary List of Indicator Chemicals for the Quarry 36

3.8 Final List of Indicator Radionuclides and Chemicals for the Quarry 39

4.1 Potential Pathways of Human Exposure to Contaminants at the Weldon Spring Quarry 42

4.2 Exposure Point Concentrations of Indicator Radionuclides in Surface Soils and Air at the Quarry 47

4.3 Exposure Point Concentrations of Indicator Chemicals in Surface Soils and Air at the Quarry 48

4.4 DOE Guidelines for Residual Radioactive Material and Their Relevance to the Quarry Bulk Wastes 53

4.5 Assumptions Used for Estimating Radiological and Chemical Exposures: Passerby Scenario 56

4.6 Estimated Average Daily Intakes of Indicator Chemicals from Exposure to Fugitive Dusts: Passerby Scenario 60

TABLES (Cont'd)

4.7 Assumptions Used for Estimating Radiological and Chemical Exposures: Trespasser Scenario 61

4.8 Estimated Average Daily Intakes of Indicator Chemicals from Exposure to Fugitive Dusts: Trespasser Scenario 63

4.9 Estimated Average Daily Intakes of Indicator Chemicals from Dermal Exposure to Contaminated Surface Soils: Trespasser Scenario 64

4.10 Estimated Average Daily Intakes of Indicator Chemicals from Incidental Ingestion of Contaminated Surface Soils: Trespasser Scenario 66

5.1 References for Chemical Toxicity Data 69

6.1 Estimated Radiation Risks for the Passerby Scenario 74

6.2 Estimated Radiation Risks for the Trespasser Scenario 75

6.3 Estimated Risk of Lung Cancer Mortality from Exposure to Radon-222 Decay Products 75

6.4 Estimated Carcinogenic Risk from Inhalation Exposure to Potential Chemical Carcinogens: Passerby Scenario 78

6.5 Estimated Carcinogenic Risk from Exposure to Potential Chemical Carcinogens: Trespasser Scenario 79

6.6 Calculated Hazard Indexes for Noncarcinogenic Effects: Passerby Scenario 82

6.7 Calculated Hazard Indexes for Noncarcinogenic Effects: Trespasser Scenario 84

6.8 Total Risks and Hazard Indexes for the Passerby and Trespasser Scenarios 85

FIGURES

1.1 Area and Vicinity Map of the Weldon Spring Site, Weldon Spring, Missouri 2

1.2 Environmental Compliance Components for the Weldon Spring Quarry 3

1.3 Diagram of the Public Health Risk Evaluation Process 6

2.1 Layout of the Weldon Spring Quarry 10

2.2 Topography of the Quarry Area 11

2.3 Surface Hydrological Features in the Vicinity of the Quarry and Location of Production Wells in the St. Charles County Well Field 12

3.1 Area of Surficial Nitroaromatic Contamination at the Weldon Spring Quarry 28

3.2 Uranium-238 Radioactive Decay Series 29

3.3 Thorium-232 Radioactive Decay Series 30

4.1 Radon and External Gamma Exposure Monitoring Locations at the Weldon Spring Quarry 49

FOREWORD

The U.S. Department of Energy (DOE), under its Surplus Facilities Management Program (SFMP), is responsible for cleanup activities at the Weldon Spring site, Weldon Spring, Missouri. The site consists of two noncontiguous areas: (1) a raffinate pits and chemical plant area and (2) a quarry. This baseline risk evaluation has been prepared to support a proposed response action for management of contaminated bulk wastes in the quarry. The quarry became chemically and radioactively contaminated as a result of various wastes that were disposed of there between 1942 and 1969. This risk evaluation assesses potential impacts on human health and the environment that may result from exposure to releases of contaminants from the quarry under current site conditions.

Risk assessment is a key component of the remedial investigation/feasibility study (RI/FS) process, as identified in guidance from the U.S. Environmental Protection Agency (EPA); this process addresses sites subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act of 1986. Response actions at the Weldon Spring quarry are subject to CERCLA requirements because the quarry is listed on the EPA's National Priorities List. The DOE is also responsible for complying with the requirements of the National Environmental Policy Act (NEPA) of 1969, which requires federal agencies to consider the environmental consequences of a proposed action as part of the decision-making process for that action. Although this document has not been prepared to fulfill specific NEPA requirements, the analyses contained herein -- along with the analyses provided in the remedial investigation, feasibility study, and other supporting documents -- are intended to meet the environmental assessment requirements of NEPA.

The DOE is proposing to remove the bulk wastes from the quarry as a separate operable unit of the overall remedial action at the Weldon Spring site. The wastes will be transported to a temporary storage facility at the raffinate pits and chemical plant area of the site. The evaluation of this and other alternatives is being documented via a focused RI/FS process consisting of an RI report, this baseline risk evaluation, and an FS report. The contents of these documents were developed in consultation with EPA Region VII and the state of Missouri and reflect the narrow scope of the proposed action. Because removal of the quarry bulk wastes is an interim step in the overall remedial action, the supporting documentation focuses on data pertinent to that action. The baseline risk evaluation assesses potential risks associated with the quarry bulk wastes in the near term (i.e., the next several years). Following removal of the bulk wastes, additional characterization will be performed at the quarry to determine the need for further remediation, and a comprehensive baseline risk assessment will be prepared that addresses current and future risks associated with residual contamination in the quarry, contaminated groundwater, and contaminated vicinity properties.

Site characterization data are continuing to be collected to support the Weldon Spring project. The analyses contained in this document are based on data available as of May 1989.

NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this document. Notation used in specific tables only is defined in the respective tables.

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ARAR	applicable or relevant and appropriate requirement
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended
CFR	Code of Federal Regulations
DCG	Derived Concentration Guide
DNT	dinitrotoluene
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FS	feasibility study
ICRP	International Commission on Radiological Protection
MKT	Missouri-Kansas-Texas (railroad)
MSL	mean sea level
NPL	National Priorities List
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PHRED	*Public Health Risk Evaluation Database*
RI	remedial investigation
SPHEM	*Superfund Public Health Evaluation Manual*
SFMP	Surplus Facilities Management Program
TNT	trinitrotoluene
VOC	volatile organic compound

UNITS OF MEASURE

cm	centimeter(s)
cm^2	square centimeter(s)
d	day(s)
ft	foot (feet)
g	gram(s)
h	hour(s)
ha	hectare(s)
in.	inch(es)
kg	kilogram(s)
km	kilometer(s)
L	liter(s)
μg	microgram(s)

UNITS OF MEASURE (Cont'd)

μm	micrometer(s)
μR	microroentgen(s)
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
MeV	million electron volt(s)
mg	milligram(s)
mi	mile(s)
mo	month(s)
mph	mile(s) per hour
mrem	millirem(s)
mR	milliroentgen(s)
no.	number
pCi	picocurie(s)
ppm	part(s) per million
rem	roentgen equivalent man
s	second(s)
WL	working level(s)
WLM	working level month(s)
yd^2	square yard(s)
yd^3	cubic yard(s)
yr	year(s)

1 INTRODUCTION

1.1 SITE BACKGROUND AND SETTING

The Weldon Spring site is located near Weldon Spring, Missouri, about 48 km (30 mi) west of the city of St. Louis (Figure 1.1). It is surrounded by large tracts of land owned by the federal government and the state of Missouri. The site consists of two non-contiguous areas: (1) a raffinate pits and chemical plant area (hereafter termed the chemical plant area) and (2) a quarry. The chemical plant area is about 3.2 km (2 mi) southwest of the junction of Missouri (State) Route 94 and U.S. Route 40/61. The quarry is about 6.4 km (4 mi) south-southwest of the chemical plant area and about 8 km (5 mi) southwest of the community of Weldon Spring in St. Charles County, Missouri. The chemical plant area and the quarry are accessible from State Route 94. Both areas are fenced and closed to the public.

The U.S. Department of the Army used the Weldon Spring site to produce trinitrotoluene (TNT) and dinitrotoluene (DNT) from 1941 to 1946, and the U.S. Atomic Energy Commission (AEC) used the site to process uranium and thorium concentrates from 1957 to 1966. The quarry was used by the Army and the AEC for waste disposal since the early 1940s; it was last used for disposal in 1969. Wastes placed in the quarry include TNT and DNT residues and radioactively contaminated materials. The quarry was transferred from the Army to the AEC in July 1960; as successor to the AEC, the U.S. Department of Energy (DOE) is currently responsible for the Weldon Spring site, including the quarry, under its Surplus Facilities Management Program (SFMP). The site history and results from earlier characterization studies of the Weldon Spring site are summarized in previously published documents (DOE 1987a; Peterson et al. 1988). The results of characterization studies of the quarry are summarized in the remedial investigation (RI) report for the quarry (MK-Ferguson Company and Jacobs Engineering Group 1989b).

1.2 ENVIRONMENTAL COMPLIANCE PROCESS FOR THE QUARRY

The Weldon Spring quarry can be divided into five separate components for the purpose of environmental response actions: (1) bulk wastes, (2) contaminated surface water in the quarry pond, (3) contaminated groundwater, (4) contaminated vicinity properties, and (5) residual materials remaining after removal of the bulk wastes. These components are shown in Figure 1.2.

The DOE is proposing to remove the contaminated bulk wastes from the quarry and transport them approximately 6.4 km (4 mi) to a temporary storage facility at the chemical plant area of the Weldon Spring site. The bulk wastes are defined as various solid materials that can be removed from the quarry by standard excavation technologies; these wastes include contaminated soils and sludges, process wastes, rubble, drums, structural debris, and equipment. This action would commence prior to the record of decision for the overall remedial action at the Weldon Spring site. The decision on the final disposal of these bulk wastes will be included as part of the decision for the disposition of the contaminated materials currently located at the chemical plant area.

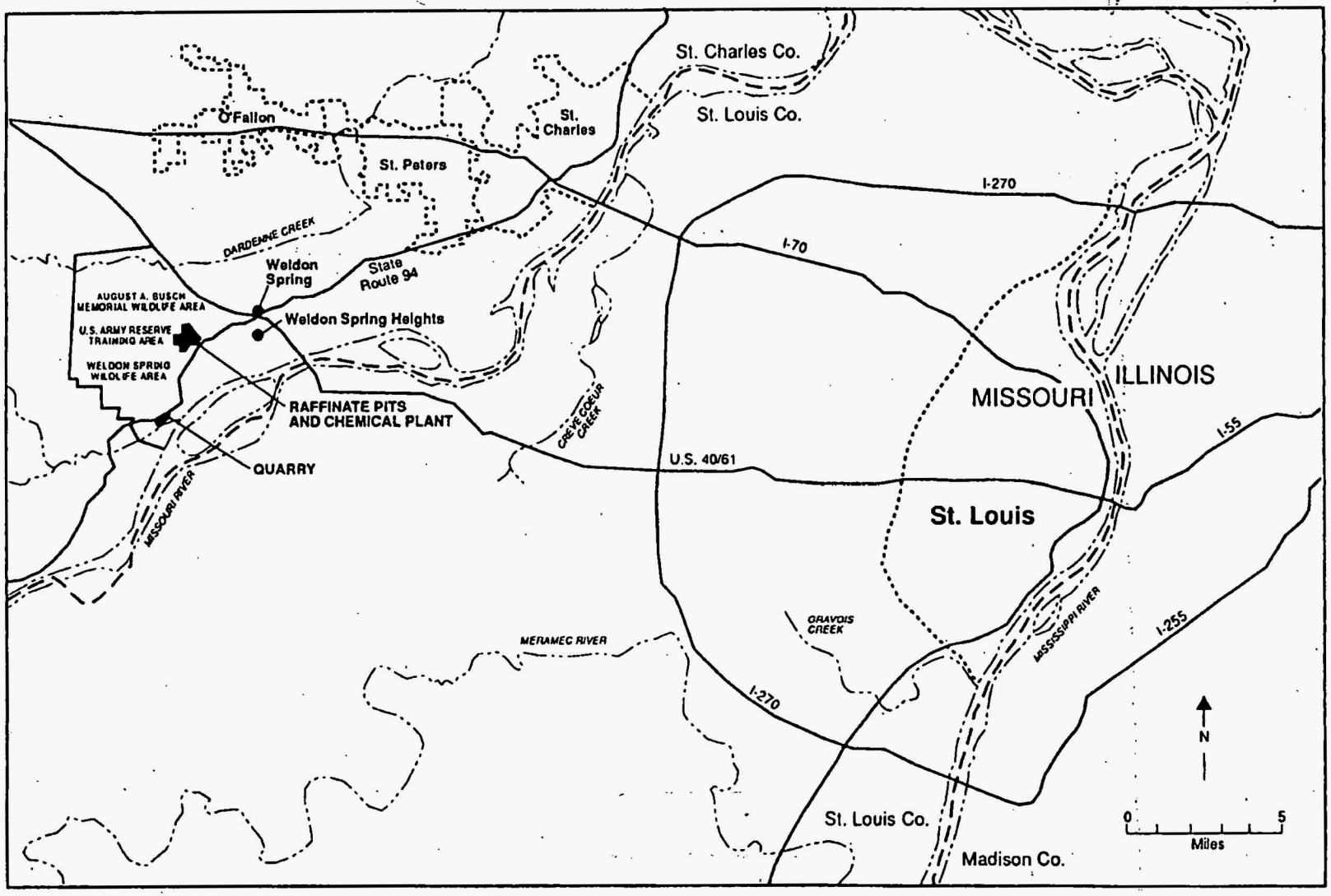


FIGURE 1.1 Area and Vicinity Map of the Weldon Spring Site, Weldon Spring, Missouri

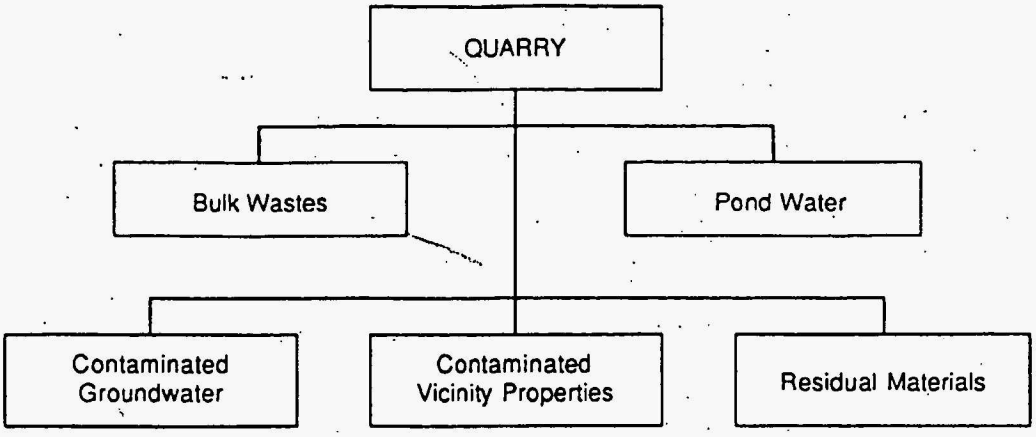


FIGURE 1.2. Environmental Compliance Components for the Weldon Spring Quarry

Contaminated water in the quarry pond and the quarry area will be removed and treated prior to and as needed during the bulk waste removal activities. The long-term remedial plan for contaminated groundwater, contaminated vicinity properties, and residual materials remaining after bulk waste removal will be developed after the bulk wastes have been removed and the extent of residual contamination in and around the quarry has been fully assessed.

Environmental compliance documentation for the Weldon Spring site is being prepared in accordance with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act of 1986. Actions at the Weldon Spring site are subject to CERCLA because the site is listed on the National Priorities List (NPL) of the U.S. Environmental Protection Agency (EPA). In accordance with CERCLA, a remedial investigation/feasibility study (RI/FS) is being undertaken for this site. Although the quarry is part of the Weldon Spring site, the bulk wastes have been defined as a separate operable unit in order to expedite the documentation and remediation processes. Action at the quarry is being addressed through a focused RI/FS process. Documentation prepared to date in support of the RI/FS process at the quarry includes this baseline risk evaluation and the RI report (MK-Ferguson Company and Jacobs Engineering Group 1989b). In addition, an engineering evaluation/cost analysis report was prepared to document the removal and treatment of water in the quarry pond (MacDonell et al. 1989). The scope of these documents was developed in consultation with EPA Region VII and the state of Missouri.

1.3 SCOPE OF THE BASELINE RISK EVALUATION

Risk assessment is a key component of the RI/FS process, as identified in guidance from the EPA. As part of the RI, a baseline risk assessment is generally conducted for the baseline (no-action) case to (1) determine potential impacts to human

health and the environment, (2) help determine appropriate cleanup criteria, and (3) provide a basis for evaluation of the effectiveness of proposed remedial action alternatives. However, because removal of bulk wastes is an interim action in the overall remedial action for the quarry, the scope and purpose of this risk evaluation was less comprehensive than that generally performed in a baseline risk assessment. For this reason, the assessment is referred to as a "baseline risk evaluation," to distinguish it from a more comprehensive baseline risk assessment. Limitations on the availability of site characterization data with respect to the extent of contamination and the pathways and mechanisms for contaminant migration from the quarry preclude the preparation of a comprehensive RI or baseline risk assessment. The detailed characterization data necessary to make such an assessment cannot be obtained until the bulk wastes have been removed from the quarry. The nature of these wastes (i.e., a heterogeneous mixture that includes rubble, structural debris, and equipment) is not conducive to the use of conventional investigative techniques such as drilling. Hence, the analyses in the baseline risk evaluation have been carried out to meet, within the limits of available data, the first of the three objectives of a risk assessment, i.e., to assess the potential impacts to human health and the environment. Current data are sufficient to perform such an assessment. A substantial amount of historical data is available on past disposal practices at the quarry, including analytical data regarding the composition of the bulk wastes. These data have confirmed the presence of radioactive and chemical contaminants consistent with the types of materials known to have been placed in the quarry.

This baseline risk evaluation has been prepared to assess the risks associated with current conditions at the quarry in the near term (i.e., the next several years). It is based on site characterization data available as of May 1989 and EPA risk estimators (carcinogenic potency factors and reference doses) available as of October 1989. Because the bulk waste removal action is planned to begin within the next 5 years, an exposure period of up to 10 years was assumed for the risk evaluation. Two exposure scenarios associated with potential short-term exposures to the bulk wastes (i.e., prior to their excavation) were evaluated: (1) a passerby scenario, which considers potential exposure of a hypothetical individual who routinely walks by the quarry, and (2) a trespasser scenario, which considers potential exposure of a hypothetical individual who enters the quarry several times per year. These scenarios were defined such that the nature and duration of the exposures would provide upper bound estimates of the potential risks to any individual exposed to releases outside the quarry fence or to an individual who might trespass into the quarry. Thus, although other more realistic scenarios were considered (e.g., a person who routinely drives by the quarry or an individual visiting the surrounding wildlife areas, such as a hiker on Katy Trail), these scenarios were not explicitly evaluated because the exposures of these receptors would be similar to but less than the exposures estimated for the passerby scenario.

Consistent with the limited scope of the quarry RI/FS, this baseline risk evaluation does not address risks associated with the contaminated pond water and groundwater at the quarry. Documentation has been prepared (MacDonell et al. 1989) to support treatment of the contaminated pond water, with discharge of the treated water to the Missouri River in compliance with a permit issued by the Missouri Department of Natural Resources; this response action will be initiated in 1990. Hence, the baseline

conditions for evaluating risks associated with the quarry bulk wastes assume that the quarry pond water has been removed and treated.

The groundwater at the quarry has been shown to contain elevated concentrations of chemical and radioactive contaminants, but it is not used as a drinking water source. The groundwater south of the quarry and at the nearby St. Charles county well field is monitored routinely, and mitigative measures would be taken, as required, if elevated concentrations of contaminants were detected in the well field. Potential long-term risks associated with contaminated groundwater will be addressed following the bulk waste removal action and the completion of hydrogeologic characterization studies necessary to perform a comprehensive risk assessment.

Potential risks to workers and the public associated with implementation of remedial action activities (i.e., excavation of the bulk wastes) will be addressed in the FS prepared to support this action. A comprehensive baseline risk assessment addressing current and future risks associated with residual contamination in the quarry, contaminated groundwater, and contaminated vicinity properties will be prepared following removal of the bulk wastes and completion of characterization studies necessary to perform such an assessment. The results of the risk assessment will be used to help develop cleanup criteria for the quarry area and will provide the basis for selecting the final remedial action alternative for that area.

This baseline risk evaluation includes a limited environmental assessment in addition to an evaluation of potential human health impacts. The assessment presented in this report was prepared prior to issuance of recent EPA guidance on performance of environmental risk assessments at NPL sites (EPA 1989d). Consistent with the scope of the human health evaluation, the environmental assessment was addressed qualitatively because comprehensive environmental data are not available. Additional information on the environmental setting and ecological resources at the quarry will be given in the FS report.

1.4 OVERVIEW OF THE BASELINE RISK EVALUATION PROCESS

During this baseline risk evaluation, all available physical, chemical, radiological, hydrological, geological, ecological, and demographic data relevant to the Weldon Spring quarry were evaluated. The objective was to describe and assess the extent, if any, of potential risk to human health and the environment resulting from the contamination present at the quarry. Although limited in scope (see Section 1.3), a public health evaluation was conducted -- to the extent possible -- using guidance given in the *Superfund Public Health Evaluation Manual* (SPHEM) (EPA 1986c) and the *Superfund Exposure Assessment Manual* (EPA 1988b). The public health risk evaluation process is diagrammed in Figure 1.3, and each of its components is briefly described in Sections 1.4.1 through 1.4.3. The environmental assessment component of the baseline risk evaluation is discussed in Section 1.4.4.

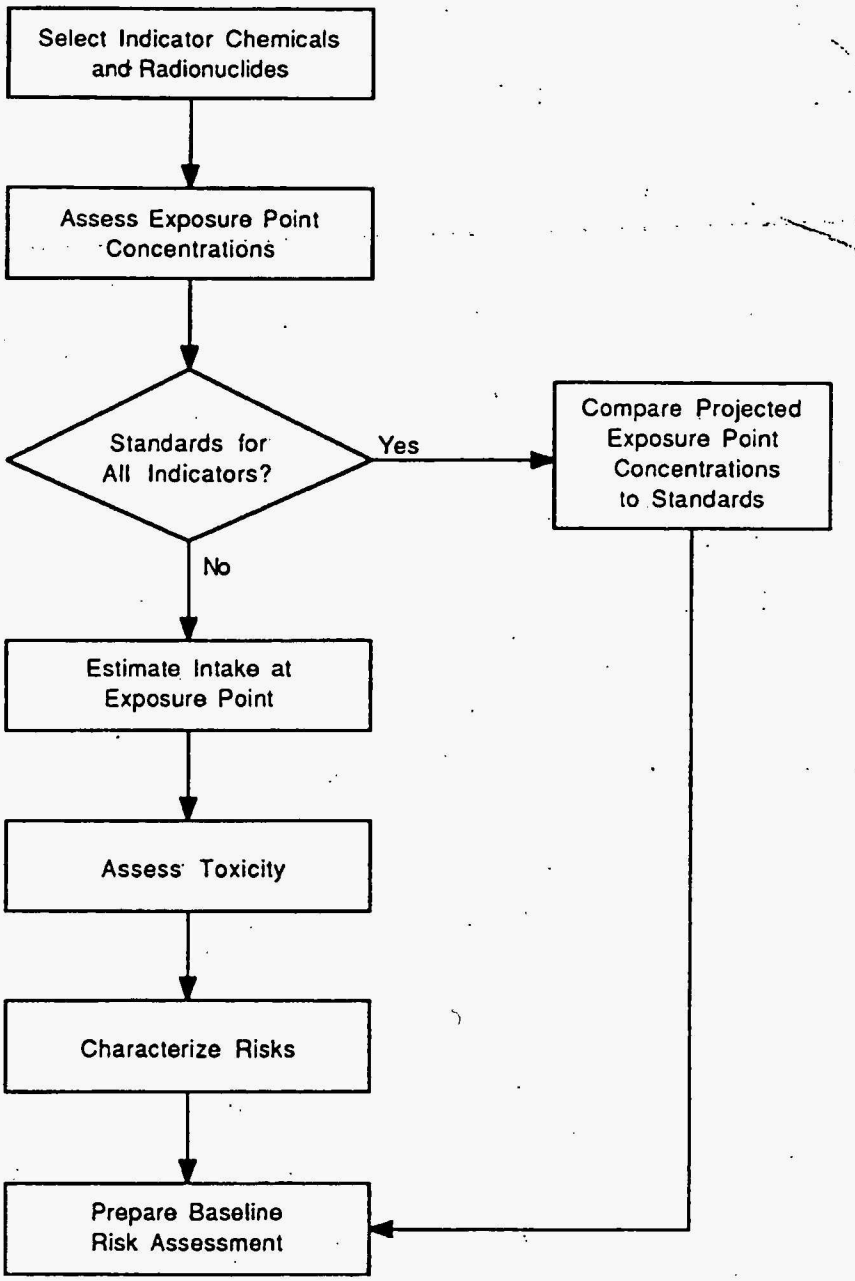


FIGURE 1.3 Diagram of the Public Health Risk Evaluation Process (Source: Modified from Peterson et al. 1988)

1.4.1 Identification of Contaminants of Concern

The first step in the risk evaluation process was selecting indicator radionuclides and chemicals at the quarry that pose the greatest potential risks to human health. In general, these contaminants are those that represent the most toxic, mobile, and/or persistent species, as well as those that are present in the largest quantities. Additional factors considered in the selection of indicator radionuclides were the components of the relevant decay series and the half-lives of the radionuclides.

1.4.2 Exposure Evaluation

The second step in the risk evaluation process was characterizing potential exposure pathways and determining exposure point concentrations. The exposure evaluation consisted of assessing (1) the sources and mechanisms of potential contaminant releases from the quarry bulk wastes, (2) the environmental fate of released contaminants — including identification of both the media by which contaminants may be transported (e.g., air and/or water) and the possible physical, chemical, and biological mechanisms by which the contaminants may be transformed, (3) the potential human receptors and routes of exposure (inhalation, ingestion, and dermal contact), (4) the exposure point concentrations, and (5) the uptake of contaminants by exposed individuals.

The concentrations of indicator chemicals and radionuclides in environmental media at exposure points were estimated using characterization and monitoring data and environmental fate and transport models, as necessary. Available information regarding environmental chemistry and contaminant fate were incorporated, where applicable. The exposure point concentrations were compared with health-based applicable or relevant and appropriate requirements (ARARs). Because ARARs were not available for all indicator contaminants, a toxicity and risk assessment was performed. Scenarios of human activity that give rise to exposure were developed, and the uptake of contaminants by potential receptors was determined.

1.4.3 Toxicity and Risk Evaluation

Potential health effects from exposure to the indicator chemicals were assessed by comparing the estimated average daily exposure estimates (intakes) to established reference doses. A reference dose is the average daily dose that can be incurred by individuals without likely adverse health effects. Potential chemical carcinogenic risks were estimated as probabilities, based on the average daily lifetime dose and on compound-specific potency factors (expressed as the lifetime cancer risk per milligram per day of the carcinogen per kilogram body weight). The risk of radiation exposure was expressed in terms of the increased likelihood for induction of fatal cancers and serious genetic effects in the offspring of exposed individuals. In this risk evaluation, the radiological and chemical risks are reported separately for clarity of presentation. Toxicological summaries of radiation exposure and indicator chemicals, which include brief summaries of their major toxic effects, are also provided.

1.4.4 Environmental Assessment

The baseline risk evaluation includes an environmental assessment in addition to an evaluation of potential impacts on human health. This environmental assessment is based on site-specific information from characterization studies and the environmental monitoring program at the quarry. Data on water and soil resources, air quality, and vegetation and wildlife (including threatened and endangered species) were used to evaluate potential adverse environmental impacts that could result from the presence of contaminated materials in the quarry. Sources of additional information used in this assessment included available literature and consultations with state and federal agencies (e.g., the Missouri Department of Conservation and the U.S. Fish and Wildlife Service). The assessment of potential impacts incorporated much of the information utilized in the public health evaluation portion of the baseline risk evaluation, including sources and mechanisms of contaminant release and transport from the quarry, environmental fates and concentrations of released contaminants, and potential environmental receptors. Potential environmental impacts associated with the presence of contaminated materials in the quarry were addressed qualitatively because comprehensive environmental data are not available, e.g., for the specific contaminants and biota present in the quarry area.

2 SITE CHARACTERIZATION

2.1 SURFACE FEATURES

The Weldon Spring quarry was excavated into a limestone ridge that borders the Missouri River alluvial floodplain; prior to 1942, it was mined for limestone to support various construction activities. The quarry is about 300 m (1,000 ft) long and covers approximately 3.6 ha (9 acres). The elevations of the existing floor and rim of the quarry are about 150 and 170 m (480 and 550 ft) mean sea level (MSL), respectively. The main quarry floor covers approximately 0.8 ha (2 acres) and contains ponded water over about 0.2 ha (0.5 acre). A wooden pier extends into the pond, which is the only surface water body within the quarry. A pyramid-shaped limestone hill rises from the quarry floor northeast of the pond to an elevation of about 158 m (518 ft) MSL. The quarry is enclosed by a 2.1-m-high (7-ft-high) chain link fence topped with three strands of barbed wire. The two entrance gates to the quarry are locked.

The Missouri-Kansas-Texas (MKT) railroad line formerly passed just south of the quarry; this line was recently dismantled, and the right-of-way has been converted to a public trail for hiking and biking (Katy Trail). A rail spur enters the quarry at its lower level from the west and extends approximately one-third of its length. The spur is overgrown with vegetation and is in a state of disrepair. The layout of the quarry is shown in Figure 2.1; the topography of the quarry area is shown in Figure 2.2.

2.2 METEOROLOGY

The climate in the vicinity of the Weldon Spring site is continental, with moderately cold winters and warm to hot summers. Alternating warm/cold, wet/dry air masses converge and pass through the area, causing frequent changes in the weather. The average annual precipitation in the area is about 93 cm (37 in.), of which more than half falls between March and May. The area is subject to frequent changes in temperature. Although winters are generally cold and summers hot, prolonged periods of very cold or very warm to hot weather are unusual. The average annual temperature at St. Charles, Missouri, located about 35 km (22 mi) northeast of the quarry, was 13°C (55°F) from 1951 through 1986. Prevailing winds in the vicinity of the site are from the south during the summer and fall and from the northwest and west-northwest during the winter and early spring. Average wind speeds recorded at St. Louis from 1941 through 1970 were 14 km/h (8.5 mph) for the months of May through November and 18 km/h (11 mph) for December through April; the annual average speed was 15 km/h (9.5 mph). Wind speeds recorded at the chemical plant meteorological station in 1985 averaged 14 km/h (8.7 mph) in the summer and fall and 18 km/h (11 mph) during the winter, corresponding well with the St. Louis data. Tornadoes occur in the St. Louis area once or twice per year, but they usually follow a narrow path and dissipate after a short distance (about 1.6 km [1.0 mi]); during the most recent 40-year period of record, only four tornadoes caused extensive damage (MK-Ferguson Company and Jacobs Engineering Group 1989b).

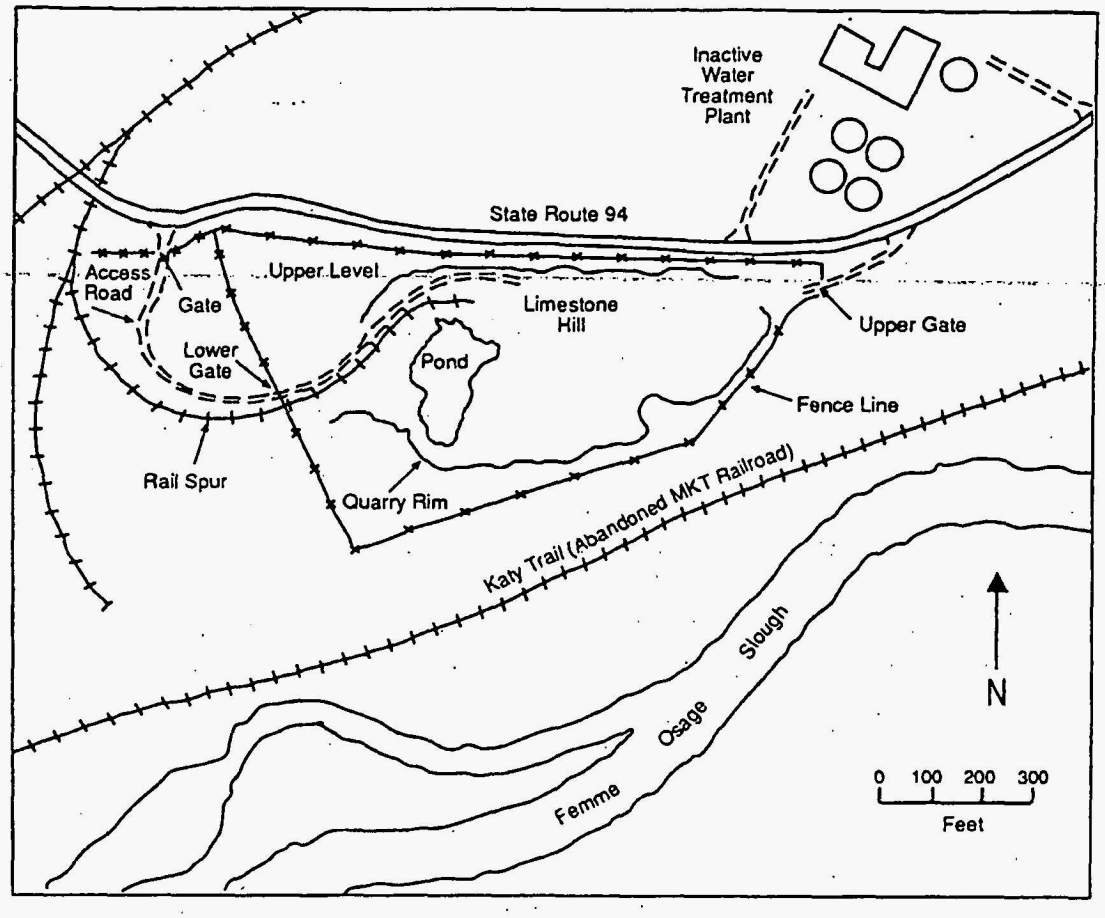


FIGURE 2.1 Layout of the Weldon Spring Quarry (Source: Modified from Peterson et al. 1988)

2.3 SURFACE WATER HYDROLOGY

The quarry is about 1.6 km (1 mi) northwest of the Missouri River and about 29 km (18 mi) south of the Mississippi River at the rivers' closest points. The drainage divide between the two rivers transects the east-southeast portion of the chemical plant area of the Weldon Spring site; surface runoff to the south of the divide, including the quarry area, flows into the Missouri River (Bechtel National 1987). Streams in the immediate vicinity of the quarry include Femme Osage Creek, Little Femme Osage Creek, and an unnamed tributary to Little Femme Osage Creek. Drainage at the quarry occurs primarily through the subsurface, with limited surface drainage on the western and southern rims; the surface drainage flows to the Missouri River through Little Femme Osage Creek and Femme Osage Creek. The high quarry rim prevents any entry of surface flow from the surrounding area; therefore, water influent from outside the quarry is limited to direct rainfall or subsurface flow.

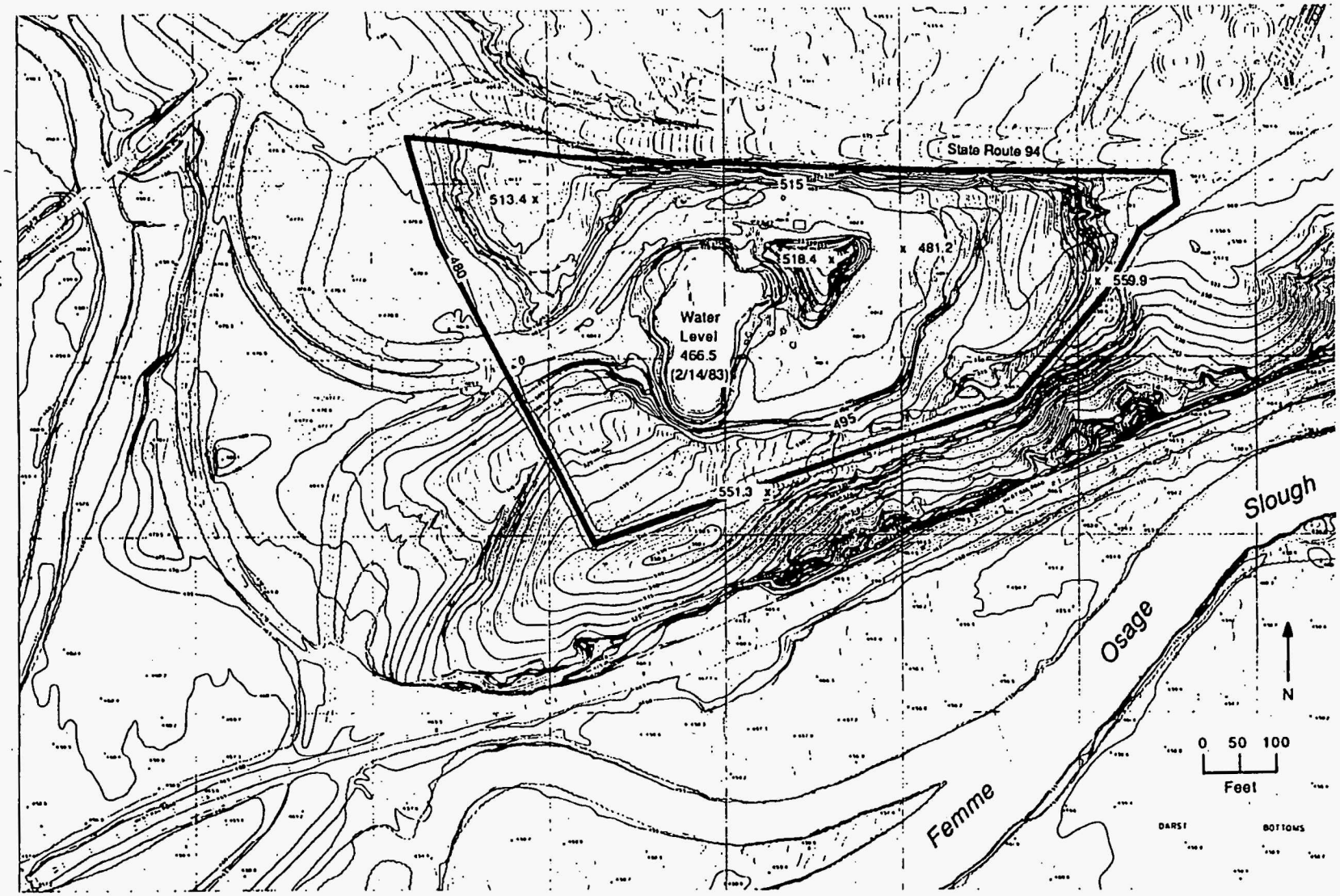


FIGURE 2.2 Topography of the Quarry Area

Approximately 90 m (300 ft) south of the quarry is a 2.4-km (1.5-mi) section of the original Femme Osage Creek that was dammed at both ends by the University of Missouri between 1960 and 1963. This body of water lies parallel to the quarry bluffs and is now called Femme Osage Slough. The St. Charles County well field is located between Femme Osage Slough and the Missouri River. Surface hydrological features in the vicinity of the quarry and the location of production wells in the well field are shown in Figure 2.3.

2.4 GEOLOGY AND HYDROGEOLOGY

The uppermost geological stratum at the quarry is Kimmswick limestone of Ordovician age, and the quarry floor is Decorah shale. Exposed rock on the quarry walls and on the steep bluffs along the Missouri River is predominantly Ordovician limestone, shale, dolomite, and sandstone. The upper layers of limestone in the quarry consist of a complex system of solution channels, joints, and fractures through which groundwater movement occurs. Two lithologically distinct aquifers comprise the near-surface

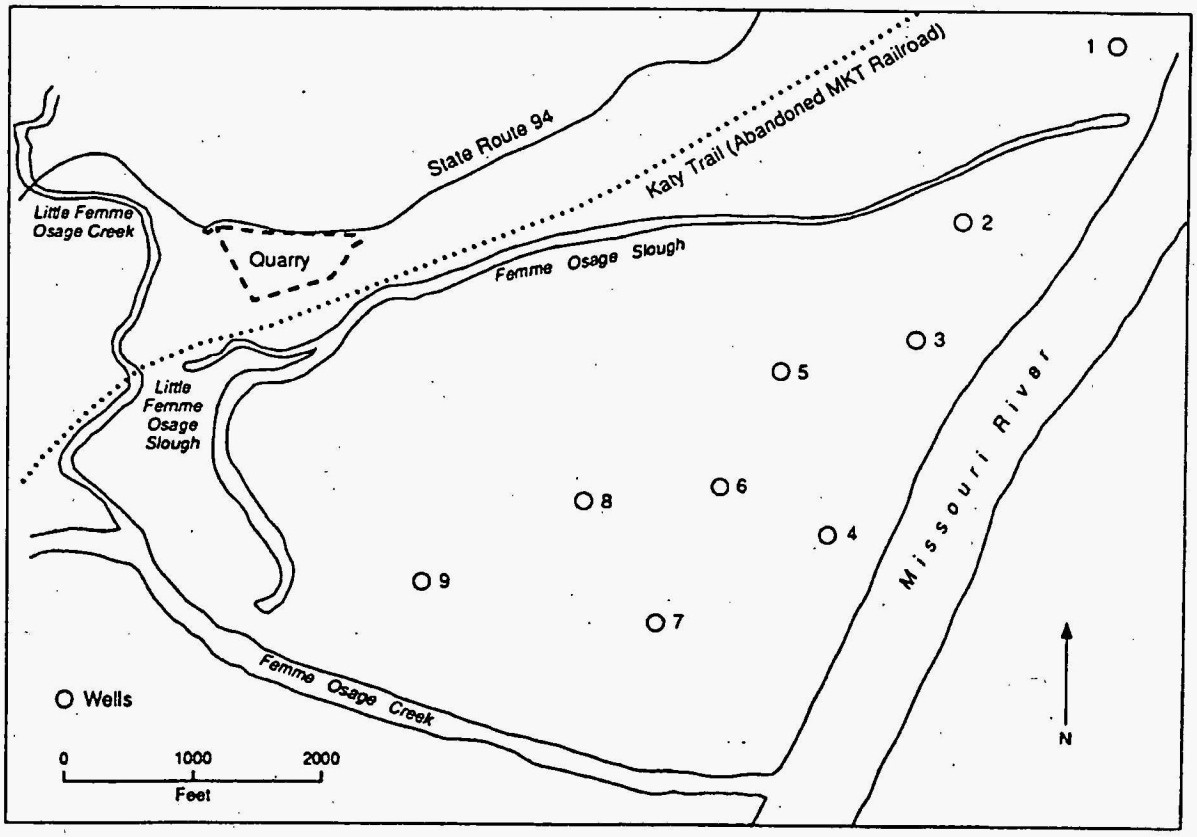


FIGURE 2.3 Surface Hydrological Features in the Vicinity of the Quarry and Location of Production Wells in the St. Charles County Well Field (Source: Modified from Peterson et al. 1988)

groundwater regime in the vicinity of the quarry (MK-Ferguson Company and Jacobs Engineering Group 1989b). The first is a predominantly limestone bedrock aquifer beneath the quarry and the second is an alluvial aquifer located generally between Femme Osage Slough and the Missouri River. The two aquifers connect in the vicinity of Femme Osage Slough. A majority of the groundwater flow from the quarry is transported by the local gradient toward the alluvium of the Missouri River floodplain. The connection of the fractured limestone aquifer beneath the quarry with the unconfined alluvial aquifer near Femme Osage Slough is not clearly understood. Although it is certain that groundwater flows toward the Missouri River from the quarry, the influence of Femme Osage Slough on this flow and the associated solute transport are uncertain. Studies reported by MK-Ferguson Company and Jacobs Engineering Group (1989b) indicate that the clay and silty alluvium at the slough may act as a groundwater barrier. This hypothesis is based on three observations: (1) groundwater velocities in the vicinity of the slough are very low to almost stagnant; (2) water levels in the alluvium south of the slough are approximately 3 m (10 ft) lower than water levels in the slough itself; and (3) the alluvial aquifer south of Femme Osage Slough is not radioactively contaminated. These observations are indicative of a poor hydraulic connection between the bedrock and the alluvial aquifers. Although there is currently no indication that groundwater flows through the alluvial material below the slough to the alluvial aquifer, groundwater may flow underneath the clay and silty material through fractured bedrock.

2.5 DEMOGRAPHY AND LAND USE

The Weldon Spring site is located in St. Charles County (see Figure 1.1) but is also considered part of the St. Louis metropolitan area, which had a population of about 2.4 million in 1980; the population of St. Charles County in 1980 was about 144,000. The communities of Weldon Spring and Weldon Spring Heights are approximately 8.0 km (5 mi) north-northeast of the quarry and have a combined population of about 800. The nearest community, Defiance, is about 4.8 km (3 mi) from the quarry and has a population of about 100. St. Charles, the largest city in the county, is about 35 km (22 mi) northeast of the quarry and has a population of about 40,000.

The Weldon Spring quarry is in a relatively unpopulated portion of the county, and most of the surrounding land consists of wildlife areas operated by the Missouri Department of Conservation. Much of the land south of the quarry along the Missouri River floodplain is being used for agriculture. The nearest residence is about 0.8 km (0.5 mi) west of the quarry on State Route 94, and a limestone quarry is currently operating about 1.2 km (0.75 mi) west of the residence. Francis Howell High School is about 7.2 km (4.5 mi) northeast of the Weldon Spring quarry on State Route 94, and a highway maintenance facility is west of the school and adjacent to the northeast boundary of the chemical plant area. A water treatment plant that is owned by the county, but not in use, is located north of the quarry adjacent to State Route 94. A second county water treatment plant is currently operating about 1.6 km (1 mi) northeast of the quarry adjacent to State Route 94.

2.6 ECOLOGY

The Weldon Spring site (including the quarry) is in the Bluestem Prairie Oak-Hickory Forest Mosaic subsection of the Prairie Parkland Province (Bailey 1978). This area is characterized by dense to open riparian woodlands interspersed with upland prairie. With the exception of the Missouri River floodplain area to the south, the surrounding topography is rugged and heavily wooded and is characterized by deeply dissected hills and deep ravines.

Much of the area around the Weldon Spring site is state-owned wildlife area. The quarry lies within the boundaries of the 2,930-ha (7,230-acre) Weldon Spring Wildlife Area, which is actively managed for wildlife. Various habitat types occur in the area -- such as forest, agricultural fields, old fields, and pasture -- and these habitats support a wide diversity of plant and animal species.

The quarry area is primarily forest, with some old-field habitat. The quarry rim and surrounding area are primarily slope forest and bottomland forest, and the predominant tree species are eastern cottonwood and sycamore. Much of the quarry floor is old-field habitat characterized by a variety of grasses, herbs, and shrubs. The Missouri Department of Conservation (Dickneite 1988) reports 25 amphibian, 47 reptilian, 29 mammalian, and 299 avian species in the area of the Weldon Spring site, and some of these species may inhabit or utilize the quarry area. For example, the terrestrial habitat at the quarry may be used by a variety of small mammals -- such as squirrels, raccoons, and mice -- and the quarry pond may provide suitable habitat for some waterfowl and amphibians.

Numerous aquatic habitats exist throughout the Weldon Spring area and in the immediate vicinity of the quarry. These include the quarry pond, the Missouri River, Little Femme Osage Creek, Femme Osage Creek, Femme Osage Slough, and numerous small, unnamed creeks, drainages, and ponds throughout the Weldon Spring Wildlife Area. In addition, the nearby August A. Busch Memorial Wildlife Area contains more than 35 ponds and lakes ranging in size from 0.4 to 74 ha (1 to 180 acres). The Missouri Department of Conservation lists more than 105 species of fish that have been recorded for St. Charles County (Dickneite 1988), and many of these may be found in the various aquatic habitats in the Weldon Spring area. Common fishes in these habitats include carp, channel catfish, buffalo, sucker, bass, sunfish, crappie, shad, freshwater drum, white bass, and a variety of minnows, shiners, and darters.

Several species classified as rare or endangered are known to occur in the area (i.e., St. Charles County, Weldon Spring Wildlife Area, August A. Busch Memorial Wildlife Area, and Howell Island Wildlife Area); these species are listed in Table 2.1. No designated critical habitat for any of these species is known to exist at the quarry. The nearby Howell Island Wildlife Area south of the quarry provides an important night roost for overwintering bald eagles (a federally endangered species), and two Category 2 fish species are known to occur in the Missouri River south of the quarry (Category 2 means candidate for federal listing as endangered or threatened). The Missouri Department of Conservation (Gaines 1988) reports 17 state endangered, 17 state rare, and 8 state "special concern" species in the vicinity of the quarry (Table 2.1). Of these species, the Cooper's hawk (*Accipiter cooperii*, state endangered) and the wood frog (*Rana sylvatica*,

TABLE 2.1 Threatened, Endangered, or Special Concern Species Reported from St. Charles County, Missouri, and Potentially Occurring in the Weldon Spring Quarry Area

Species	Status	
	Federal[a]	State[b]
Plants		
Starwort (variety)	C2	Endangered
Forbes saxifrage	C3	Watch list
Rose turtlehead	C3	Endangered
Arrow arum	-	Rare
Star duckweed	-	Rare
Bugseed (variety)	-	Watch list
Adder's tongue fern (variety)	-	Undetermined
Salt meadow grass (variety)	-	Undetermined
Fish		
Pallid sturgeon	C2	Endangered
Pugnose minnow	-	Endangered
Sturgeon chub	C2	Rare
Sicklefin chub	C2	Rare
Alligator gar	-	Rare
Brown bullhead	-	Rare
Alabama shad	-	Rare
Starhead topminnow	-	Watch list
Western sand darter	-	Watch list
Reptiles and Amphibians		
Western fox snake	-	Endangered
Rattlesnake	-	Endangered
Western smooth green snake	-	Endangered
Wood frog	-	Rare
Northern crawfish frog	-	Watch list
Birds		
Bald eagle	Endangered	Endangered
Peregrine falcon	Endangered	Endangered
Least tern	C2	Endangered
Cooper's hawk	-	Endangered
Northern harrier	-	Endangered

TABLE 2.1 (Cont'd)

Species	Status	
	Federal[a]	State[b]
Birds (Cont'd)		
Sharp-shinned hawk	-	Endangered
Osprey	-	Endangered
Barn owl	-	Endangered
Double-crested cormorant	-	Endangered
Snowy egret	-	Endangered
Bachman's sparrow	-	Endangered
American bittern	-	Rare
Yellow-headed blackbird	-	Rare
Red-shouldered hawk	-	Rare
Black-crowned night heron	-	Rare
Little blue heron	-	Rare
Mississippi kite	-	Rare
Upland sandpiper	-	Rare
Henslow's sparrow	-	Rare
Sedge wren	-	Watch list
Mammals		
Long-tailed weasel	-	Rare

[a]C2 = federal candidate for listing as a threatened or endangered species.

C3 = former federal candidate species.

[b]Special concern species include those classified by the state as rare, on the watch list, or status undetermined.

Watch list = species of possible concern for which the Missouri Department of Conservation is seeking further information; this listing does not imply that these species are imperiled.

Undetermined = possibly rare or endangered but insufficient information is available to determine the proper status.

Sources: Dickneite (1988); Gaines (1988).

state rare) have been reported to occur at the Weldon Spring Wildlife Area, and these species could use the habitats at and around the quarry. Several natural communities of high quality have also been identified in the area of the Weldon Spring site (Gaines 1988); however, none of these communities occurs at or near the quarry.

3 IDENTIFICATION OF CONTAMINANTS OF CONCERN

The results of characterization studies for the Weldon Spring quarry have been reported in detail in the RI report (MK-Ferguson Company and Jacobs Engineering Group 1989b). A brief summary of the results of contaminant investigations of the quarry bulk wastes is presented in Section 3.1 of this report. The process of selecting indicator contaminants for this baseline risk evaluation is described in Section 3.2.

3.1 SOURCES AND TYPES OF CONTAMINATION

Studies of the bulk wastes in the Weldon Spring quarry have confirmed the presence of radioactive and chemical contaminants consistent with the quarry's burial history (see Table 3.1). Natural-series radionuclides have been detected at concentrations typical of uranium-processing wastes, and metals have been measured at concentrations typical of plant rubble and thorium wastes. Organic compounds have been identified that would be expected from past disposal activities, i.e., nitroaromatic compounds and polynuclear aromatic hydrocarbons (PAHs) from burning operations. The chemical and radioactive species in the quarry are not found in discrete, homogeneous areas, but are intermixed at varying concentrations in a soil/rubble matrix.

Based on historical data and characterization results, an estimated 73,000 m^3 (95,000 yd^3) of contaminated materials is present in the quarry -- of which approximately 31,000 m^3 (40,000 yd^3) is rubble, 39,000 m^3 (51,000 yd^3) is soil and clay, and 3,000 m^3 (4,000 yd^3) is pond sediment (DOE 1987a). Additional radiological and chemical characterization of these bulk wastes will be performed following their removal from the quarry.

3.1.1 Radioactive Contaminants

Radioactively contaminated wastes on the main floor of the quarry cover an area of about 2,800 m^2 (3,300 yd^2) and extend to a depth of about 12 m (40 ft). Radioactive contamination in the entire quarry covers an area of about 18,400 m^2 (22,000 yd^2) and extends to an average depth of about 4 m (13 ft). Two studies have been performed to evaluate the radiological characteristics of the quarry wastes. Berkeley Geosciences Associates performed radiological surveys intermittently from 1979 through 1981 (Berkeley Geosciences Associates 1984), and Bechtel National performed an additional survey in 1984-1985 (Bechtel National 1985). The concentrations of radionuclides in the quarry wastes as determined from these studies are summarized in Table 3.2, and they provide the basis for the radiological characterization presented in this evaluation. The results of these studies are evaluated in detail in the RI report (MK-Ferguson Company and Jacobs Engineering Group 1989b).

The presence of gamma-emitting radionuclides in the quarry results in elevated exposure rates in certain areas of the quarry. These exposure rates are highly variable with location. Surface gamma exposure rates reported by Berkeley Geosciences Associates (1984) ranged from background levels to 625 μR/h. Gamma exposure rates at

TABLE 3.1 History of Disposal Activities at the Weldon Spring Quarry

Time Period	Waste Type	Estimated Volume[a] m^3	Estimated Volume[a] yd^3
1942-1945	TNT and DNT process waste (burn areas)	-	-
1946	TNT and DNT process waste (burn areas)	b	b
1946-1957	TNT and DNT residues and contaminated rubble from cleanup of the ordnance works (in deepest part and in northeast corner of quarry)	-	-
1959	3.8% thorium residues (drummed, currently below water level)	150	200
1960-1963	Uranium- and radium-contaminated rubble from demolition of the St. Louis Destrehan Street feed plant (covering 0.4 ha [1 acre] to a 9-m [30-ft] depth in deepest part of quarry)	38,000	50,000
1963-1965	High-thorium-content waste (in northeast corner of quarry)[c]	760	1,000
1963-1966	Uranium and thorium residues from the chemical plant and off-site facilities; building rubble and process equipment (both drummed and uncontained)	-	-
1966	3.0% thorium residues (drummed, placed above water level in northeast corner of quarry);	460	600
	TNT residues from cleanup of the ordnance works (placed to cover the drums)	-	-
1968-1969	Uranium- and thorium-contaminated rubble and equipment from interior of some chemical plant buildings (101, 103, and 105)	4,600	6,000

[a]A hyphen indicates that the waste volume estimate is not available.

[b]An estimated 90 tons of TNT/DNT waste was burned in 1946.

[c]This was a portion of the waste originally stored at the Army Arsenal in Granite City, Illinois; most of this material was subsequently removed from the quarry for the purpose of recovering rare earth elements.

Sources: MK-Ferguson Company and Jacobs Engineering Group (1989b); Lenhard et al. (1967); Pennak (1975); Weidner and Boback (1982); Bechtel National (1983); Berkeley Geosciences Associates (1984); Kleeschulte and Emmett (1986); U.S. Nuclear Regulatory Commission (1988).

TABLE 3.2 Concentrations of Radionuclides in the Quarry Bulk Wastes

Radionuclide	Average Surficial Concentration[a] (pCi/g)	Average Bulk Waste Concentration[b] (pCi/g)
Uranium-238	170	200
Thorium-232	-[c]	26
Thorium-230	150	330
Radium-228	20	96
Radium-226	110	110

[a]Samples obtained from the top 15 cm (6 in.) of the quarry bulk wastes.

[b]Average concentration for all bulk wastes in the quarry.

[c]No data available.

Source: Data from MK-Ferguson Company and Jacobs Engineering Group (1989b); all data rounded to two significant figures.

0.9 m (3 ft) above the quarry surface reported by Bechtel National (1985) ranged from background levels to 286 μR/h. Both studies also reported elevated levels of radon gas.*

3.1.2 Chemical Contaminants

A preliminary chemical characterization study of the quarry was conducted in 1984 and 1985 by Bechtel National (1985). One surface sample and six borehole samples from the bulk wastes were analyzed for priority pollutant** metals and organic

*In this report, the term *radon* refers to all isotopes of radon.

**A list of "priority pollutants" was established by EPA in response to a June 7, 1978, court settlement to implement portions of the Federal Water Pollution Control Act. The list consists of 129 priority pollutants and includes organic compounds, metals, pesticides and PCBs, asbestos, and cyanide. A target compound list was subsequently developed by EPA for use in response to remediation of hazardous waste sites.

compounds, cyanide, and other selected compounds. Based on the results of that study, a more extensive chemical characterization study was conducted by Bechtel in 1986, which included analysis for volatile organic compounds (VOCs), semivolatile organic compounds, polychlorinated biphenyls (PCBs), and nitroaromatic compounds; a total of 88 samples was collected from 17 borings within the quarry (Kaye and Davis 1987). The results of these two studies are summarized in Tables 3.3 and 3.4. Due to the heterogeneous nature of the quarry wastes and the limited number of samples taken, the average concentrations presented in Tables 3.3 and 3.4 may not be representative of the entire waste material; however, the data indicate which of the constituents that were analyzed for are present in the quarry.

Surficial discoloration of soils on the exposed slope in the northeastern portion of the quarry suggested the presence of nitroaromatic compounds. Surface soil samples were collected from this area in 1987 and analyzed for these compounds (Meyer 1988). The results of these analyses are summarized in Table 3.5; the area of surficial contamination is shown in Figure 3.1.

3.2 SELECTION OF INDICATOR CONTAMINANTS

The first step in the risk evaluation process is to select those radionuclides and chemicals at a site that present the greatest potential risk to human health. For this baseline risk evaluation, the radionuclides of concern, i.e., indicator radionuclides, were selected based on knowledge of the disposal history at the quarry, results of previous radiological investigations, and the radioactive decay series of the principal radionuclides present. The chemical contaminants of concern were selected on the basis of SPHEM methodology (EPA 1986c). This methodology suggests that where a large number of chemical contaminants are present, those of concern be selected based on their (1) distribution and concentrations in environmental media, (2) toxicity, and (3) physical/chemical properties that affect their mobility and persistence in the environment. The selection of indicator radionuclides and chemicals for the Weldon Spring quarry is described in Sections 3.2.1 and 3.2.2.

3.2.1 Preliminary List

Radionuclides. The radioactive materials disposed of in the quarry consist of wastes from the Weldon Spring chemical plant and wastes brought in from other areas, including (1) materials associated with the processing of uranium and thorium concentrates, (2) uranium- and radium-contaminated rubble, (3) high-thorium-content materials (most of which were subsequently removed from the quarry for the purpose of recovering rare earth elements), and (4) 3.0% thorium residues (see Table 3.1). Therefore, the radioactive contaminants of concern are those associated with the uranium-238 and thorium-232 decay series (see Figures 3.2 and 3.3).

Radiological investigations of the quarry bulk wastes indicate that, compared with natural uranium, some of the quarry bulk wastes contain slightly elevated

TABLE 3.3 Concentrations of Chemicals Detected in the Quarry Bulk Wastes in the 1984-1985 Characterization Study and Background Concentrations in Missouri Soils

Chemical[a]	Composite Borehole Sample Concentration (mg/kg)		Number of Boreholes in Which Chemical Detected	Surface Sample Concentration (mg/kg)	Average Background Concentration[c] (mg/kg)
	Range[b]	Average[b]			
Priority Pollutants:					
Metals and Cyanide					
Antimony	<20[d]		0	71	<200[d]
Arsenic	73-120	100	6	100	8.7
Beryllium	0.45-0.83	0.62	6	0.61	0.8
Cadmium	1.8-98	19	6	2.0	<1
Chromium	19-49	30	6	24	54
Copper	38-160	100	6	140	13
Lead	130-410	280	6	950	20
Mercury	0.18-6.3	2.0	6	0.7	0.039
Nickel	19-120	43	6	300	14
Selenium	17-28	23	6	22	0.28
Silver	5.8-8.3	7.0	3	7.5	<0.7
Thallium	3.0-6.2	4.7	6	5.1	<50[d]
Zinc	68-870	340	6	39	49
Cyanide	0.2-0.6	0.38	5	0.2	NA[e]
Organic Priority Pollutants[f]					
α-Benzene hexachloride	0.0051-0.0053	0.0052	2[g]	-	NA
δ-Benzene hexachloride	0.019-0.095	0.045	3[g]	0.0035	NA
γ-Benzene hexachloride (lindane)	0.0013	0.0013	1[g]	-	NA
PCBs (Aroclor 1254)	0.56-46	12	5	1.0	NA
PCBs (Aroclor 1260)	9.0	9.0	1	-	NA

TABLE 3.3 (Cont'd)

Chemical[a]	Composite Borehole Sample Concentration (mg/kg)		Number of Boreholes in Which Chemical Detected	Surface Sample Concentration (mg/kg)	Average Background Concentration[c] (mg/kg)
	Range[b]	Average[b]			
Other Organic Pollutants					
2-Pentanone-4-hydroxy-4-methyl (diacetone alcohol)	2-6[h]	4.6[h]	5	14[h]	NA
2-Methylnaphthalene	0.67	0.67	1	<0.06[d]	NA

[a]All compounds that had one or more positive results above detection limits are listed; concentrations are rounded to two significant figures. Samples were taken from six boreholes in the bulk wastes and from a surface waste pile.

[b]Ranges and averages are for detected values only and do not necessarily indicate the average concentration for the entire waste material.

[c]Concentrations in Missouri agricultural soils (Tidball 1984).

[d]Lower limit of detection.

[e]NA means data not available.

[f]The 29 volatile priority pollutants analyzed for were not detected at a sensitivity level of 20 μg/kg. Thirteen semivolatile organic compounds were detected in one borehole; these compounds are indicated in Table 3.4 (identified by footnote f). The presence of PCBs prevented the detection of most pesticides.

[g]Concentrations of α-, δ-, and γ-benzene hexachloride, were reported for only 2, 3, and 1 of the borehole samples, respectively.

[h]Estimated concentrations.

Sources: Data from Bechtel National (1985), except as noted.

TABLE 3.4 Concentrations of Organic Compounds Detected in the Quarry Bulk Wastes in the 1986 Characterization Study

Chemical[a]	Concentration (mg/kg) Range[b]	Average[b]	Number of Boreholes in Which Chemical Detected[c]
Volatile Compounds[d,e]			
Acetone	1.4-52	13	6
2-Butanone	0.86-1.7	1.4	2
Ethylbenzene	0.68-1.8	0.99	8
Methylene chloride	0.79-6.4	2.9	8
Toluene	0.75	0.75	1
Total xylenes	0.66-1.4	0.95	2
Trichloroethene	0.9	0.9	1
Semivolatile Compounds[e]			
Acenaphthene	1.7-18	7.6	4
Dibenzofuran[f]	1.4-3.6	2.5	2
Fluorene[f]	6.6-19	13	2
Phenanthrene[f]	0.73-150	26	6
Anthracene[f]	0.34-37	9.7	6
Fluoranthene[f]	0.78-190	24	6
Pyrene[f]	0.68-170	23	6
Benz(a)anthracene[f]	0.53-86	15	6
Chrysene[f]	0.46-89	13	6
Benzo(b)fluoranthene[f]	0.62-110	17	6
Benzo(k)fluoranthene[f]	0.78-0.98	0.88	2
Benzo(a)pyrene[f]	0.46-68	11	6
Indeno(1,2,3-cd)pyrene	0.45-49	9.3	6
Dibenz(a,h)anthracene	0.33-17	2.9	4
Benzo(g,h,i)perylene	0.41-50	10	6
2,4-DNT[g]	1.7-10	6.3	1
2,6-DNT[g]	0.53-3.7	1.6	1
Di-n-butylphthalate[f]	0.47-0.58	0.53	2
Bis(2-ethylhexyl)phthalate	0.66-1.6	1.0	3
Naphthalene[f]	1.3	1.3	1
PCBs[e]			
Aroclor 1254[f]	0.46-120	21	9
Aroclor 1260[f]	9.1-12	11	1

TABLE 3.4 (Cont'd)

Chemical[a]	Concentration (mg/kg) Range[b]	Average[b]	Number of Boreholes in which Chemical Detected[c]
Nitroaromatic Compounds[h]			
2,6-Diamino-4-nitrotoluene	0.33-0.58	0.47	3
2,4,6-TNT	0.38-1600	260	6
2,4-DNT[i]	0.46-33	8.1	3
2,6-DNT[i]	0.36-68	9.5	3
2,4-Diamino-6-nitrotoluene	1.3-7.3	4.8	2

[a]All compounds that had one or more positive results above detection limits are listed; concentrations are rounded to two significant figures. Samples were taken in the last quarter of 1986 from 17 boreholes in the bulk wastes.

[b]Ranges and averages are for detected values only and do not necessarily indicate the average concentration for the entire waste material.

[c]Detection of a chemical indicates that the species was detected in at least one incremental sample from a borehole. Each incremental sample was not necessarily tested for all chemical species.

[d]Except for trichloroethene, all of the volatile compounds detected in the samples were also detected in method and/or field blanks.

[e]Analyses for volatile organics, semivolatile organics, and PCBs were performed in accordance with the EPA Contract Laboratory Program.

[f]This compound was also detected in the 1984-1985 study by Bechtel National (1985).

[g]This compound is also listed in this table under nitroaromatic compounds (see footnote i).

[h]Analyses for nitroaromatic compounds were performed according to Method 4B of the U.S. Army Toxic and Hazardous Materials Agency using high-pressure liquid chromatography.

[i]This compound is also listed in this table under semivolatile compounds. Split samples were analyzed in accordance with the EPA Contract Laboratory Program and Method 4B of the U.S. Army Toxic and Hazardous Materials Agency. Information is not provided in the Kaye and Davis (1987) report to explain the discrepancy in results or in the number of boreholes in which these compounds were detected based on the two methods.

Source: Data from Kaye and Davis (1987).

TABLE 3.5 Concentrations of Nitroaromatic Compounds in Surface Soils at the Quarry[a]

Nitroaromatic Compound	Concentration (mg/kg) Range	Average
2,4,6-TNT	4,900-20,000	13,000
2,4-DNT	6.6-29	18
2,6-DNT	<1.2-8.6	5.0
Nitrobenzene	8.4-130	78
1,3,5-Trinitrobenzene	18-280	140
1,3-Dinitrobenzene	<0.8[b]	-

[a]Three surface samples were taken from the exposed slope in the northeastern corner of the quarry (see Figure 3.1).

[b]Lower limit of detection.

Source: Data from Meyer (1988); concentrations rounded to two significant figures.

concentrations of uranium-235 and its decay products (e.g., thorium-227, actinium-227, and possibly protactinium-231). The concentration of uranium-235 in natural uranium is 0.72 weight percent. Of the 42 samples radiochemically analyzed for uranium-238, uranium-234, and uranium-235 by Bechtel National (1985), 15 had concentrations of uranium-235 greater than 0.72 weight percent -- ranging up to 2.3 weight percent of the total uranium present in the samples. Ten of these 15 samples were from two closely grouped boreholes, indicating that the areas of enriched uranium contamination are very localized. Twenty-one of the 42 samples had uranium-235 concentrations below those in natural uranium. The radiological hazards of natural uranium are dominated by radionuclides in the uranium-238 decay series. The existence of slightly enriched uranium in a relatively small portion of the quarry wastes poses no additional hazard beyond that of natural uranium at the same concentration because the contribution from uranium-235 decay series radionuclides is small in comparison. Hence, the evaluation of radiological hazards associated with uranium-contaminated wastes in the quarry is limited to potential hazards associated with the uranium-238 decay series.

In nature, the radionuclides in the uranium-238 and thorium-232 decay series are in a state of secular equilibrium in which the activities of all radionuclides in each series are equal. However, this natural state is altered during the processing of uranium and thorium ores. The rate at which equilibrium conditions are reestablished depends on the half-lives of the decay products.

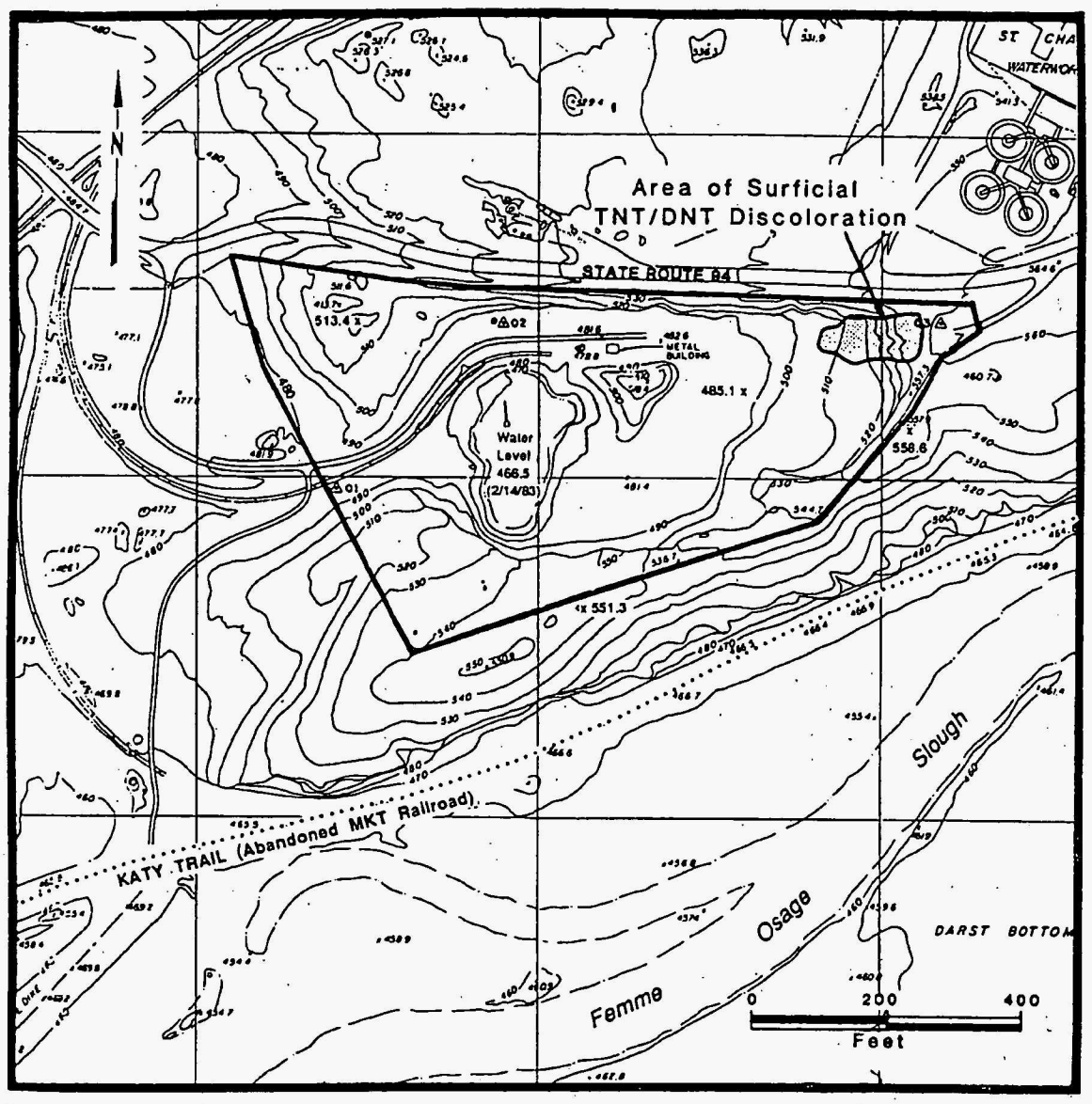
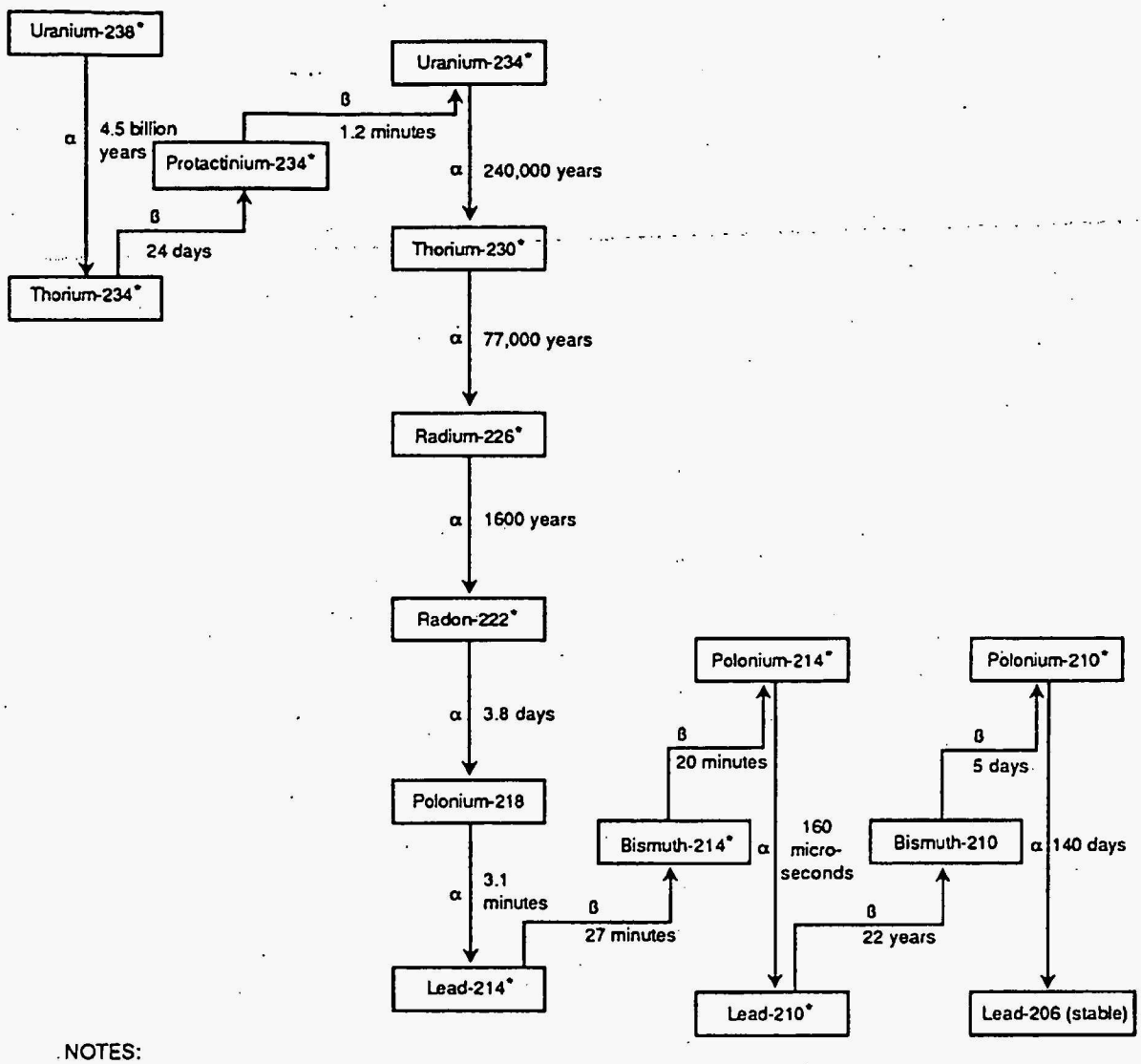


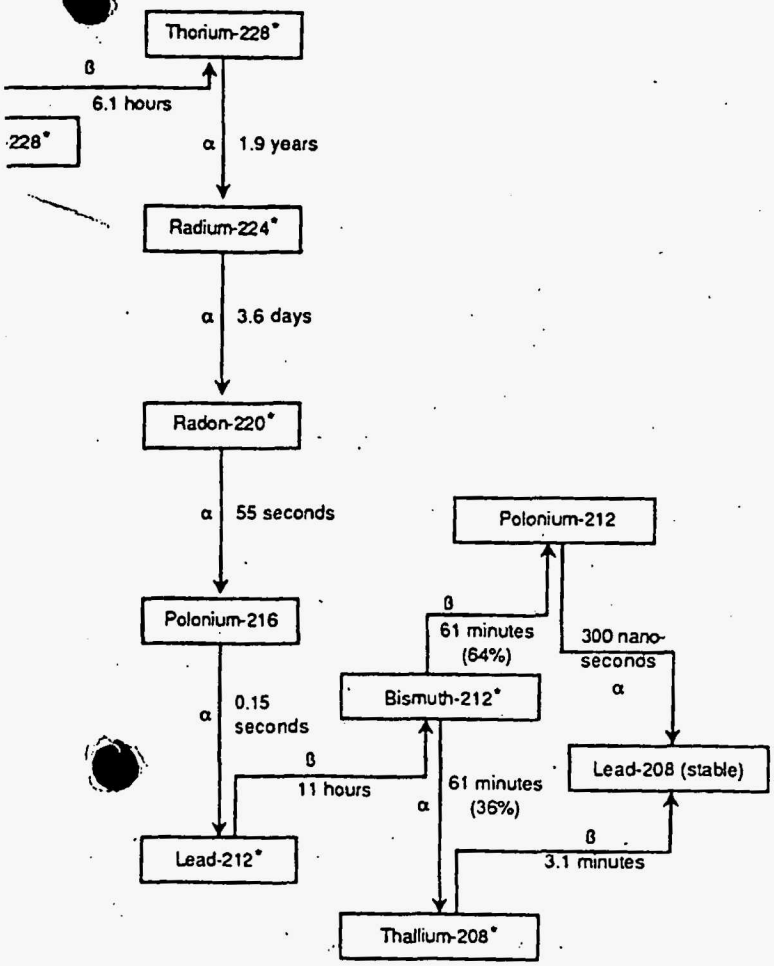
FIGURE 3.1 Area of Surficial Nitroaromatic Contamination at the Weldon Spring Quarry (Source: Modified from Peterson et al. 1988)

This risk evaluation of the quarry bulk wastes was based on the following assumptions. All radionuclides in the thorium-232 decay series from thorium-228 through lead-208 are in secular equilibrium because the radionuclides from radium-224 through lead-208 all have half-lives that are much shorter than the half-life of thorium-228. Because thorium-228 and radium-228 have similar half-lives, these radionuclides are in transient equilibrium in which the activity ratio is constant (but the activities are not necessarily the same) with time. The intermediate radionuclide actinium-228 is in secular equilibrium with radium-228. Thus, the radiological hazards of the thorium-232



NOTES:
Only the dominant decay mode is shown.
The times shown are half-lives.
The symbols α and ß indicate alpha and beta decay.
An asterisk indicates that the isotope is also a gamma emitter.

FIGURE 3.2 Uranium-238 Radioactive Decay Series



de

ɔs.

32 Radioactive Decay Series

decay series can be described by the activity concentrations of thorium-232 and radium-228.

Similarly, the radiological hazards of the various radionuclides in the uranium-238 decay series can be determined from the activity concentrations of uranium-238, thorium-230, and radium-226. Activities of the radionuclides from uranium-238 through uranium-234 can be assumed to be equal to that of uranium-238 (because the activities of uranium-238 and uranium-234 are equal in natural uranium and thorium-234 and protactinium-234 have short half-lives). Also, the activities of the radionuclides from radium-226 through lead-206 can be assumed to be equal to that of radium-226. The latter assumption is supported by measured subsurface concentrations of lead-210 reported by Bechtel National (1985); these concentrations are higher than those of radium-226 in some samples, but the concentrations of the two radionuclides are generally comparable. The radioactive constituents in the bulk wastes will be characterized in detail following removal of the wastes from the quarry.

In both the uranium-238 and thorium-232 decay series, one member of the series is a gas (radon-222 and radon-220, respectively). Characterization activities do not generally include surveying for these gases. Rather, the contaminated materials are typically analyzed for radium-226 and radium-228, and these values are used to estimate the concentrations of radon-222 and radon-220 in the atmosphere. However, radon gas concentrations have been measured at the quarry fence as part of the annual environmental monitoring program, and radon-222 and radon-220 decay product concentrations have been measured within the quarry; these measured values have been used in the exposure assessment presented in Section 4.5 of this risk evaluation.

As radionuclides decay, they emit various types of radiation; certain of these can traverse environmental media and penetrate human skin. Thus, close proximity to radioactive materials can pose hazards to individuals without actual uptake by the body (i.e., ingestion or inhalation). The most energetic form of electromagnetic radiation emitted by radionuclides is the gamma ray. Gamma exposure rates have been measured regularly at the quarry fence as part of the annual environmental monitoring program; gamma levels within the quarry have been measured in two previous radiological characterization studies (Berkeley Geosciences Associates 1984; Bechtel National 1985). The doses from gamma radiation exposure are estimated in Section 4.5 of this risk evaluation.

Based on the assumptions and data sources described above, the preliminary list of radioactive contaminants of concern for the quarry consists of uranium-238, thorium-232, thorium-230, radium-228, radium-226, radon-222, and radon-220. The risks association with gamma exposure are also considered in this evaluation.

Chemicals. The chemicals considered in this risk evaluation were selected from those species detected in surface soils or in borehole samples. These species are listed in Tables 3.2, 3.3, 3.4, and 3.5. They comprise (1) the metals, VOCs, semivolatile compounds, PCBs, and pesticides detected in an exposed surface waste pile and in the boreholes; (2) the nitroaromatic compounds in surface soils on the exposed northeastern

slope of the quarry; and (3) uranium, thorium, and radium. The latter three elements were considered in the selection of both indicator radionuclides and indicator chemicals.

A preliminary list of indicator chemicals was selected based on the following algorithm, which considers both the concentrations of contaminants in environmental media and their relative toxicities. That is,

$$IS_i = \sum_{j=1}^{k} (C_{ij} \times T_{ij}) \tag{3.1}$$

where:

IS_i = indicator score for chemical i (dimensionless),

C_{ij} = concentration of contaminant i in medium j (mg/L in water, mg/kg in soil, and mg/m^3 in air), and

T_{ij} = toxicity constant of contaminant i in medium j (L/mg in water, kg/mg in soil, and m^3/mg in air).

The C × T values were calculated for each chemical and each environmental medium. The applicable media for determining indicator contaminants at the Weldon Spring quarry are surface soil and air. However, because air has not been monitored for chemical contaminants since termination of disposal activities at the quarry, data are not available for this medium. Values for toxicity constants were obtained from the *Public Health Risk Evaluation Database* (PHRED) developed by the EPA Office of Emergency and Remedial Response (EPA 1988a) and from the SPHEM report (EPA 1986c). Separate toxicity constants are available for carcinogenic and noncarcinogenic effects.

Indicator scores were calculated for each detected chemical contaminant that has the following four characteristics: (1) it has been detected in surface soils at levels above the detection limit for the analysis, (2) it has been detected in more than one sample, (3) it is present at a level above the normal background concentration for Missouri soils, and (4) a toxicity constant is available from the EPA data base (EPA 1986c, 1988a). Background concentrations, which are available only for metals, are listed in Table 3.3. Beryllium and chromium were screened from further consideration because they are present at levels below the background concentrations in soil. Toluene and trichloroethene were also screened from further consideration because they were not detected in surface soils and were detected in only one borehole sample. This is consistent with EPA guidance, which suggests that the extent of contamination should be considered in the selection of indicator chemicals. Toxicity constants are available for 20 of the remaining 52 chemicals and are listed in Table 3.6.

Indicator scores were calculated for these 20 chemicals using representative concentrations in surface soils in the quarry, where such data were available. Surface soil concentrations were used because the only complete exposure pathways for chemical

TABLE 3.6 Scoring for Indicator Chemical Selection: Toxicity Information

Chemical	Toxicologic Class[a]	Toxicity Rating/ Carcinogenic Weight-of-Evidence[b] Oral	Inhalation	Toxicity Constants for Soil (kg/mg)
Volatile Compounds				
Ethylbenzene	NC	4	4	5.52×10^{-7}
Methylene chloride	PC	B2	B2	-[c]
	NC	10	10	4.60×10^{-8}
Semivolatile Compounds				
Benz(a)anthracene	PC	B2	B2	2.91×10^{-5}
Benzo(a)pyrene	PC	B2	B2	2.28×10^{-4}
	NC	8	6	1.33×10^{-3}
Bis(2-ethylhexyl)phthalate	PC	B2	B2	2.86×10^{-8}
Dibenz(a,h)anthracene	PC	B2	B2	3.57×10^{-4}
PCBs				
Aroclor 1254, 1260	PC	B2	B2	7.21×10^{-5}
Nitroaromatic Compounds				
2,4-DNT	PC	B2	B2	5.46×10^{-6}
	NC	9	9	4.39×10^{-5}
2,6-DNT	PC	C	C	-[c]
	NC	9	9	3.01×10^{-5}
Metals				
Antimony	NC	10	8	2.17×10^{-4}
Arsenic and arsenic compounds	PC	A	A	2.03×10^{-4}
	NC	9	9	9.00×10^{-4}
Cadmium	PC	-[c]	B1	-[c]
	NC	10	8	2.23×10^{-4}

TABLE 3.6 (Cont'd)

Chemical	Toxicologic Class[a]	Toxicity Rating/ Carcinogenic Weight-of-Evidence[b] Oral	Inhalation	Toxicity Constants for Soil (kg/mg)
Metals (Cont'd				
Copper and copper compounds	NC	5	5	3.57×10^{-5}
Lead and lead compounds	PC	B2	B2	–[c]
(inorganic)	NC	10	10	4.46×10^{-5}
Mercury (inorganic)	NC	7	8	9.21×10^{-4}
Nickel and nickel compounds	PC	A	A	–[c]
	NC	10	10	2.13×10^{-4}
Selenium and selenium compounds	NC	10	10	5.26×10^{-3}
Silver	NC	1	1	1.00×10^{-3}
Uranium and uranium compounds	PC	A	A	–[c]
	NC	6	6	3.53×10^{-4}
Zinc	NC	8	8	5.33×10^{-6}

[a]Abbreviations: PC, potential carcinogen; NC, noncarcinogen.

[b]Toxicity rating is for severity of toxic effect for noncarcinogens, ranging from 1 (low) to 10 (high); carcinogenic weight-of-evidence is a quantitative designation for potential carcinogens: A, human carcinogen; B1 and B2, probable human carcinogen; C, possible human carcinogen.

[c]Data not available.

Source: Data from EPA (1986c, 1988a, 1989c).

contaminants result from surface soil contamination (see Section 4.1). Characterization data to estimate the concentrations of contaminants in surface soils were reported in three studies, with different sampling methods employed and different compounds analyzed in each of the studies. For this reason, and because the contamination in the quarry is highly nonuniform, it was necessary to use different criteria for the selection of representative concentrations for the individual contaminants. The concentration used for each nitroaromatic compound was the average concentration detected in surface soils on the exposed slope of the northeastern corner of the quarry (Meyer 1988). The highest concentrations of these compounds occur in this area of the quarry. For the VOCs, semivolatile compounds, PCBs, and pesticides, the average concentrations in 0- to 0.9-m (0- to 3-ft) borehole samples were used, based on data reported in Kaye and Davis (1987). Concentrations of metals in surface soils were available for only one sample from the study by Bechtel National (1985). However, data were available for composite borehole samples, and the higher of the average concentration in the composite borehole samples and the surface sample concentration was used as the representative concentration. For all compounds, the calculated averages were the arithmetic means of the concentrations in samples above detection limits and did not include samples at or below the limits of detection. Thus, these values are representative of the concentrations of the contaminated areas and not of the entire quarry. The representative contaminant concentrations and the preliminary list of indicator chemicals, ranked by their indicator scores for carcinogenic and noncarcinogenic effects, are listed in Table 3.7.

3.2.2 Final Selection

The preliminary list of indicator chemicals (Table 3.7) was reviewed to determine if certain contaminants should be added to or removed from the list based on additional criteria. Of particular concern was the fact that an indicator score could not be derived for many of the contaminants identified at the site due to the lack of EPA toxicity constants for these compounds. For this reason, each chemical group was reviewed — i.e., VOCs, semivolatile compounds, nitroaromatic compounds, PCBs and pesticides, and metals and cyanide — and the reasons were assessed for retaining, removing, or adding a chemical to arrive at the final list of indicator chemicals. No further screening of the indicator radionuclides was necessary because all were retained from the preliminary list.

Volatile Organic Compounds. Seven VOCs were detected in the 1986 characterization study (Kaye and Davis 1987; see Table 3.4), but the presence of six of these compounds in method and field blanks suggests that all but trichloroethene were laboratory contaminants. The failure of the preliminary characterization study (Bechtel National 1985) to detect VOCs further supports this interpretation. Three VOCs (ethyl benzene, toluene, and xylene) were detected in two groundwater samples from the quarry (DOE 1987c), but subsequent testing failed to detect them (DOE 1988). Thus, the available data are not sufficient to determine whether VOCs are present at the quarry or to allow an evaluation of potential risk. Toluene and trichloroethene were detected in only one sample and, hence, based on the criteria developed earlier in this section, indicator scores were not calculated for these compounds. Indicator scores were

TABLE 3.7 Preliminary List of Indicator Chemicals for the Quarry

Chemical	Representative Concentration[b] (mg/kg)	Indicator Score	Rank
Carcinogens			
Arsenic and arsenic compounds[a]	100	2.0×10^{-2}	1
PCBs	26	1.9×10^{-3}	2
Benzo(a)pyrene[a]	2.1	4.8×10^{-4}	3
Dibenz(a,h)anthracene	0.98	3.5×10^{-4}	4
2,4-DNT[a]	18	9.8×10^{-5}	5
Benz(a)anthracene	2.8	8.1×10^{-5}	6
Bis(2-ethylhexyl)phthalate	0.73	2.1×10^{-8}	7
Noncarcinogens			
Uranium and uranium compounds[c]	510	1.8×10^{-1}	1
Selenium and selenium compounds	23	1.2×10^{-1}	2
Arsenic and arsenic compounds[a]	100	9.0×10^{-2}	3
Nickel and nickel compounds[c]	300	6.4×10^{-2}	4
Lead and lead compounds (inorganic)[c]	950	4.2×10^{-2}	5
Antimony	71	1.5×10^{-2}	6
Silver and silver compounds	7.5	7.5×10^{-3}	7
Copper and copper compounds	140	5.0×10^{-3}	8
Cadmium[c]	19	4.2×10^{-3}	9
Benzo(a)pyrene[a]	2.1	2.8×10^{-3}	10
Mercury (inorganic)	2.0	1.8×10^{-3}	11
Zinc and zinc compounds	340	1.8×10^{-3}	12
2,4-DNT[a]	18	7.9×10^{-4}	13
2,6-DNT[c]	5.0	1.5×10^{-4}	14
Ethylbenzene	0.95	5.2×10^{-7}	15
Methylene chloride[c]	4.8	2.2×10^{-7}	16

[a]Indicator scores were calculated for both the carcinogenic and noncarcinogenic effects of these compounds.

[b]Determination of the representative concentration is described in Section 3.2.1.

[c]Indicator scores were calculated only for the noncarcinogenic effects of these compounds because toxicity constants based on carcinogenic effects were not available.

calculated for two VOCs -- methylene chloride and ethylbenzene -- but these compounds were deleted from the list of indicator chemicals because they had the lowest noncarcinogenic indicator scores. Methylene chloride is a potential carcinogen, but a carcinogenic indicator score could not be calculated because a toxicity constant for carcinogenic effects is not available. This compound was not added to the indicator contaminant list because, as with the other VOCs, its presence in samples is believed to have resulted from laboratory or field contamination. For this same reason, none of the other VOCs was added to the list.

Screening of the VOCs from further consideration at this stage in the baseline risk evaluation is not expected to significantly affect the health risk estimates. Wastes were last disposed of in the quarry in 1969, and it can reasonably be assumed that, if present, the concentrations of VOCs in the surface soils would be low. The main pathway of concern would be exposure to groundwater contaminated by the leaching of these compounds from the subsurface wastes; however, the groundwater at the quarry is not used as a source of drinking water and VOCs have not been detected in the St. Charles county well field located south of the quarry.

Semivolatile Organic Compounds. A large number of PAHs have been detected at the quarry. The presence of PAHs is probably the result of the quarry being used as a burn area for TNT and DNT process wastes and other materials. The PAHs always occur in the environment as complex mixtures.

The toxicological properties of only a few of the individual PAHs have been adequately characterized, and only limited information is available on the relative potencies of the different compounds. Certain members of this class of compounds are carcinogenic (see Section 5.2.4) and, for this baseline risk evaluation, it was conservatively assumed that all have other toxic effects. To assess the risks associated with these compounds, it was considered more appropriate to group the PAHs into two classes -- carcinogenic PAHs and total PAHs -- rather than to assess only those few compounds for which specific information is available. For carcinogenic PAHs, the dose estimates are the sum of all carcinogenic PAHs identified at the quarry; for total PAHs, the dose estimates represent both the carcinogenic and noncarcinogenic PAHs (the carcinogenic PAHs are also capable of inducing other toxic effects). The toxicity value selected to assess the carcinogenic risk of the PAHs was the value corresponding to the most potent member of the class for which a carcinogenic potency factor is available, i.e., benzo(a)pyrene. This is consistent with EPA guidance on assessment of PAHs, although this approach is currently under review; the approach being developed is expected to be based on the relative carcinogenic potencies of the individual compounds, which would generally result in less conservative risk estimates. Toxicity values are not available for the assessment of noncarcingenic effects of PAHs. However, intake of total PAHs is assessed in Section 4.5, and the uncertainty introduced into the risk assessment due to lack of toxicity constants for PAHs (and other indicator chemicals) is discussed, qualitatively, in Section 6.4.

None of the remaining semivolatile compounds were added to the list because they were evaluated through assessment of the PAHs. For this reason, and because it received the lowest indicator score, bis(2-ethylhexyl)phthalate was deleted from the list.

Nitroaromatic Compounds. The only nitroaromatic compounds for which indicator scores could be calculated were 2,4-DNT and 2,6-DNT. The compound 2,4-DNT was retained on the list because of its carcinogenicity and its presence in surface soils at the quarry. The ranking of 2,6-DNT, based on its noncarcinogenic effects, was very low and it could not be scored as a carcinogen because the appropriate toxicity constant is not available. However, 2,6-DNT is classified as a Group C possible human carcinogen (see Section 5.2.1), and a carcinogenic potency factor for mixtures of 2,4-DNT and 2,6-DNT has recently been determined (EPA 1989b). These compounds were therefore assessed as a mixture in this risk evaluation. The compounds 2,4,6-TNT and 1,3,5-trinitrobenzene were added to the list because of their presence in quarry surface soils at relatively high concentrations (see Table 3.5); TNT is classified as a Group C possible human carcinogen, and both TNT and trinitrobenzene are toxic to the hematopoietic system and liver. The remaining nitroaromatic compounds were not added to the list because they are adequately represented by the nitroaromatic compounds that were evaluated.

PCBs and Pesticides. The PCBs were retained on the list because they represent the second-highest-ranking potential carcinogen at the quarry. The presence of PCBs in soils at the quarry prevented an analysis for pesticides in most samples. However, based on the history of disposal activities, elevated concentrations of pesticides are not expected. The limited data on pesticide concentrations presented in Table 3.3 indicate that the concentrations are very low. For these reasons, pesticides were not added to the list.

Metals and Cyanide. Toxicity constants have been identified for most of the metals detected at the quarry, and these metals therefore appear on the preliminary list. However, this tends to overemphasize the metals relative to the other contaminants present at the site for which there are no toxicity constants. The five metals receiving the highest indicator scores -- arsenic, lead, nickel, selenium, and uranium -- were retained on the indicator contaminant list. However, antimony, cadmium, copper, mercury, silver, and zinc were deleted because of their low indicator scores and because the potential routes of exposure to all metals are the same; therefore, they are adequately represented by the metals retained for evaluation.

The indicator score for uranium was calculated based on its noncarcinogenic (and, hence, nonradiological) effects. Uranium was retained on the list because it is the highest ranking noncarcinogenic chemical. Thorium and radium appear on the list of indicator radionuclides, but they were also reviewed with respect to their chemical toxicity. These metals were not included on the preliminary list of indicator chemicals because toxicity constants are not available. The chemical toxicity of thorium is low, and the concentration of radium is low (<1 μg/kg); thus, thorium and radium were not

added to the list of indicator chemicals. Similarly, cyanide was not added to the list because its concentration in quarry surface soils is low.

Final List of Indicator Radionuclides and Chemicals. The contaminants retained on the final list as indicator radionuclides and chemicals for the Weldon Spring quarry were selected on the basis of indicator scores, a review of background concentrations and toxicological properties, and — for the radionuclides — the decay series and half-lives of the radionuclides. The final list is presented in Table 3.8.

TABLE 3.8 Final List of Indicator Radionuclides and Chemicals for the Quarry

	Indicator Chemicals		
Indicator Radionuclides[a]	Metals	Nitroaromatics	Other Organics
Uranium-238	Arsenic	2,4-DNT and 2,6-DNT	PAHs (carcinogens)
Thorium-232	Lead	2,4,6-TNT	PAHs (total)
Thorium-230	Nickel	1,3,5-Trinitrobenzene	PCBs
Radium-228	Selenium		
Radium-226	Uranium		
Radon-222			
Radon-220			

[a]The gamma exposure rates resulting from the presence of these radionuclides were also evaluated.

4 EXPOSURE ASSESSMENT

The potential pathways of human exposure to contaminants at the Weldon Spring quarry and the estimated levels of contaminant intakes are characterized in this chapter. The assessment of potential impacts on vegetation and wildlife is presented in Chapter 7 (Section 7.4).

A complete exposure pathway consists of four components: (1) a source and mechanism of contaminant release to the environment, (2) an environmental transport medium (e.g., air) for the released contaminants, (3) a point of human contact with the contaminated medium (referred to as the exposure point), and (4) a route of human exposure (e.g., inhalation) at the exposure point. If any of these four components are missing, the pathway is incomplete and is not considered further in a risk evaluation.

The sources of contaminants and the selection of indicator contaminants for the Weldon Spring quarry are described in Chapter 3. The following key factors were considered in developing the exposure pathways at the quarry: (1) the quarry is fenced, closed to the public, and surrounded by wildlife areas; (2) the nearest residence is 0.8 km (0.5 mi) west of the quarry on State Route 94; and (3) no remedial action activities are currently taking place at the quarry. The exposure pathways considered in this risk evaluation are those directly associated with the bulk wastes. The potential risks associated with contaminated groundwater at the quarry and with contaminated vicinity properties will be addressed in a comprehensive risk assessment following bulk waste removal (see Sections 1.3 and 4.1). Potential risks to workers and the public associated with the bulk waste removal action (i.e., excavation of the wastes) will be addressed in the FS to support this action.

This exposure assessment is based on current land-use conditions and contaminant concentrations. Potential exposure pathways are identified in Section 4.1, receptors and exposure scenarios are defined in Section 4.2, exposure point concentrations are determined in Section 4.3 and compared to ARARs in Section 4.4, and contaminant intakes are estimated in Section 4.5.

4.1 IDENTIFICATION OF EXPOSURE PATHWAYS

The potential pathways of human exposure to contaminants at the Weldon Spring quarry are summarized in Table 4.1. The contaminant source, release mechanism, transport medium, and route of exposure associated with each pathway are discussed below.

The main source of contamination within the quarry is the bulk wastes. The principal release mechanisms and the release media associated with these wastes are:

- Emission of radon-220 and radon-222 from radium-contaminated materials to the atmosphere,
- Emission of gamma radiation from contaminated materials to the atmosphere,

TABLE 4.1 Potential Pathways of Human Exposure to Contaminants at the Weldon Spring Quarry

Exposure Medium	Potential Exposure Routes	Potential Receptors	Pathway Status
Air	Inhalation	Persons temporarily occupying the quarry or nearby areas that are impacted by air-borne releases	Pathway complete. Although the quarry is fenced and its gates locked, a trespasser could gain access. Elevated radon levels have been measured within the quarry and at the fence.
Air	Inhalation	Residents of homes west of the quarry on State Route 94	Pathway complete but not significant. Estimated levels of radon and airborne particulates at 0.8 km (0.5 mi) west of the quarry (location of the nearest residence) are very low compared with background levels.
Soil (on-site)	External gamma exposure	Persons temporarily occupying the quarry or nearby areas that are impacted by site releases	Pathway complete. Elevated external gamma exposure rates have been measured within the quarry and at the fence.
Soil (on-site)	Dermal absorption; incidental ingestion	Persons temporarily occupying the quarry	Pathway complete. Elevated levels of radioactive and chemical contaminants have been measured in surface soils in the quarry.
Game animals	Ingestion	Hunters	Pathway potentially complete but not significant. No small mammals were caught in the vicinity of the quarry in the recently completed sampling program, and the fence limits larger game animals from entering the quarry.

- Emission of fugitive dusts from contaminated surface materials to the atmosphere,
- Direct contact with contaminated surface materials, and
- Leaching of contaminated surface and/or subsurface materials to groundwater.

Radon concentrations and external gamma radiation are measured continuously in the vicinity of the quarry, and the results are reported annually in environmental monitoring reports (e.g., see DOE 1988 for 1987 results). Elevated readings of both parameters have been measured in recent years.

Concentrations of airborne particulates have not been measured since disposal activities were terminated at the quarry in 1969. However, because most of the contamination is below ground, below surface water, or covered with vegetation -- and because no remedial action activities are currently occurring at the quarry -- generation of dusts is limited to wind erosion of exposed areas. The main exposed area with surficial contamination is the northeastern corner of the quarry, which is contaminated with nitroaromatic compounds (see Figure 3.1); estimates of fugitive dust emissions from this area have been made in this risk evaluation to assess potential inhalation exposure. Although elevated concentrations of radioactive and chemical contaminants have been detected in surface soils throughout the quarry, dust generation from areas other than the exposed area is expected to be negligible because of the vegetative cover. However, potential exposures resulting from direct contact with these surface soils (through dermal exposure and incidental ingestion) have been assessed.

Additional potential release mechanisms were assessed but were not considered to represent significant mechanisms of contaminant release from the quarry or were considered to be beyond the scope of this risk evaluation. Although migration of contaminants over the surface by storm-water runoff is possible, most precipitation falling within the quarry area flows to the quarry pond. Only precipitation falling along the western and southwestern periphery of the quarry could drain away from the quarry boundary. This area is generally uncontaminated, although limited surface contamination exists along the access road and railroad at the west end of the quarry area (MK-Ferguson Company and Jacobs Engineering Group 1989b). The potential for exposure resulting from contact with this contamination would be lower than that resulting from the surface contamination pathways within the quarry. Potential exposure of the population could result from transport of contaminants outside the quarry via the shoes or clothing of trespassers entering the contaminated area; however, this is an unlikely source of significant exposure and is not included in this risk evaluation. The potential for exposure of a trespasser would occur primarily while the trespasser was present within the quarry fence, and this exposure is assessed.

A potential pathway of human exposure is ingestion of contaminants that have entered the animal food chain either through direct ingestion by animals or through uptake by plants and subsequent ingestion of these plants by animals. This pathway will be assessed in the comprehensive risk assessment for the quarry area that will be carried

out following removal of the bulk wastes (see Section 1.3). Exclusion of this pathway from the risk evaluation would tend to underestimate potential risk; however, human exposure via this pathway is expected to be insignificant relative to other exposure pathways at the quarry. A recent sampling program failed to collect any small mammals in the quarry and fish are not present in the quarry pond. The high fence (2.1 m [7 ft]) limits larger game animals (e.g., deer) from entering the quarry. Although game birds could enter the quarry, significant uptake of contaminants by migratory birds is not expected. Studies in the vicinity of the chemical plant area, where the potential for exposure of wildlife would be similar to that in the quarry, measured very low or negligible contaminant levels in fish and mammals (see Section 7.4).

The potential for future exposure to contaminated groundwater will also be assessed in the follow-on risk assessment, at which time additional characterization data will be available to make such an assessment. Groundwater at the quarry is not used as a drinking water source and, hence, does not represent a complete exposure pathway under current land-use conditions.

Based on the above discussion, this risk evaluation has considered the principal contaminants at the Weldon Spring quarry and the potential routes of human exposure to these contaminants to be:

- Inhalation of radon-220, radon-222, and their short-lived decay products,
- Exposure to external gamma radiation,
- Inhalation of radioactively and chemically contaminated airborne dusts,
- Dermal contact with chemically contaminated surface soils, and
- Ingestion of radioactively and chemically contaminated surface soils.

4.2 EXPOSURE SCENARIOS

4.2.1 Impacted Area

Individuals within an 8-km (5-mi) radius of the quarry are considered to be potential receptors of contaminants released from the quarry. However, the areas known or reasonably expected to be contaminated by releases from the quarry bulk wastes are limited to the quarry and the immediately surrounding area, i.e., the area within the quarry fence and the area outside but immediately adjacent to the fence. Although elevated radon levels and elevated external gamma exposure rates have been measured at the quarry fence, these levels decrease rapidly with distance. At a distance of 0.5 km (0.3 mi) from the edge of the quarry, the concentration of radon resulting from emissions

at the quarry is about 10% of the ambient radon level of about 0.3 pCi/L in the Weldon Spring area. (The radon concentration at 0.5 km [0.3 mi] from the edge of the quarry was calculated using the MILDOS Gaussian plume dispersion model [Strenge and Bander 1981], which was modified to more accurately assess airborne concentrations of releases from large areas [Yuan et al. 1989].) Therefore, the 0.5-km (0.3-mi) distance has been defined as the outer boundary (along State Route 94) of the area within which receptors are considered to be potentially impacted by exposure to site contaminants.

4.2.2 Scenario Definition

The exposure scenarios developed for this evaluation are considered to be realistic, but conservative, descriptions of possible human activities that could result in exposure to contaminants associated with the quarry bulk wastes. The potential for human contact with site contaminants is low because (1) the quarry is situated in a relatively isolated setting and is fenced and closed to the public and (2) no private residences or other structures are located within the area currently impacted by site releases. Therefore, scenarios were developed for hypothetical individuals temporarily occupying the impacted area, i.e., "passerby" and "trespasser" scenarios. Under both scenarios, two cases were developed to estimate "representative exposure" and "plausible maximum exposure." The passerby and trespasser scenarios were defined such that the nature and duration of the exposures would provide upper bound estimates of the potential risks to any individual exposed to releases outside the quarry fence or to an individual who might trespass into the quarry. The assumptions used in assessing the potential exposures resulting from the passerby and trespasser scenarios are described in detail in Section 4.5.

Passerby Scenario. State Route 94 passes along the northern boundary of the quarry, about 4.5 m (15 ft) from the fence. An individual walking by the quarry along this route is potentially exposed to contaminants via the air pathway. For the representative exposure case, it was assumed that a hypothetical individual walks by the site twice per day, 250 days per year, over a period of 5 years; for the plausible maximum exposure case, the exposure was assumed to be 365 days per year over a period of 10 years. Total exposure for both cases was determined for (1) inhalation of radon-220, radon-222, and their short-lived decay products, (2) exposure to external gamma radiation, and (3) inhalation of contaminated dusts. Although other more realistic scenarios were considered for evaluation (e.g., a person who routinely drives by the quarry or an individual visiting the surrounding wildlife areas, such as a hiker on Katy Trail), these scenarios were not explicitly evaluated because the risk to these receptors would be less than the risks estimated for the passerby scenario considered here. Risks to the passerby were found to be negligible (see Chapter 6).

Trespasser Scenario. The quarry is fenced and closed to the public; however, it is possible that individuals might climb over (or under) the fence and enter the contaminated area. For the representative exposure case, it was assumed that a hypothetical youth (11 to 15 years old) enters the area, remains there for a period of

2 hours, and repeats this activity 12 times per year over a period of 5 years. For the plausible maximum exposure case, it was assumed that the youth (9 to 18 years old) enters the quarry once per week for 4 hours, 50 weeks per year, over a period of 10 years. Total exposure for both the representative and plausible maximum cases was determined for (1) inhalation of radon-220, radon-222, and their short-lived decay products, (2) direct external gamma radiation, (3) inhalation of contaminated dusts, (4) dermal exposure to chemically contaminated soils, and (5) incidental ingestion of radioactively and chemically contaminated soils.

4.3 ESTIMATION OF EXPOSURE POINT CONCENTRATIONS

4.3.1 Surface Soils

Radioactive Contaminants. Surface soils in the quarry are contaminated with radionuclides of the uranium-238 and thorium-232 decay series. The contamination is highly nonuniform, ranging from the background soil concentration of about 1 pCi/g to values in excess of 1,000 pCi/g. This exposure assessment used the average surficial concentrations within the upper 15 m (6 in.) at the quarry, as given in Table 4.2. Radioactive decay and ingrowth will not result in significant changes in these concentrations in the near term due to the long half-lives of the major radionuclides in the uranium-238 and thorium-232 decay series (see Figures 3.2 and 3.3).

Chemical Contaminants. The data available to estimate concentrations of chemical contaminants in surface soils at the quarry are very limited. For this reason, and because the contamination in the quarry is highly nonuniform, it was necessary to use different criteria for the selection of representative exposure point concentrations for different indicator chemicals.

For nitroaromatic compounds, the average concentration detected in surface soils on the exposed slope of the northeastern corner of the quarry was used for the exposure assessment. This is considered to be a conservative estimate because the highest concentrations of these compounds in the quarry occur in this area. The data used for PCBs and PAHs were the average concentrations in 0- to 0.9-m (0- to 3-ft) borehole samples, as reported by Kaye and Davis (1987). The sampling locations in this study were selected based on the quarry disposal history and are believed to represent the areas of higher contamination at the quarry. Concentrations of metals in surface soils were available for only one sample from the study by Bechtel National (1985). However, data were available for composite borehole samples, and the higher of the surface sample concentration and the average concentration of the composite borehole samples was used as the exposure point concentration. (In all cases, the concentration of the surface sample was greater than or equal to the average concentration of the borehole samples.) Finally, for uranium, the concentration (in mg/kg) was determined from the activity concentration (in pCi/g) of uranium-238 given in Table 4.2. The exposure point concentrations for the indicator chemicals are summarized in Table 4.3.

TABLE 4.2 Exposure Point Concentrations of Indicator Radionuclides in Surface Soils and Air at the Quarry

Contaminant	Average Surficial Soil Concentration[a] (pCi/g)	Estimated Air Concentration (pCi/m^3) Respirable[b]	Total[c]
Uranium-238	170	1.3×10^{-3}	6.5×10^{-3}
Thorium-232	26[d]	2.0×10^{-4}	1.0×10^{-3}
Thorium-230	150	1.1×10^{-3}	5.5×10^{-3}
Radium-228	20	6.6×10^{-4}	3.3×10^{-3}
Radium-226	110	8.6×10^{-5}	4.3×10^{-4}

[a]Concentrations within the upper 15 cm (6 in.). Source: MK-Ferguson Company and Jacobs Engineering Group (1989b).

[b]Estimated concentrations of respirable particulates (<10 μm), based on surface soil concentrations. Methodology used to estimate air concentrations is given in Appendix A. Concentrations at the fence and within the quarry were conservatively estimated using the area with surficial nitroaromatic contamination to represent the exposed area (i.e., not covered with water, vegetation, etc.) that has surficial radioactive contamination.

[c]Estimated concentrations of total particulates at the fence and within the quarry, based on the concentration of respirable particulates (see footnote b). Total particulates were assumed to be five times respirable particulates.

[d]Average concentration within the bulk wastes; no value is available for the surficial concentration.

(Concentrations in Table 4.3 will not in all cases be the same as the concentrations in Tables 3.3, 3.4, and 3.5 because of the use of surface soil concentrations, where available, to estimate the exposure point concentrations.)

For all compounds, the calculated averages used as exposure point concentrations were the arithmetic means of the concentrations in samples above detection limits and did not include samples at or below the detection limits. In addition, as described above, the studies from which the concentrations were derived tended to focus on the contaminated areas within the quarry. Thus, within the limits of the available characterization data, these values are considered to be representative of the areas of contamination within the quarry, not of the entire quarry. The use of these averages in the exposure

TABLE 4.3 Exposure Point Concentrations of Indicator Chemicals in Surface Soils and Air at the Quarry

Contaminant	Representative Soil Concentration[a] (mg/kg)	Estimated Air Concentration (mg/m^3)	
		Respirable[b]	Total[c]
Nitroaromatic Compounds			
2,4,6-TNT	13,000	1.0×10^{-4}	5.0×10^{-4}
2,4-DNT and 2,6-DNT	23	1.8×10^{-7}	9.0×10^{-7}
1,3,5-Trinitrobenzene	140	1.1×10^{-6}	5.5×10^{-6}
PAHs			
Carcinogens	12	NQ[d]	NQ
Total	28	NQ	NQ
PCBs	26	NQ	NQ
Metals			
Arsenic	100	NQ	NQ
Lead	950	NQ	NQ
Nickel	300	NQ	NQ
Selenium	23	NQ	NQ
Uranium	510	4.0×10^{-6}	2.0×10^{-5}

[a]Soil concentrations are as follows: (1) for nitroaromatic compounds, the average concentration detected in surface soils (from Table 3.5); (2) for PCBs and PAHs, the average concentration detected in the 0- to 0.9-m borehole samples (Kaye and Davis 1987); (3) for metals other than uranium, the concentration of the surface sample (from Table 3.3); (4) for uranium, concentration as determined from the activity concentration (pCi/g) of uranium-238 (from Table 4.2).

[b]Estimated concentration of respirable particulates (<10 μm) based on surface soil concentrations. Methodology used to estimate air concentrations is given in Appendix A. Concentrations at the fence and within the quarry were conservatively assumed to be the concentrations estimated for the area above the source (i.e., the area with surficial nitroaromatic contamination).

[c]Estimated concentration of total particulates, based on concentration of respirable particulates (see footnote b). Total particulates were assumed to be five times respirable particulates.

[d]NQ = not quantified; air concentrations are considered to be negligible (see Section 4.1).

assessment is equivalent to assuming that the individual is exposed only to the contaminated (and not to the uncontaminated) areas. Because it is likely that the individual would also spend time in areas of the quarry that are uncontaminated, this assumption will tend to overestimate the potential exposure.

4.3.2 Air

Radioactive Contaminants. Radon concentrations and external gamma exposure rates are measured as part of the ongoing annual environmental monitoring program for the Weldon Spring site. Radon is measured at six perimeter monitoring locations along the quarry fence (see Figure 4.1). The 1987 average annual concentration of radon (including background) for the six stations was 1.2 pCi/L; the background concentration of radon in the Weldon Spring area is about 0.3 pCi/L. The maximum concentration

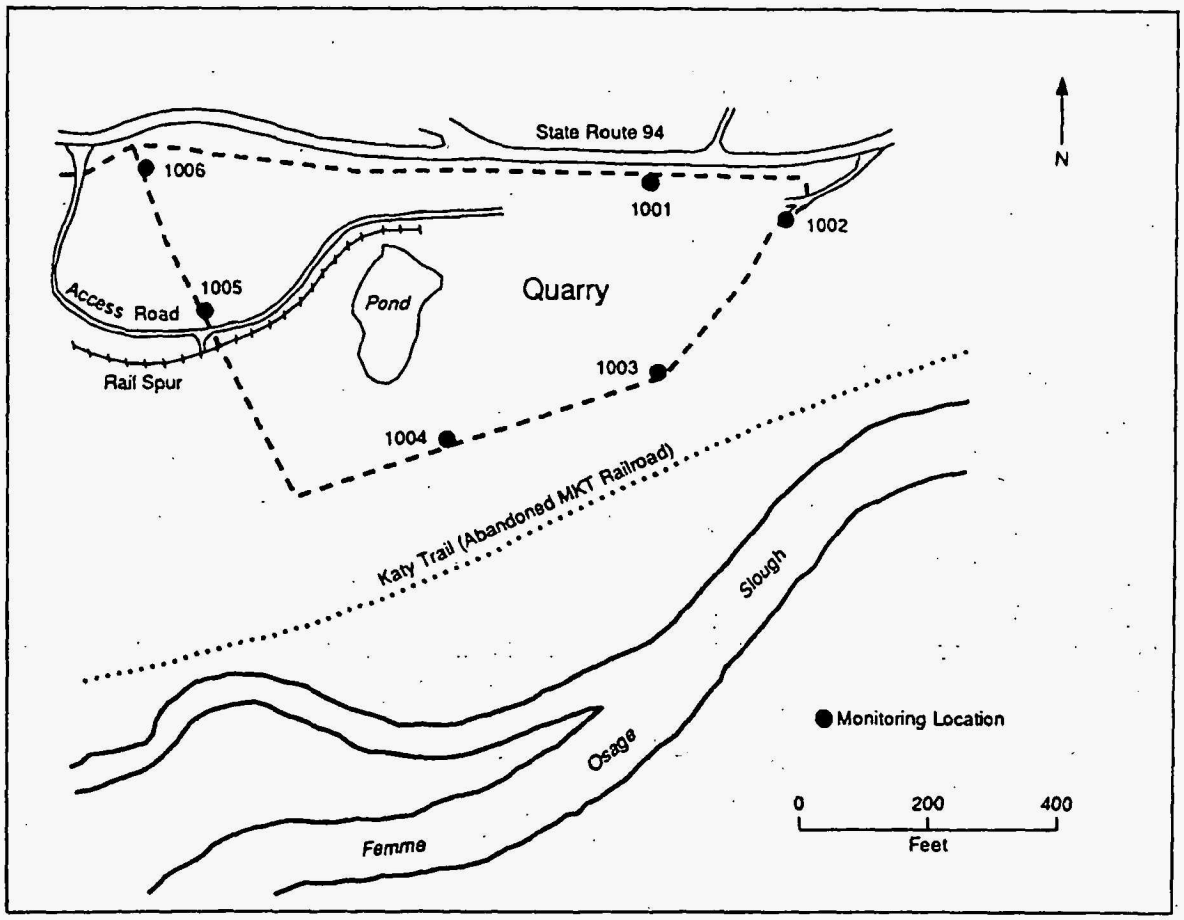


FIGURE 4.1 Radon and External Gamma Exposure Monitoring Locations at the Weldon Spring Quarry

occurred near the upper gate in the northeastern corner of the quarry in 1987. At that location, concentrations ranged from 0.7 to 4.0 pCi/L, with an annual average of 2.6 pCi/L (DOE 1988). Concentrations of radon measured by Berkeley Geosciences Associates (1984) within the quarry ranged from 0.8 to 18 pCi/L, averaging about 14 pCi/L. Additional measurements of radon within the quarry are currently being taken.

The risk associated with radon is due primarily to the inhalation of its short-lived decay products. Hence, the concentration of radon by itself is not a good measure of the hazard associated with this element. A more appropriate measure is an estimate of the potential alpha energy associated with its short-lived decay products, e.g., as expressed in the working level (WL) unit of measure.* One working level corresponds to 100 pCi/L of radon-222 in equilibrium with its short-lived decay products. Equilibrium conditions do not occur at the quarry because the radon gas produced by the bulk wastes is rapidly dispersed into the atmosphere. Measurements of radon-222 in WL units have been made in the quarry (MK-Ferguson Company and Jacobs Engineering Group 1989a). A value of 1.3×10^{-2} WL, which is the average of these measured values, was used for the trespasser scenario in this exposure assessment.

The concentration of radon-222 decay products is lower at the quarry fence than in the quarry itself because of atmospheric dispersion. The concentration of radon-222 decay products was estimated to be 2.4×10^{-3} WL at the quarry fence. This value was obtained using the measured value in the quarry (1.3×10^{-2} WL) and reducing it by the ratio of measured radon concentrations at the quarry fence (2.6 pCi/L) to that in the quarry (14 pCi/L). This estimated value of 2.4×10^{-3} WL for radon-222 decay products was used for the passerby scenario.

The concentration of radon-220 decay products has also been measured in the quarry (MK-Ferguson Company and Jacobs Engineering Group 1989a). A value of 4.3×10^{-3} WL, which is the average of these measured values, was used for the trespasser scenario. Using the same procedure that was used for radon-222, the concentration of radon-220 decay products was estimated to be 8.0×10^{-4} WL at the quarry fence; this value was used for the passerby scenario.

Gamma exposure rates have been measured at the quarry fence as part of the environmental monitoring program. Annual average values have ranged from 62 to 158 mR/yr (or 7.1 to 18 μR/h). The average background exposure rate for the Weldon Spring area measured in 1987 was 85 mR/yr (or 9.7 μR/h) (MK-Ferguson Company and Jacobs Engineering Group 1989b). A value of 18 μR/h, corresponding to the maximum exposure rate measured at the quarry fence, was used for the passerby scenario. Measured gamma exposure rates within the quarry indicate that the exposure rates are highly variable with location, ranging from background levels up to 625 μR/h (Berkeley Geosciences Associates 1984; Bechtel National 1985). Many measurements were less than 20 μR/h. For this exposure assessment, the exposure rate to a trespasser was

*One working level is any combination of short-lived radon decay products in one liter of air without regard to the degree of equilibrium that will result in the ultimate emission of 1.3×10^5 MeV of alpha energy.

assumed to be 60 μR/h. This value is the average of the exposure rates measured by Berkeley Geosciences Associates (1984).

The concentrations of airborne radioactive particulates are presented in Table 4.2. These were estimated using the same procedure that was used to predict the concentrations of airborne chemical particulates (as described in the following subsection).

Chemical Contaminants. Concentrations of airborne particulates were estimated for the only large area in the quarry that has surficial chemical contamination and is exposed to wind erosion (see Section 4.1). Emissions of fugitive dusts from this area (in the northeastern corner of the quarry) were estimated based on an approach developed by Cowherd et al. (1985) for evaluating respirable particulate emissions from uncontrolled waste sites. Contaminant air concentrations within the quarry were then determined based on a box model approach developed by EPA for estimating on-site concentrations from an area source (EPA 1986a; Hwang 1987). The estimated air concentrations of indicator chemicals are presented in Table 4.3; the models are described in Appendix A. As a conservative assumption, the estimated air concentrations of chemical contaminants within the quarry were used to approximate the exposure point concentrations for both the passerby and trespasser scenarios.

4.4 COMPARISON WITH STANDARDS AND CRITERIA

Consistent with guidance provided in SPHEM (EPA 1986c), the concentrations of contaminants at exposure points were compared with ARARs. Air and soil are the environmental media of concern with regard to the quarry bulk wastes under current land-use conditions.

4.4.1 Radioactive Contaminants

The DOE has developed guidelines for residual radioactive material at remote SFMP sites such as the Weldon Spring quarry (DOE 1987b). These guidelines are applicable to cleanup of residual radioactive materials and to management of the resulting wastes and residues. The guidelines -- which are largely based on DOE departmental orders, standards promulgated by the EPA (i.e., 40 CFR Part 192), and guidelines developed by the U.S. Nuclear Regulatory Commission (1982) -- provide the basis for defining the extent and nature of response action activities. The overriding consideration in these guidelines is the provision of an adequate margin of safety to the general public from exposure to residual radioactivity. Although the guidelines are not true ARARs in that they are not promulgated standards, they are based, in part, on standards promulgated by the EPA. Hence, these guidelines represent the "to-be-considered" category for CERCLA actions.

The basic limit established in DOE guidelines for the annual radiation dose received by an individual member of the general public is 100 mrem/yr (DOE 1987b). The dose is calculated as the internal 50-year committed effective dose equivalent, as

defined in Publication 26 of the International Commission on Radiological Protection (ICRP 1977) and calculated by dosimetry models described in ICRP Publication 30 (ICRP 1979-1982), combined with the dose from penetrating radiation sources external to the body. In addition, the dose equivalent to any tissue cannot exceed 5 rem/yr. It is DOE policy to ensure that the actual doses to the public are as far below the basic limit as is reasonably achievable and to adhere to dose limits established by the EPA for specific exposure modes, e.g., 40 CFR Part 61 for airborne emissions and 40 CFR Part 141 for drinking water supplies.

Other than the basic dose limit, some specific criteria in the DOE guidelines are more directly applicable to the presence of radioactively contaminated bulk wastes in the quarry. The DOE guidelines for residual radioactive material, which specify the requirements for releasing areas for use without radiological restrictions (DOE 1987b), and their relevance to the bulk wastes in the quarry are presented in Table 4.4.

The DOE derived concentration guides (DCGs) for airborne radioactivity are the applicable regulations for radioactive air contaminants (see Table 4.4). The DCGs for airborne radioactive particulates are based on a committed effective dose equivalent of 100 mrem for the radionuclides taken into the body for one year by inhalation; DCGs are reported separately for individual radionuclides. For known mixtures of radionuclides, the sum of the ratio of the observed concentration of a particular radionuclide and its corresponding DCG for all radionuclides in the mixture must not exceed 1.0. The concentration limit is 3 pCi/L for both radon-220 and radon-222.

The radiation dose from airborne particulate releases represents an insignificant risk relative to that from radon-220, radon-222, and their short-lived decay products. The concentrations of respirable airborne particulates within the quarry and at the quarry fence (see Table 4.2) were estimated to be considerably below the DOE limits (see Table 4.4) whereas the measured concentration of radon exceeds the DOE limit for unrestricted areas within the quarry. The measured radon concentration at the nearest exposure point (i.e., the fence at the northeastern corner of the quarry) is very close to the limit for radon-222. Based on this fact, the radiation dose associated with airborne particulate releases would be only a small fraction of that from radon-220, radon-222, and their short-lived decay products and was therefore not considered further in this risk evaluation.

4.4.2 Chemical Contaminants

The National Ambient Air Quality Standards are potentially applicable to airborne chemical contaminants at the quarry. However, no such standards are available for the specific indicator chemicals identified in the air pathway, i.e., nitroaromatic compounds (2,4,6-TNT, 2,4-DNT, 2,6-DNT, and 1,3,5-trinitrobenzene) and uranium. The estimated contaminant concentrations in air can be compared with occupational exposure limits (permissible exposure limits), although these limits are not considered to be ARARs. The following exposure limits are the time-weighted average concentrations reported by the Occupational Safety and Health Administration (1989): 2,4,6-TNT, 0.5 mg/m^3; DNT, 1.5 mg/m^3; insoluble uranium compounds, 0.2 mg/m^3 (as uranium); and soluble uranium compounds, 0.05 mg/m^3 (as uranium). Permissible exposure limits are

TABLE 4.4 DOE Guidelines for Residual Radioactive Material and Their Relevance to the Quarry Bulk Wastes

Specific Criteria	Relevance to Quarry Bulk Wastes
The concentrations of radium-226, radium-228, thorium-230, or thorium-232 shall not exceed 5 pCi/g averaged over the first 15 cm (6 in.) of soil below the surface and 15 pCi/g averaged over 15-cm-thick layers of soil more than 15 cm below the surface. If either thorium-230 and radium-226 or thorium-232 and radium-228 are both present, not in secular equilibrium, the appropriate guideline is applied as a limit to the radionuclide with the higher concentration.	The average radium-226 concentrations are 110 pCi/g in the top 15 cm (6 in.) of the quarry soil/wastes and 110 pCi/g throughout the waste volume. The average thorium-230 concentrations are 150 pCi/g in the top 15 cm and 330 pCi/g throughout the waste volume. Concentrations of radium-226 will increase with time due to ingrowth. Average thorium-232 concentrations are 26 pCi/g in the waste volume. The average radium-228 concentrations are 20 pCi/g in the top 15 cm and 100 pCi/g throughout the waste volume. Thus, the bulk wastes exceed residual radioactive guidelines so that the quarry cannot be released for use without radiological restrictions. The quarry is currently fenced and access is controlled.
In any occupied or habitable building, the objective of remedial action shall be, and a reasonable effort shall be made to achieve, an annual average radon decay product concentration (including background) not to exceed 0.02 WL. In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL.	No habitable buildings are currently located at the quarry.
The average level of gamma radiation inside a building or habitable structure shall not exceed the background level by more than 20 μR/h.	No habitable buildings are currently located at the quarry.

TABLE 4.4 (Cont'd)

Specific Criteria	Relevance to Quarry Bulk Wastes
Residual concentrations of radionuclides in air shall be controlled to levels required by DOE environmental protection guidance and orders. For uncontrolled areas, these levels for the indicator radionuclides are as follows:	Airborne particulate concentrations have not been measured. However, conservatively estimated concentrations of these radionuclides within the quarry (see Table 4.2) are below these limits. Radon concentrations (largely due to radon-222) exceeded 3 pCi/L (above background) during part of 1987 at one sampling location. However, the annual average value at all locations was below 3 pCi/L.

Radionuclide	Airborne Concentration above Background
Uranium-238	0.1 pCi/m^3
Thorium-232	0.007 pCi/m^3
Thorium-230	0.04 pCi/m^3
Radium-228	3 pCi/m^3
Radium-226	1 pCi/m^3
Radon-220	3 pCi/L[a]
Radon-222	3 pCi/L[a]

[a]Based on immersion in a semi-infinite cloud.

the time-weighted average concentrations for a normal 8-hour work day and a 40-hour work week to which nearly all workers may be repeatedly exposed without adverse effects. All air concentrations of these compounds at the quarry (Table 4.3) are considerably below the recommended occupational exposure limits.

No promulgated standards are available for permissible levels of chemical contaminants in soils. However, EPA regulations (40 CFR 761.125) related to decontaminating spills of PCBs at concentrations of 50 mg/kg (50 ppm) or greater in nonrestricted access areas require that "soil contaminated by the spill will be decontaminated to [10 mg/kg] 10 ppm by weight provided that soil is excavated to a minimum depth of [25.4 cm] 10 inches and the excavated soil will be replaced with clean soil, i.e., containing less than [1 mg/kg] 1 ppm PCBs ...." The concentration of PCBs in the quarry averaged 20 mg/kg (20 ppm) and ranged from less than detection to 120 mg/kg (120 ppm).

When ARARs are not available for all contaminants and pathways of concern in an exposure assessment, SPHEM guidance (EPA 1986c) directs that a quantitative

exposure and risk assessment be performed. These final steps for the quarry bulk wastes are presented in Section 4.5 and Chapter 6.

4.5 ESTIMATION OF CONTAMINANT INTAKES

Exposure is expressed in terms of intake, which is the amount of contaminant taken into the body per unit body weight per unit time. Estimates of exposure are based on the concentrations of contaminants in the exposure medium (e.g., air), the intake factors appropriate to each medium (e.g., inhalation rates), and the amounts of contaminants actually absorbed. Scenario-specific intake factors and absorption factors for the chemical and radioactive contaminants at the quarry were estimated from data available in the literature.

4.5.1 Passerby Scenario

The passerby scenario considers potential exposures to a hypothetical individual who routinely walks by the northern boundary of the quarry along State Route 94 (see Section 4.2.2). The exposure pathways applicable to this scenario are:

- Inhalation of radon-220, radon-222, and their short-lived decay products,
- Exposure to external gamma radiation, and
- Inhalation of chemically contaminated airborne dusts.

The potential exposures (intakes) associated with these pathways depend upon the parameters specific to this scenario. The assumptions used for estimating radiological and chemical exposures are summarized in Table 4.5. Inhalation rates depend on the age and size of an individual and the level of activity during exposure. The commonly used value of 20 m^3/d (or 0.83 m^3/h averaged over 24 hours) is that recommended by the EPA for situations when exposure is continuous or when specific activity patterns are not known (EPA 1989a). Data compiled by Anderson et al. (1985) and summarized in EPA (1989a) provide inhalation rates for specific levels of activity. For example, the reported rates in adult males are 0.7, 0.8, 2.5, and 4.8 m^3/h during resting, light, moderate, and heavy levels of activity, respectively. For this risk evaluation, the level of activity for the passerby was assumed to be between light (e.g., similar to performing domestic work) and moderate (e.g., similar to performing heavy outdoor cleanup activities or climbing stairs). A value of 1.2 m^3/h was used for both the representative and plausible maximum exposure cases. This value is the same as the inhalation rate for the ICRP reference man (ICRP 1975). For the representative case, an exposure event was assumed to occur twice per day, with an average residence time of 12 minutes per event, 250 days per year, over a period of 5 years. For the plausible maximum case, events were assumed to occur 365 days per year for a period of 10 years.

TABLE 4.5 Assumptions Used for Estimating Radiological and Chemical Exposures: Passerby Scenario

Parameter	Unit	Value: Representative Exposure Case	Value: Plausible Maximum Exposure Case
Age of exposed individual	-	Adult	Adult
Average body weight	kg	70	70
Inhalation rate	m^3/h	1.2	1.2
Duration of each exposure event	h	0.2	0.2
Exposure events	no./yr	500	730
Years of exposure	yr	5	10

Inhalation of Radon-222 and Its Short-Lived Decay Products. The risk associated with radon-222 is due primarily to inhalation of its short-lived decay products. For the passerby scenario, it was assumed that the affected individual is exposed to radon-222 decay products at a concentration of 2.4×10^{-3} WL. The individual was assumed to be exposed to radon-222 decay products originating from the quarry bulk wastes over a distance of 1.0 km (0.6 mi). The effect of atmospheric dispersion (with distance from the quarry) was assumed to be offset by decay product ingrowth so that the individual is exposed to a radon-222 decay product concentration of 2.4×10^{-3} WL for the entire 1.0 km (0.6 mi).

Exposure to radon-222 and its short-lived decay products can be expressed in the unit of working-level month (WLM). When originally proposed, 1 WL was considered to be an acceptable maximum concentration for uranium miners working a 40-hour week (or 170 hours per month). Hence, exposure of a worker to a radon-222 decay product concentration of 1 WL for 170 hours, with an inhalation rate of 1.2 m^3/h, would result in an exposure of 1 WLM. The annual exposure to the passerby in WLM was calculated as follows:

$$RD = \frac{(C)\ (I_r)\ (T)\ (E)}{K} \tag{4.1}$$

where:

RD = annual exposure to radon-222 decay products (WLM/yr),

C = air concentration of radon-222 decay products (WL),

I_r = inhalation rate (m^3/h),

T = duration of each exposure event (hours/event),

E = exposure events (no./yr), and

K = conversion factor (204 m^3/mo).

The conversion factor K in Equation 4.1 is the product of the inhalation rate (1.2 m^3/h) and the number of working hours in one month (170).

For this evaluation, the exposure time was assumed to be 100 hours per year for the representative exposure case (i.e., 0.2 hours per event for 500 events per year) and 146 hours per year for the plausible maximum exposure case (i.e., 0.2 hours per event for 730 events per year). The annual exposure is estimated to be 1.4×10^{-3} WLM/yr for the representative exposure case and 2.1×10^{-3} WLM/yr for the plausible maximum exposure case. The lifetime exposure is estimated to be 7.0×10^{-3} WLM for the representative exposure case (assuming 5 years of exposure) and 2.1×10^{-2} WLM for the plausible maximum exposure case (assuming 10 years of exposure).

Inhalation of Radon-220 and Its Short-Lived Decay Products. The risk associated with radon-220 is due primarily to inhalation of its short-lived decay products. The concentration of radon-220 decay products at the quarry fence is estimated to be 8.0×10^{-4}. The effects of atmospheric dispersion were assumed to be offset by decay product ingrowth so that the individual is exposed to a radon-220 decay product concentration of 8.0×10^{-4} WL for the entire 1.0 km (0.6 mi). Using Equation 4.1, the annual exposure is estimated to be 4.7×10^{-4} WLM/yr for the representative exposure case and 6.9×10^{-4} WLM/yr for the plausible maximum exposure case. The lifetime exposure is estimated to be 2.4×10^{-3} WLM for the representative exposure case (assuming 5 years of exposure) and 6.9×10^{-3} WLM for the plausible maximum exposure case (assuming 10 years of exposure).

Exposure to External Gamma Radiation. The radiation dose from external gamma radiation is calculated by multiplying the length of time an individual is exposed to gamma radiation by the radiation field strength. Gamma exposure rates have been measured at the quarry fence as part of the environmental monitoring program. Annual average exposure rates measured at the fence have ranged from 62 to 158 mR/yr (7.1 to 18 μR/h). The average background rate measured in 1987 was 85 mR/yr (9.7 μR/h) (MK-Ferguson Company and Jacobs Engineering Group 1989b). For this evaluation, it was assumed that the affected individual is exposed to an exposure rate of 18 μR/h for the entire 1.0 km (0.6 mi). The contribution from background gamma exposure rates is included in the calculated dose estimates.

The annual exposure time was assumed to be 100 hours per year for the representative exposure case and 146 hours per year for the plausible maximum exposure case. Using a dose conversion factor of 0.95 mrem/mR, the annual doses are estimated to be

1.7 mrem/yr for the representative exposure case and 2.5 mrem/yr for the plausible maximum exposure case. The lifetime dose is estimated to be 8.5 mrem for the representative exposure case (assuming 5 years of exposure) and 25 mrem for the plausible maximum exposure case (assuming 10 years of exposure).

Inhalation of Chemically Contaminated Airborne Dusts. Chemical intakes resulting from exposure to contaminated airborne dusts were estimated for nitroaromatic compounds and uranium. For the passerby scenario, it was assumed that the individual is exposed to the exposure point concentrations of airborne contaminants listed in Table 4.3 over the entire 1.0 km (0.6 mi). The exposure point concentrations in Table 4.3 were estimated for the area of highest air contaminant concentrations in the quarry, i.e., at the area of exposed surface contamination near the fence in the northeastern corner of the quarry (see Section 4.3.2). Although these assumptions tend to overestimate intake, the risks estimated for the passerby were very low (see Section 6.2) and a more detailed analysis based on more realistic, but less conservative, assumptions was not performed.

Intake estimates for the inhalation pathway were calculated as follows:

$$I_{ex} = \frac{(C_{ai})\ (I_r)\ (T)\ (E)\ (Yr)}{(BW)\ (D)} \qquad (4.2)$$

where:

I_{ex} = inhalation intake of contaminant i (mg/kg-d),

C_{ai} = air concentration of contaminant i (mg/m^3),

I_r = inhalation rate (m^3/h),

T = duration of each exposure event (hours/event),

E = number of exposure events per year (events/year),

Yr = number of years over which exposure occurs (yr),

BW = average body weight over the exposure period (kg), and

D = days over which exposure is averaged (d).

Two dose estimates (in mg/kg-d) were calculated for each exposure case. The first is the estimated average daily intake for the exposure period of 5 or 10 years; this value is used to estimate the potential noncarcinogenic hazards of the indicator chemicals. The second is the total dose received during the 5- or 10-year exposure period averaged over a lifetime of 70 years. The total doses for the exposure period and lifetime estimates are the same, but the averaging period is different. The lifetime dose estimate is used for calculating carcinogenic risks because the carcinogenic potency

factors used to estimate carcinogenic risks assume that the exposure has occurred over a period of 70 years. The estimated intakes of the passerby resulting from inhalation of airborne chemical contaminants are given in Table 4.6. The estimated carcinogenic and noncarcinogenic risks are given in Chapter 6.

4.5.2 Trespasser Scenario

The trespasser scenario considers potential exposures to an individual (presumably a youth) who enters the quarry several times per year (see Section 4.2.2). The exposure pathways applicable to this scenario are:

- Inhalation of radon-220, radon-222, and their short-lived decay products,
- Exposure to external gamma radiation,
- Inhalation of chemically contaminated airborne dusts,
- Dermal contact with chemically contaminated surface soils, and
- Ingestion of radioactively and chemically contaminated surface soils.

For this scenario, the age group was assumed to be 11 to 15 years old for the representative exposure case and 9 to 18 years old for the plausible maximum exposure case. Based on the limited data presented in Anderson et al. (1985) regarding inhalation rates in these age groups, the inhalation rate was assumed to be 1.2 m^3/h, assuming light to moderate levels of activity (see Section 4.5.1). Although this value is the same as that for the adult passerby, and therefore may appear to be high because of the lower body weight of the trespasser, data in Anderson et al. (1985) indicate that inhalation rates for adolescents are similar to or higher than those of adults at the same activity level. The exposure events were assumed to occur 12 times per year for the representative case and 50 times per year for the plausible maximum case; the duration of each exposure event was assumed to be 2 and 4 hours, respectively. An average body weight of 50 kg was used, based on data provided in Anderson et al. (1985). The assumptions used for estimating radiological and chemical exposures are summarized in Table 4.7.

Inhalation of Radon-222 and Its Short-Lived Decay Products. For this evaluation, it was assumed that the affected individual inhales radon-222 decay products at a concentration of 1.3×10^{-2} WL. The annual exposure time was assumed to be 24 hours per year for the representative exposure case and 200 hours per year for the plausible maximum exposure case. Using Equation 4.1, the annual doses to the trespasser are estimated to be 1.8×10^{-3} WLM/yr for the representative exposure case and 1.5×10^{-2} WLM/yr for the plausible maximum exposure case. The lifetime dose is estimated to be 9.0×10^{-3} WLM for the representative exposure case (assuming 5 years of exposure) and 1.5×10^{-1} WLM for the plausible maximum exposure case (assuming 10 years of exposure).

TABLE 4.6 Estimated Average Daily Intakes of Indicator Chemicals from Exposure to Fugitive Dusts: Passerby Scenario[a]

Contaminant	Estimated Daily Intake Averaged over Exposure Period (mg/kg-d)	
	Representative Exposure Case	Plausible Maximum Exposure Case
Nitroaromatic Compounds		
2,4,6-TNT	4.7×10^{-7}	6.9×10^{-7}
2,4-DNT and 2,6-DNT	8.5×10^{-10}	1.2×10^{-9}
1,3,5-Trinitrobenzene	5.2×10^{-9}	7.5×10^{-9}
Uranium	1.9×10^{-8}	2.7×10^{-8}

Contaminant	Estimated Daily Intake Averaged over Lifetime[b] (mg/kg-d)	
	Representative Exposure Case	Plausible Maximum Exposure Case
Nitroaromatic Compounds		
2,4,6-TNT	3.4×10^{-8}	9.8×10^{-8}
2,4-DNT and 2,6-DNT	6.0×10^{-11}	1.8×10^{-10}

[a]Based on exposure point concentrations given in Table 4.3.

[b]Estimated for the carcinogenic indicator contaminants only (see text).

Inhalation of Radon-220 and Its Short-Lived Decay Products. The concentration of radon-220 decay products in the quarry atmosphere was estimated to be 4.3×10^{-3} WL. The annual exposure time was assumed to be 24 hours per year for the representative exposure case and 200 hours per year for the plausible maximum exposure case. Using Equation 4.1, the annual doses to the trespasser are estimated to be 6.1×10^{-4} WLM/yr for the representative exposure case and 5.1×10^{-3} WLM/yr for the plausible maximum exposure case. The lifetime dose is estimated to be 3.1×10^{-3} WLM for the representative exposure case (assuming 5 years of exposure) and 5.1×10^{-2} WLM for the plausible maximum exposure case (assuming 10 years of exposure).

Exposure to External Gamma Radiation. For this evaluation, it was assumed that the trespasser is exposed to a gamma radiation field of 60 μR/h. The annual exposure

TABLE 4.7 Assumptions Used for Estimating Radiological and Chemical Exposures: Trespasser Scenario

Parameter	Unit	Value: Representative Exposure Case	Value: Plausible Maximum Exposure Case
Age of exposed individual	yr	11-15	9-18
Average body weight	kg	50	50
Inhalation rate	m^3/h	1.2	1.2
Average exposed surface area per event	cm^2	2,600	2,600
Dust adherence to skin	mg/cm^2	0.5	1.5
Fraction of compound absorbed from contaminated soils through dermal contact			
Organic compounds	-	0.015	0.03
Metals	-	0	0
Incidental soil ingestion	mg/event	100	100
Duration of each exposure event	h	2	4
Exposure events	no./yr	12	50
Years of exposure	yr	5	10

time was assumed to be 24 hours per year for the representative exposure case and 200 hours per year for the plausible maximum exposure case. Using the methodology described in Section 4.5.1, the annual doses are estimated to be 1.4 mrem/yr for the representative exposure case and 11 mrem/yr for the plausible maximum exposure case. The lifetime dose is estimated to be 7.0 mrem for the representative exposure case (assuming 5 years of exposure) and 110 mrem for the plausible maximum exposure case (assuming 10 years of exposure).

Inhalation of Chemically Contaminated Airborne Dusts. Chemical intakes resulting from exposure to contaminated airborne dusts were estimated for nitroaromatic

compounds and uranium, based on the exposure point concentrations given in Table 4.3. The concentrations in Table 4.3 were estimated for the area of highest air contaminant concentrations in the quarry, i.e., at the area of exposed surface contamination in the northeastern corner of the quarry. Intakes were estimated using Equation 4.2; the results are presented in Table 4.8.

Dermal Contact with Chemically Contaminated Surface Soils. Intake estimates for dermal absorption of indicator chemicals in soils were calculated as follows:

$$D_{ex} = \frac{(C_{si})\ (C_r)\ (E)\ (Yr)\ (ABS)\ (Z)}{(BW)\ (D)} \tag{4.3}$$

where:

D_{ex} = intake estimate for dermal absorption (mg/kg-d),

C_{si} = soil concentration of contaminant i (mg/kg),

C_r = contact rate for soil (mg/event),

ABS = fraction of contaminant i absorbed, and

Z = conversion factor (1×10^{-6} kg/mg).

The contact rate (C_r) for soils was based on estimates of the exposed skin area per event and dust adherence to the skin. A time-weighted estimate of the exposed skin area per event was made based on estimates of skin surface area taken from Anderson et al. (1985) and consideration of the type of clothing that would be worn during an exposure event. Assuming that the hands would be exposed in the winter months, the hands and forearms in the fall and spring, and the hands, forearms, and lower legs in the summer, the average exposed skin area per event was estimated to be 2,600 cm^2. Limited estimates of dust adherence to skin in the literature range from 0.5 to 1.5 mg/cm^2 (Lepow 1975; Roels et al. 1980). In the absence of site-specific information, values of 0.5 and 1.5 mg/cm^2 were selected for the representative and plausible maximum exposure cases in this evaluation. The intake of chemicals resulting from this contact depends on the amount of dermal absorption of organic contaminants from a soil matrix, which in turn depends on several factors -- including soil type and water content, concentration gradient, and duration of contact. Estimates in the literature range from 0.07 to 5% (Hawley 1985; EPA 1986a). Absorption factors of 1.5 and 3.0% were used in this evaluation for the representative and plausible maximum exposure cases, respectively. Absorption of metal ions from a soil matrix is considered to be negligible and was therefore not quantified. The estimated intakes resulting from dermal absorption are presented in Table 4.9, based on the exposure point concentrations of indicator chemicals in soils given in Table 4.3.

TABLE 4.8 Estimated Average Daily Intakes of Indicator Chemicals from Exposure to Fugitive Dusts: Trespasser Scenario[a]

Contaminant	Estimated Daily Intake Averaged over Exposure Period (mg/kg-d)	
	Representative Exposure Case	Plausible Maximum Exposure Case
Nitroaromatic Compounds		
2,4,6-TNT	1.6×10^{-7}	1.3×10^{-6}
2,4-DNT and 2,6-DNT	2.8×10^{-10}	2.4×10^{-9}
1,3,5-Trinitrobenzene	1.7×10^{-9}	1.4×10^{-8}
Uranium	6.3×10^{-9}	5.3×10^{-8}

Contaminant	Estimated Daily Intake Averaged over Lifetime[b] (mg/kg-d)	
	Representative Exposure Case	Plausible Maximum Exposure Case
Nitroaromatic Compounds		
2,4,6-TNT	1.1×10^{-8}	1.9×10^{-7}
2,4-DNT and 2,6-DNT	2.0×10^{-11}	3.4×10^{-10}

[a]Based on exposure-point concentrations given in Table 4.3.

[b]Estimated for the carcinogenic indicator contaminants only (see Section 4.5.1).

The assumptions used for estimating dermal absorption are based on very limited data. Few experimental data are available for estimating dust adherence to skin or absorption of chemicals adsorbed to a soil matrix, and specific guidance is not available from EPA. For these reasons, the estimates of intake by this route of exposure are considered to be highly uncertain. However, intakes have been calculated in order to provide a crude estimate of the potential intakes by this route of exposure.

Exposure from Incidental Soil Ingestion. Individuals may ingest soil either inadvertently (e.g., by transfer of soil on hands and fingers to food or cigarettes) or intentionally (pica). Pica is a behavior generally associated with young children (2 to 6 years old) and is therefore not considered to be significant for the age group considered

TABLE 4.9 Estimated Average Daily Intakes of Indicator Chemicals from Dermal Exposure to Contaminated Surface Soils: Trespasser Scenario[a]

Contaminant	Estimated Daily Intake Averaged over Exposure Period (mg/kg-d)	
	Representative Exposure Case	Plausible Maximum Exposure Case
Nitroaromatic Compounds		
2,4,6-TNT	1.7×10^{-4}	4.2×10^{-3}
2,4-DNT and 2,6-DNT	2.9×10^{-7}	7.4×10^{-6}
1,3,5-Trinitrobenzene	1.8×10^{-6}	4.5×10^{-5}
PAHs (total)	3.6×10^{-7}	9.0×10^{-6}
PCBs	3.3×10^{-7}	8.3×10^{-6}

Contaminant	Estimated Daily Intake Averaged over Lifetime (mg/kg-d)	
	Representative Exposure Case	Plausible Maximum Exposure Case
Nitroaromatic Compounds		
2,4,6-TNT	1.2×10^{-5}	6.0×10^{-4}
2,4-DNT and 2,6-DNT	2.1×10^{-8}	1.1×10^{-6}
1,3,5-Trinitrobenzene	1.3×10^{-7}	6.4×10^{-6}
PAHs (carcinogenic)	1.1×10^{-8}	5.5×10^{-7}
PCBs	2.4×10^{-8}	1.2×10^{-6}

[a]Based on exposure point concentrations given in Table 4.3.

in this assessment. Interim guidance from the EPA for soil ingestion rates is 100 mg/d for adults and 200 mg/d for children one to six years of age (Porter 1989). The limited data available suggest that ingestion rates of the age group considered in this risk evaluation would be typical of those of an adult. Therefore, a soil ingestion rate of 100 mg/d was used for the representative and plausible maximum exposure cases.

The estimated radiation doses associated with incidental soil ingestion were based on the surficial soil concentrations presented in Table 4.2 and on the assumed ingestion values given above. An individual was therefore estimated to ingest 200 pCi of uranium-238, 31 pCi of thorium-232, 180 pCi of thorium-230, 24 pCi of radium-228, and 130 pCi of radium-226 each year for 5 years for the representative exposure case. The dose contributions from intermediate decay products in the uranium-238 and thorium-232 decay series were included in this evaluation. Using appropriate dose conversion factors (Gilbert et al. 1989), the annual radiation dose associated with the ingestion pathway is estimated to be 1.4 mrem/yr. The lifetime dose is estimated to be 7.0 mrem (assuming 5 years of exposure).

The assumed annual soil ingestion rate is 4.2 times higher per year for the plausible maximum exposure case than for the representative exposure case. The annual dose would therefore be 4.2 times higher, or 5.9 mrem/yr. The lifetime dose for the plausible maximum exposure case is estimated to be 59 mrem (assuming 10 years of exposure).

Chemical intakes resulting from incidental ingestion of contaminated surface soils were estimated for all indicator chemicals, based on the exposure point concentrations given in Table 4.3. Intake estimates were calculated as follows:

$$O_{ex} = \frac{(C_{si})\ (S)\ (E)\ (Yr)\ (Z)}{(BW)\ (D)} \tag{4.4}$$

where:

O_{ex} = oral intake of contaminant i (mg/kg-d),

C_{si} = soil concentration of contaminant i (mg/kg), and

S = amount of soil ingested (mg/event).

The estimated intakes resulting from incidental soil ingestion are given in Table 4.10.

TABLE 4.10 Estimated Average Daily Intakes of Indicator Chemicals from Incidental Ingestion of Contaminated Surface Soils: Trespasser Scenario[a]

Contaminant	Estimated Daily Intake Averaged over Exposure Period (mg/kg-d)		Estimated Daily Intake Averaged over Lifetime (mg/kg-d)	
	Representative Exposure Case	Plausible Maximum Exposure Case	Representative Exposure Case	Plausible Maximum Exposure Case
Nitroaromatic Compounds				
2,4,6-TNT	8.5×10^{-4}	3.6×10^{-3}	6.1×10^{-5}	5.1×10^{-4}
2,4-DNT and 2,6-DNT	1.5×10^{-6}	6.3×10^{-6}	1.1×10^{-7}	9.0×10^{-7}
1,3,5-Trinitrobenzene	9.2×10^{-6}	3.8×10^{-5}	6.6×10^{-7}	5.5×10^{-6}
PAHs				
Carcinogens	7.9×10^{-7}	3.3×10^{-6}	5.6×10^{-8}	4.7×10^{-7}
Total	1.8×10^{-6}	7.7×10^{-6}	1.3×10^{-7}	1.1×10^{-6}
PCBs	1.7×10^{-7}	7.1×10^{-6}	1.2×10^{-7}	1.0×10^{-6}
Metals				
Arsenic	6.6×10^{-6}	2.7×10^{-5}	4.7×10^{-7}	3.9×10^{-6}
Lead	6.2×10^{-5}	2.6×10^{-4}	4.5×10^{-6}	3.7×10^{-5}
Nickel	2.0×10^{-5}	8.2×10^{-5}	1.4×10^{-6}	1.2×10^{-5}
Selenium	1.5×10^{-6}	6.3×10^{-6}	1.1×10^{-7}	9.0×10^{-7}
Uranium	3.4×10^{-5}	1.4×10^{-4}	2.4×10^{-6}	2.0×10^{-5}

[a]Based on exposure point concentrations given in Table 4.3.

5 SUMMARY TOXICITY PROFILES

As background information for this baseline risk evaluation, a general description of the toxicological effects associated with radiation exposure and short summaries of the major toxicological effects of the quarry chemical contaminants (including uranium) are presented in Sections 5.1 and 5.2, respectively. Many of the acute effects described for the chemical contaminants of concern occur at high doses, either from accidental human exposure or as induced in laboratory animals. Such effects would not generally be expected to result from the levels at which these contaminants occur in the quarry. However, effects from long-term or repeated exposure to these compounds might occur at doses approaching those that could result from long-term exposure to a contaminated environment such as the quarry.

5.1 RADIATION TOXICITY

The potential health effects associated with exposure to low levels of radiation may include a small increase in the occurrence of cancer, depending on the organ irradiated, and possible genetic effects that may occur in future generations. Radiation is a unique type of contaminant in that it is naturally present in the environment. The dose to any individual from background sources of radiation averages about 300 mrem/yr (National Council on Radiation Protection and Measurements 1987). The major contributor to this background dose is radon-222 and its short-lived decay products, largely due to the buildup of radon-222 decay products in dwellings.

The potential health impacts associated with radiation exposure can be divided into two categories: stochastic effects and nonstochastic effects. Stochastic effects are those for which only the probability of occurrence, not the severity, is related to the radiation dose received. The two principal stochastic effects are cancer induction and genetic defects in offspring. Nonstochastic effects are those for which both the probability of occurrence and the severity of the effect are a function of dose. Examples of nonstochastic effects include cataracts, nonmalignant damage to the skin, and gonadal cell damage leading to impairment of fertility. The major potential impact associated with radiation exposure resulting from the radioactive contaminants in the quarry is the induction of cancer.

Physiological effects to an individual from radiation exposure are clinically detectable only from exposure resulting in a dose greater than about 10 rem (to the whole body) for a few individuals and about 25 rem for nearly all individuals over a short period of time (hours). Doses about 10 to 20 times higher, also received over a relatively short period of time (hours to a few days), can be expected to result in some fatalities.

Lower levels of exposures also constitute a health risk, but a direct cause-and-effect relationship between a known exposure to radiation and any given health effect is difficult to define because of the many other possible reasons for which a particular effect is observed in a specific individual. For this reason, such effects -- including an increased incidence of cancer in the exposed population and genetic changes in future generations after exposure of a prospective parent -- must be assessed on a statistical

basis. Occurrences of cancer in the exposed population may begin to develop after a lapse of about 2 to 20 years following exposure (latent period) and may then continue over a period of about 30 years (plateau period). However, in the case of exposure of fetuses (in utero), occurrences of cancer may begin to develop at birth (no latent period) and end at age 10 (i.e., the plateau period is 10 years). The occurrence of cancer itself does not necessarily result in fatality. Most authorities agree that a reasonable -- and probably conservative -- estimate of the randomly occurring number of health effects in a large number of individuals from exposure to low levels of radiation is within the range of about 10 to 500 potential cancer deaths per million person-rem. The source of this range is the BEIR III report of the National Research Council (1980), which also indicates a probable value of 150. The ICRP estimates that 165 fatal cancers and serious genetic effects per million person-rem will occur in the first two generations following radiation exposure (ICRP 1977).

5.2 CHEMICAL TOXICITY

The information presented in this section was taken from the references listed in Table 5.1. The EPA classifications of carcinogenicity were obtained from the *Integrated Risk Information System* data base (EPA 1989c) and the *Health Effects Assessment Summary Tables* (EPA 1989b).

5.2.1 Nitroaromatic Compounds

Dinitrotoluene. The major isomers of technical grade dinitrotoluene (tDNT) are 2,4-dinitrotoluene (2,4-DNT) and 2,6-dinitrotoluene (2,6-DNT); all isomers are man-made compounds. The principal uses of tDNT are in the manufacture of explosives, dyes, and pigments and as a chemical intermediate in the manufacture of polyurethane.

Studies in experimental animals indicate that hepatocellular carcinomas are induced following the oral administration of tDNT and 2,6-DNT and that 2,4-DNT has tumor-promoting activity. The compound 2,4-DNT is classified as a Group B2 probable human carcinogen, and 2,6-DNT is classified as a Group C possible human carcinogen. These compounds can induce methemoglobinemia, a reduction in the oxygen-carrying capacity of the blood, especially in infants. Other effects include toxicity of the liver, kidney, and nervous system. Although no effect on the reproductive system (e.g., abnormal sperm count or morphology) has been observed in male workers exposed to tDNT, adverse effects — including testicular atrophy and decreased spermatogenesis -- have been observed in experimental animals.

Studies in several animal species indicate that approximately 75 to 85% of an oral dose of 2,4-DNT is absorbed; in mice, the absorption is only about 17%. Studies in humans indicate that nitroaromatic compounds are absorbed following inhalation and ingestion and that these compounds are capable of penetrating the skin.

TABLE 5.1 References for Chemical Toxicity Data

Chemical Species	References[a]
Arsenic	EPA (1984a); ATSDR (1987a); Seiler and Sigel (1988)
Lead	EPA (1984b); ATSDR (1988); Seiler and Sigel (1988)
Nickel	EPA (1984c); ATSDR (1987b); Seiler and Sigel (1988)
Selenium	EPA (1984e); Seiler and Sigel (1988)
Uranium	Hodge et al. (1973); Berlin and Rudell (1986); Seiler and Sigel (1988)
PAHs	International Agency for Research on Cancer (1983); EPA (1984d); Sittig (1985); ATSDR (1987d, 1987e, 1987f, 1987g)
PCBs	ATSDR (1987c)
Nitroaromatic compounds	EPA (1980); Rickert et al. (1983); Sax (1984); Rickert (1985); Sittig (1985); Etnier (1987); Gordon and Hartley (1989)

[a]Acronyms: ATSDR, Agency for Toxic Substances and Disease Registry; EPA, U.S. Environmental Protection Agency.

Trinitrotoluene. The principal use of the man-made compound 2,4,6-trinitrotoluene (2,4,6-TNT) is in the manufacture of explosives. Based on studies of carcinogenicity in experimental animals, the EPA has recently classified TNT as a Group C possible human carcinogen. The main site of TNT-induced toxicity is the hematopoietic system, the effects of which include methemoglobinemia and aplastic anemia. Other adverse effects include hepatotoxicity (hepatitis and jaundice), cataracts, and dermatitis. Testicular atrophy has been reported in experimental animals following exposure to high levels of TNT.

Approximately 60 to 75% of the dose is absorbed following oral administration of TNT to rats. Studies of humans indicate that nitroaromatic compounds are absorbed following inhalation and ingestion and that these compounds are capable of penetrating the skin.

1,3,5-Trinitrobenzene. Acute and chronic exposures to 1,3,5-trinitrobenzene induce anemia and cyanosis. Other adverse effects induced by chronic exposure include

toxicity of the liver, kidney, and nervous system. The compound 1,3,5-trinitrobenzene is absorbed following inhalation and ingestion, and it is capable of penetrating the skin.

5.2.2 Metals

Arsenic. Arsenic is a naturally occurring metalloid that occurs ubiquitously in the environment. It can be present in a number of different valence states and as a constituent of both organic and inorganic compounds. In the United States, arsenic is primarily used in pesticides.

Following ingestion of inorganic arsenic, the principal acute effect in humans is severe irritation of the gastrointestinal tract. Chronic oral exposure may lead to anemia, peripheral neuropathy, hepatotoxicity, nephrotoxicity, cardiotoxicity, and skin disorders characterized by hyperpigmentation and hyperkeratosis. Chronic oral exposure is also associated with an increased risk of skin cancer. Inhalation of dusts or aerosols containing inorganic arsenic is associated with an increased risk of lung cancer. Arsenic and arsenic compounds have been classified by the EPA as Group A human carcinogens. Dermal contact with arsenic compounds may produce severe skin irritation but is not usually associated with any systemic effects.

Absorption of arsenic depends on the chemical form of the compound. In general, inorganic arsenic compounds are well absorbed following exposure by inhalation or ingestion. Insufficient information exists to evaluate dermal absorption.

Lead. Lead is a naturally occurring metal that occurs ubiquitously in the environment. It is used in the manufacture of a large number of products, including storage batteries, paints, ammunition, solder, pipes, and various chemicals.

The toxic effects resulting from the ingestion or inhalation of lead are independent of the route of exposure but are correlated with internal levels, usually measured as blood lead levels. Exposure to high levels of lead may result in encephalopathy, gastrointestinal disturbances, anemia, and nephropathy. The nervous system is the critical target of chronic exposure to low concentrations. Fetuses and preschool-age children are particularly sensitive to the effects of lead. Exposure of pregnant women may result in reproductive effects, including reduced birth weight and learning disabilities in the child. Learning disabilities and growth retardation have been observed in children in the absence of other overt signs of lead toxicity. Although inorganic lead compounds have been shown to induce cancer in experimental animals, the data are inadequate to evaluate the possible carcinogenicity of lead to humans.

Lead is well absorbed following exposure by ingestion or inhalation; dermal absorption is significantly less. Absorption from the gastrointestinal tract is estimated to be 10 to 15% in adults and 30 to 50% in children. Lead accumulates in the body, primarily in the bone.

Nickel. Nickel is a naturally occurring metal that is found in small quantities in the crust of the earth. It is used primarily in making various steels and alloys and in electroplating.

In humans, the inhalation of aerosols or dusts of metallic nickel and certain nickel compounds is associated with increased incidence of cancers of the lung and nasal cavity. Nickel and nickel compounds have been classified by the EPA as Group A human carcinogens. Respiratory disorders, including bronchitis and asthma, have been observed among workers exposed to nickel dusts and aerosols. There is no evidence that nickel is carcinogenic when ingested. Nickel salts can induce allergic contact dermatitis. Studies in experimental animals indicate that exposure to high levels of some nickel compounds induces adverse effects on reproduction, including miscarriages and low birth weights in newborns.

Absorption of nickel from the pulmonary tract is a function of the chemical and physical form of the compound. Particulate nickel is absorbed to a limited degree, with absorption rates greater for smaller particles. Following ingestion, about 1 to 10% of the dose is absorbed in man and in experimental animals.

Selenium. Selenium is a naturally occurring element that occurs in fairly high concentrations in many soils in the United States and worldwide. It can be present in a number of different valence states. Selenium is used in the manufacture of many products, including electronic devices, pigments, dyes, and insecticides.

Selenium is an essential trace element for many species, including humans, but is toxic in amounts only slightly above the required levels. Symptoms of chronic toxicity in humans include dermatitis, partial loss of hair and nails, effects on the central nervous system, and gastrointestinal disturbances. Direct contact with selenium compounds may induce eye and skin irritations. There is no evidence that selenium is carcinogenic to humans. Studies in animals demonstrate that high doses of selenium are teratogenic and induce other adverse reproductive effects.

The gastrointestinal absorption of selenium metal is negligible, although limited data in humans indicate that absorption of the selenite form ranges from 40 to 70%; in rats, gastrointestinal absorption is greater than 95%. Limited data for humans also indicate that selenium is absorbed following inhalation.

Uranium. Uranium is a heavy metal that occurs ubiquitously in the crust of the earth. Natural uranium consists of three isotopes -- uranium-238, uranium-235, and uranium-234 -- in the relative abundance of 99.27, 0.72, and 0.006% by weight, respectively. Two main hazards are associated with uranium compounds: kidney damage caused by the chemical toxicity of soluble uranium compounds and cell damage caused by the ionizing radiation resulting from the radioactive decay of uranium isotopes. Which of these will be the limiting factor for exposure depends on a number of factors, including the solubility of the compound, the route of exposure, and the relative isotopic composition. The kidney is the main target organ for the chemical toxicity of uranium in

both humans and experimental animals. Uranium also affects the blood vascular system and liver and muscle tissue.

The absorption and metabolism of uranium depend on its chemical form and solubility in the body. Soluble compounds are highly transportable from the lung to other parts of the body whereas insoluble uranium compounds may remain in the lungs and tracheobronchial lymph nodes for years. Absorption from the intestinal tract varies with the solubility of the uranium salt; however, even with soluble compounds, less than 5% of the intake is absorbed.

5.2.3 Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) have been used widely in the United States as coolants and lubricants in transformers, capacitors, and electrical equipment. As a group, PCBs have been shown to induce cancer of the liver in experimental animals and are classified by the EPA as Group B2 probable human carcinogens. In experimental animals, chronic exposure to PCBs has induced effects such as severe weight loss, liver damage, toxicity to the immune system, adverse reproductive effects, and malformations in offspring. In humans exposed to these compounds, the skin and liver are the primary sites affected, but the gastrointestinal and neuromuscular systems can also be affected. The only significant adverse health effects that have been observed in PCB-exposed workers are occasional skin irritations, usually acne-like lesions and rashes, and liver damage. Following oral exposure, gastrointestinal absorption of most isomers is greater that 90%; limited data indicate that PCBs can also be absorbed following exposure by inhalation or dermal contact.

5.2.4 Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAHs) are a diverse class of compounds formed as a result of the incomplete combustion of organic materials. Of the PAHs identified at the Weldon Spring quarry, benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, dibenz(a,h)anthracene, and chrysene are classified by the EPA as Group B2 probable human carcinogens; and indeno(1,2,3-cd)pyrene is classified as a Group C possible human carcinogen. The International Agency for Research on Cancer (1983) has determined that benzo(k)fluoranthene is carcinogenic to experimental animals. Most of the available data are for benzo(a)pyrene, which has been shown to induce skin, lung, and stomach tumors in experimental animals. Toxic effects of PAHs include skin disorders, immunosuppression, and liver and kidney damage in experimental animals. As a class, PAHs are highly lipid-soluble and are expected to be readily absorbed through the gastrointestinal tract and via the respiratory system.

6 HEALTH RISK EVALUATION

Radiological and chemical health risks could result from exposure to the quarry contaminants under current conditions; for clarity of presentation, the evaluation of these risks is discussed separately in Sections 6.1 and 6.2, respectively. The potential effects to hypothetical individuals resulting from radiation exposure were evaluated in terms of the increased likelihood of inducing fatal cancers and serious genetic effects in future generations. The potential for adverse health effects resulting from exposure to chemical contaminants was assessed by comparing the average daily exposure estimates (intakes) to established reference doses. Potential carcinogenic risks resulting from these exposures were also assessed. Details of the exposure assessment are described in Section 4.5 of this document.

6.1 RADIOLOGICAL RISKS

The estimated radiation doses and resultant health risks for the passerby and trespasser scenarios are summarized in Tables 6.1 and 6.2, respectively. The lifetime risks range from 4.2×10^{-6} for the passerby representative exposure case to 8.7×10^{-5} for the trespasser plausible maximum exposure case. The major exposure pathway in all cases is inhalation of radon-222 and its short-lived decay products. For purposes of comparison, the dose from background radiation is about 300 mrem/yr -- which corresponds to an annual risk of about 5×10^{-5}/yr for the induction of fatal cancers and serious genetic effects in the first two generations following radiation exposure.

The estimated doses for inhalation of radon decay products (Tables 6.1 and 6.2) are not true doses; rather, they are exposures expressed in the unit of WLM (see Section 4.5.1). The WLM unit is used because the risk of inhalation of radon decay products is typically expressed in this unit. The recently issued BEIR IV study (National Research Council 1988) examined the health risks associated with inhalation of radon-222 decay products. A cancer risk factor of 3.5×10^{-4}/WLM is recommended by the BEIR IV study, and this was the risk factor used in this baseline risk evaluation for the quarry bulk wastes. Although the BEIR IV study did not address the health risks associated with inhalation of radon-220 decay products, the ICRP has estimated that the risk from inhalation of radon-220 decay products is about one-third of the risk from inhalation of radon-222 decay products (ICRP 1981). Therefore, a risk estimator of 1.2×10^{-4}/WLM was used in this evaluation for the inhalation of radon-220 decay products. A summary of cancer risk estimates from various organizations for exposure to radon-222 decay products is presented in Table 6.3.

The estimated radiation doses from ingestion of contaminated soil (Table 6.2) are 50-year committed effective dose equivalents, which have been estimated using the methodology developed by the ICRP (1977, 1979-1982). The estimated doses from external gamma exposure (Tables 6.1 and 6.2) were based on the assumption of uniform irradiation of the entire body. The health risks resulting from these exposures were estimated by multiplying the doses by the risk estimator of 1.65×10^{-7}/mrem (ICRP

TABLE 6.1 Estimated Radiation Risks for the Passerby Scenario

	Representative Exposure Case		
Exposure Pathway	Dose	Risk Factor	Risk
Radon-222 inhalation	7.0×10^{-3} WLM	3.5×10^{-4}/WLM	2.5×10^{-6}
Radon-220 inhalation	2.4×10^{-3} WLM	1.2×10^{-4}/WLM	2.9×10^{-7}
External gamma	8.5 mrem	1.65×10^{-7}/mrem	1.4×10^{-6}
Total risk			4.2×10^{-6}

	Plausible Maximum Exposure Case		
Exposure Pathway	Dose	Risk Factor	Risk
Radon-222 inhalation	2.1×10^{-2} WLM	3.5×10^{-4}/WLM	7.4×10^{-6}
Radon-220 inhalation	6.9×10^{-3} WLM	1.2×10^{-4}/WLM	8.3×10^{-7}
External gamma	25 mrem	1.65×10^{-7}/mrem	4.1×10^{-6}
Total risk			1.2×10^{-5}

1977) for the induction of fatal cancers and serious genetic effects in the first two generations following radiation exposure.

The most significant potential risk associated with exposure to the radioactive contaminants in the quarry bulk wastes is the induction of cancer, largely resulting from inhalation of radon-222 and its short-lived decay products; the probability of genetic effects is low relative to that of cancer induction. For the quarry bulk wastes, the risk of a fatal cancer is estimated to be less than 1×10^{-4} for all cases. Because access to the quarry is controlled and the perimeter is fenced, prolonged exposure to the quarry bulk wastes is not likely. Thus, under current land-use conditions, the bulk wastes in the quarry do not present an unacceptable short-term risk to human health as a result of radiation exposure.

The radiological risks presented in this baseline risk evaluation include the contributions from background sources of radiation. Inclusion of background values in the risk estimates results in overestimating the hazard attributable to the quarry bulk wastes. This effect is much more pronounced for the passerby scenario than for the trespasser scenario, largely due to the external gamma exposure pathway. The risk associated with external gamma exposure for the passerby scenario was based on an external gamma exposure rate of 18 μR/h, of which 9.7 μR/h can be attributed to background sources (see Section 4.5). Hence, inclusion of background gamma exposure for the passerby scenario results in a risk estimate that is approximately twofold higher

TABLE 6.2 Estimated Radiation Risks for the Trespasser Scenario

Exposure Pathway	Representative Exposure Case		
	Dose	Risk Factor	Risk
Radon-222 inhalation	9.0×10^{-3} WLM	3.5×10^{-4}/WLM	3.2×10^{-6}
Radon-220 inhalation	3.1×10^{-3} WLM	1.2×10^{-4}/WLM	3.7×10^{-7}
External gamma	7.0 mrem	1.65×10^{-7}/mrem	1.2×10^{-6}
Soil ingestion	7.0 mrem	1.65×10^{-7}/mrem	1.2×10^{-6}
Total risk			6.0×10^{-6}

Exposure Pathway	Plausible Maximum Exposure Case		
	Dose	Risk Factor	Risk
Radon-222 inhalation	1.5×10^{-1} WLM	3.5×10^{-4}/WLM	5.3×10^{-5}
Radon-220 inhalation	5.1×10^{-2} WLM	1.2×10^{-4}/WLM	6.1×10^{-6}
External gamma	110 mrem	1.65×10^{-7}/mrem	1.8×10^{-5}
Soil ingestion	59 mrem	1.65×10^{-7}/mrem	9.7×10^{-6}
Total risk			8.7×10^{-5}

TABLE 6.3 Estimated Risk of Lung Cancer Mortality from Exposure to Radon-222 Decay Products

Study	Estimated Risk of Fatal Lung Cancer[a] (no./WLM)
National Council on Radiation Protection and Measurements (1984)	1.3×10^{-4}
National Research Council (1980) -- BEIR III study	7.3×10^{-4}
National Research Council (1988) -- BEIR IV study	3.5×10^{-4}
United Nations Scientific Committee on the Effects of Atomic Radiation (1977)	2.0×10^{-4} to 4.5×10^{-4}

[a]Source: Data from National Research Council (1988).

than if background sources were excluded. However, this pathway contributes only about one-third of the total risk for this scenario (see Table 6.1), which minimizes the overall significance of the background contribution. By comparison, the risk from external gamma exposure for the trespasser scenario was based on an exposure rate of 60 μR/h, which is much larger than the background value of 9.7 μR/h.

The effect of including the contributions from background sources will be much less for radon than external gamma for both scenarios because the background radon concentration is about 0.3 pCi/L in the Weldon Spring area whereas measured radon concentrations, both within the quarry and at the upper gate in the northeastern corner of the quarry, are much larger (see Section 4.5). The same is true for the soil ingestion pathway for the trespasser scenario in that surficial soil concentrations for the indicator radionuclides are much greater than background soil concentrations. Hence, inclusion of background sources of radiation for these two pathways has a very small impact on the estimated risks.

Overall, including background sources of radiation in the passerby scenario results in a risk estimate that is about 20 to 30% higher than the risk estimate resulting from the quarry bulk wastes alone. The impact for the trespasser scenario is much lower, i.e., less than 5%. In both cases, this impact is well within the uncertainty associated with this evaluation.

6.2 CHEMICAL RISKS

6.2.1 Carcinogenic Risks

The potential risk resulting from exposure to chemical carcinogens is expressed as the increased probability of a cancer occurring in an individual over the course of a lifetime. To calculate the excess cancer risk, the daily intake averaged over a lifetime is multiplied by a chemical-specific carcinogenic potency factor (q_1*). The potency factors for a number of carcinogens have been derived by the EPA and represent the lifetime cancer risk per milligram of carcinogen per kilogram body weight, assuming that the exposure occurs over a lifetime of 70 years.

A potency factor is specific to the chemical and the route of exposure (i.e., inhalation or ingestion; potency factors have not been derived for the dermal route). With regard to the trespasser scenario, the potential exists for oral exposure (through incidental ingestion of contaminated soils) to all of the carcinogenic indicator chemicals (i.e., 2,4,6-TNT, 2,4-DNT, 2,6-DNT, PAHs, PCBs, arsenic, and lead). With the exception of lead, oral potency factors are available for these contaminants. For the passerby and trespasser scenarios, the potential exists for inhalation exposure to the carcinogenic nitroaromatic contaminants, i.e., 2,4,6-TNT, 2,4-DNT, and 2,6-DNT; however, inhalation potency factors are not available for these compounds. Therefore, in the absence of inhalation potency factors, oral potency factors were used in this evaluation to estimate the risks associated with the inhalation pathway. According to EPA guidance (EPA 1986b), the extrapolation of potency factors from one route of exposure to another may be appropriate if supporting data are available. Although experimental data are limited,

comparative studies of toxic effects, pharmacokinetics, and metabolism of the nitroaromatic compounds indicate that following both oral and inhalation exposures, these compounds induce similar toxic responses, are well absorbed, and are subject to similar metabolic pathways (see Table 5.1 for references). Thus, subject to some uncertainty, the application of these potency factors allows a quantitative estimate of the potential risks associated with the inhalation pathway. Risks associated with the dermal pathway were quantified using the oral potency factors. However, these estimates are not shown in the summary tables due to the high uncertainty associated with these values, resulting from both the uncertainty in the dose estimates (see Section 4.5.2) and the lack of experimental data supporting the use of oral carcinogenic potency factors for dermal exposures. The estimated risks associated with dermal exposure are presented in the text, providing a crude estimate of the potential risks associated with this pathway.

For each carcinogenic indicator chemical in the quarry bulk wastes, a route-specific risk was calculated, and these values were then summed to estimate the total risk from exposure to that chemical. Finally, the total carcinogenic risk from exposure to all indicator carcinogens was estimated by summing the risks for the individual chemicals.

Passerby Scenario. For the passerby scenario, the only potential route of exposure to chemical carcinogens present at the quarry is inhalation of airborne dusts contaminated with 2,4,6-TNT, 2,4-DNT, and 2,6-DNT. Although other chemical carcinogens are present at the quarry (PAHs, PCBs, arsenic, lead, and nickel), they do not occur in areas subject to fugitive dust generation and exposure to these compounds is not expected. The estimated average daily intakes of the carcinogenic indicator chemicals, their potency factors, and the estimated risks are summarized in Table 6.4. The total carcinogenic risk for the passerby scenario is estimated to be 1.0×10^{-9} for the representative exposure case and 3.0×10^{-9} for the plausible maximum exposure case.

Trespasser Scenario. For the trespasser scenario, the potential routes of exposure to the chemical carcinogens present at the quarry are (1) inhalation of dusts contaminated with 2,4,6-TNT, 2,4-DNT, and 2,6-DNT and (2) direct contact with surficially contaminated soils, resulting in incidental ingestion and/or dermal absorption. The carcinogenic indicator chemicals present in these soils are 2,4,6-TNT, 2,4-DNT, 2,6-DNT, PAHs, PCBs, arsenic, lead, and nickel. (Although considered to be carcinogenic through the inhalation pathway, nickel is not considered to be carcinogenic through the ingestion pathway.) The estimated average daily intakes of these compounds, their carcinogenic potency factors, and the estimated risks are summarized in Table 6.5. The total carcinogenic risk for the trespasser scenario is estimated to be 4.3×10^{-6} for the representative exposure case and 3.6×10^{-5} for the plausible maximum exposure case. The estimated doses are more than 1,000-fold greater for the ingestion pathway than for the inhalation pathway; hence, use of the oral potency factors does not significantly affect the total risk estimates for these compounds. The estimated risks to the trespasser from the dermal route are 6.8×10^{-7} for the representative exposure case and 3.4×10^{-5} for the plausible maximum exposure case. If dermal exposure is added to the risks shown in Table 6.5, the total carcinogenic risks to the trespasser are estimated

TABLE 6.4 Estimated Carcinogenic Risk from Inhalation Exposure to Potential Chemical Carcinogens: Passerby Scenario

	Representative Exposure Case		
Contaminant	Average Daily Intake[a] (mg/kg-d)	Carcinogenic Potency Factor[b] ($[mg/kg\text{-}d]^{-1}$)	Risk
2,4,6-TNT	3.4×10^{-8}	3.0×10^{-2}	1.0×10^{-9}
2,4-DNT and 2,6-DNT	6.0×10^{-11}	6.8×10^{-1}	4.1×10^{-11}
Total risk			1.0×10^{-9}

	Plausible Maximum Exposure Case		
Contaminant	Average Daily Intake[a] (mg/kg-d)	Carcinogenic Potency Factor[b] ($[mg/kg\text{-}d]^{-1}$)	Risk
2,4,6-TNT	9.8×10^{-8}	3.0×10^{-2}	2.9×10^{-9}
2,4-DNT and 2,6-DNT	1.8×10^{-10}	6.8×10^{-1}	1.2×10^{-10}
Total risk			3.0×10^{-9}

[a]Daily intake averaged over lifetime exposure (from Table 4.6).

[b]Oral potency factor; potency factor for inhalation route not available. Sources: 2,4,6-TNT, EPA (1989c); 2,4-DNT and 2,6-DNT, EPA (1989b).

to be 5.0×10^{-6} and 7.0×10^{-5} for the two exposure cases compared with 4.3×10^{-6} and 3.6×10^{-5}, respectively, excluding dermal exposure.

Summary. The estimated carcinogenic risks for the passerby scenario range from 1.0×10^{-9} to 3.0×10^{-9} for the representative and plausible maximum exposure cases, respectively. Based on these very low risks, no adverse effects to the general public would result from exposures to site releases of chemical carcinogens outside the quarry fence. The estimated carcinogenic risks for the trespasser scenario range from 4.3×10^{-6} to 7.0×10^{-5}. The highest risk is for the plausible maximum exposure case and includes the risk from all three exposure routes, i.e., inhalation, ingestion, and dermal contact. Carcinogenic risks to the trespasser fall within the target risk range of 1×10^{-4} to 1×10^{-7} defined by the EPA. Although possible, it is unlikely that under current land-use conditions, any individual would actually enter the quarry as frequently as assumed

TABLE 6.5 Estimated Carcinogenic Risk from Exposure to Potential Chemical Carcinogens: Trespasser Scenario

Contaminant	Exposure Route	Representative Exposure Case: Average Daily Intake[a] (mg/kg-d)	Carcinogenic Potency Factor[b] ($[mg/kg\text{-}d]^{-1}$)	Route-Specific Risk	Total Chemical-Specific Risk
2,4,6-TNT	Inhalation	1.1×10^{-8}	-	3.3×10^{-10}	
	Dermal	1.2×10^{-5}	-	NQ[c]	
	Oral	6.1×10^{-5}	3.0×10^{-2}	1.8×10^{-6}	1.8×10^{-6}
2,4-DNT and 2,6-DNT	Inhalation	2.0×10^{-11}	-	1.4×10^{-11}	
	Dermal	2.1×10^{-8}	-	NQ	
	Oral	1.1×10^{-7}	6.8×10^{-1}	7.5×10^{-8}	7.5×10^{-8}
PAHs (carcinogens)	Dermal	1.1×10^{-8}	-	NQ	
	Oral	5.6×10^{-8}	1.15×10^{1}	6.4×10^{-7}	6.4×10^{-7}
PCBs	Dermal	2.4×10^{-8}	-	NQ	
	Oral	1.2×10^{-7}	7.7	9.2×10^{-7}	9.2×10^{-7}
Arsenic	Oral	4.7×10^{-7}	1.75	8.2×10^{-7}	8.2×10^{-7}
Total risk					4.3×10^{-6}

TABLE 6.5 (Cont'd)

Contaminant	Exposure Route	Plausible Maximum Exposure Case: Average Daily Intake[a] (mg/kg-d)	Carcinogenic Potency Factor[b] ($[mg/kg\text{-}d]^{-1}$)	Route-Specific Risk	Total Chemical-Specific Risk
2,4,6-TNT	Inhalation	1.9×10^{-7}	-	5.7×10^{-9}	
	Dermal	6.0×10^{-4}	-	NQ	
	Oral	5.1×10^{-4}	3.0×10^{-2}	1.5×10^{-5}	1.5×10^{-5}
2,4-DNT and 2,6-DNT	Inhalation	3.4×10^{-10}	-	2.3×10^{-10}	
	Dermal	1.1×10^{-6}	-	NQ	
	Oral	9.0×10^{-7}	6.8×10^{-1}	6.1×10^{-7}	6.1×10^{-7}
PAHs (carcinogens)	Dermal	5.5×10^{-7}	-	NQ	
	Oral	4.7×10^{-7}	1.15×10^{1}	5.4×10^{-6}	5.4×10^{-6}
PCBs	Dermal	1.2×10^{-6}	-	NQ	
	Oral	1.0×10^{-6}	7.7	7.7×10^{-6}	7.7×10^{-6}
Arsenic	Oral	3.9×10^{-6}	1.75	6.8×10^{-6}	6.8×10^{-6}
Total risk					3.6×10^{-5}

[a]Daily intake averaged over lifetime exposure (from Tables 4.8, 4.9, and 4.10).

[b]A hyphen indicates that a carcinogenic potency factor specific to this route of exposure is not available. The oral potency factor was used to calculate risk for the inhalation pathway; sources: 2,4,6-TNT and PCBs, EPA (1989c); 2,4-DNT and 2,6-DNT, EPA (1989b); PAHs, EPA (1986c); arsenic, derived from the unit risk value of 5.0×10^{-5} µg/L, EPA (1989c).

[c]NQ = not quantified. Risk from dermal intake was not quantified due to lack of accepted methodology (see discussion in Section 6.2.1).

for the trespasser scenario. From this assessment, it can be concluded that in the near term and under current conditions, the bulk wastes in the quarry do not present an unacceptable carcinogenic risk to human health from chemical exposure.

6.2.2 Noncarcinogenic Risks

The potential for adverse health effects resulting from exposure to chemical contaminants is assessed by comparing exposure estimates (intakes) to EPA-established reference doses; a reference dose is the average daily dose that can be incurred without likely adverse health effects, assuming chronic exposure to a compound. A reference dose is specific to the chemical and the route of exposure (i.e., inhalation, ingestion, or dermal contact). As in the case of carcinogenic potency factors, reference doses are available only for the oral route of exposure for the indicator chemicals and routes of exposure considered for the quarry bulk wastes. Reference doses are available for all of the noncarcinogenic indicator chemicals at the quarry as well as for some of the carcinogenic indicator chemicals. (Chemical carcinogens induce other toxic -- i.e., noncarcinogenic -- effects, and reference doses based on these noncarcinogenic effects have been established for some carcinogens.) Potential risks from exposure to a compound are assessed by dividing the estimated intake by the reference dose to derive the "hazard index" for the compound. The individual hazard indexes are then summed to obtain an overall hazard index for an exposure scenario. If the hazard index for any individual compound or scenario is greater than one, adverse health effects could potentially result. Similar to the approach used for estimating carcinogenic risks, the oral reference doses were applied to the inhalation and dermal exposure routes. The risk estimates for the dermal route are discussed in the text but are not shown in the summary tables.

Passerby Scenario. For the passerby scenario, the only potential route of exposure is inhalation of dusts contaminated with nitroaromatic compounds (2,4,6-TNT, 2,4-DNT, 2,6-DNT, and 1,3,5-trinitrobenzene) and uranium. (Other contaminants present at the quarry do not occur in areas subject to fugitive dust generation.) Of these contaminants, reference doses are available for 2,4,6-TNT, 1,3,5-trinitrobenzene, and uranium. The estimated average daily doses, reference doses, and hazard indexes for these contaminants are given in Table 6.6. The total hazard index is 1.0×10^{-3} for the representative exposure case and 1.6×10^{-3} for the plausible maximum exposure case. These values are considerably below one, indicating a very low potential for adverse health effects for this scenario. Although the lack of reference doses for 2,4-DNT and 2,6-DNT results in an underestimation of the potential for adverse health effects based on the hazard indexes, the daily intakes of these contaminants would result in very low doses and the potential for adverse health effects from exposure to these contaminants would also be low.

Trespasser Scenario. For the trespasser scenario, the potential routes of exposure to the indicator chemicals are inhalation of contaminated dusts and direct contact with surficially contaminated soils, resulting in dermal absorption and/or

TABLE 6.6 Calculated Hazard Indexes for Noncarcinogenic Effects: Passerby Scenario

	Representative Exposure Case		
Contaminant	Average Daily Intake[a] (mg/kg-d)	Oral Reference Dose[b] (mg/kg-d)	Hazard Index[c]
2,4,6-TNT	4.7×10^{-7}	5.0×10^{-4}	9.4×10^{-4}
1,3,5-Trinitrobenzene	5.2×10^{-9}	5.0×10^{-5}	1.0×10^{-4}
Uranium	1.9×10^{-8}	3.0×10^{-3}	6.3×10^{-6}
Total hazard index			1.0×10^{-3}

	Plausible Maximum Exposure Case		
Contaminant	Average Daily Intake[a] (mg/kg-d)	Oral Reference Dose[b] (mg/kg-d)	Hazard Index[c]
2,4,6-TNT	6.9×10^{-7}	5.0×10^{-4}	1.4×10^{-3}
1,3,5-Trinitrobenzene	7.5×10^{-9}	5.0×10^{-5}	1.5×10^{-4}
Uranium	2.7×10^{-8}	3.0×10^{-3}	9.0×10^{-6}
Total hazard index			1.6×10^{-3}

[a]Daily intake averaged over exposure period (from Table 4.6).

[b]The oral reference dose was used to calculate the hazard index for the inhalation pathway (source: EPA 1989c).

[c]The hazard index is the average daily intake divided by the reference dose; a hazard index of less than one is considered to indicate a nonhazardous situation.

incidental ingestion. The contaminants of concern for the inhalation pathway are those considered for the passerby scenario (i.e., nitroaromatic compounds and uranium); however, for the direct contact pathway, there is potential for contact with all indicator chemicals present at the quarry. Reference doses are not available for 2,4-DNT, 2,6-DNT, PAHs, or PCBs. Thus, the potential exposure routes for which a hazard index could be calculated were (1) inhalation of dusts contaminated with 2,4,6-TNT, 1,3,5-trinitrobenzene, and uranium and (2) ingestion of soils contaminated with 2,4,6-TNT, 1,3,5-trinitrobenzene, arsenic, lead, nickel, selenium, and uranium. The estimated average daily doses, reference doses, and hazard indexes for these contaminants are

summarized in Table 6.7. The total hazard index for the trespasser scenario is 2.0 for the representative exposure case and 8.5 for the plausible maximum exposure case.

The lack of reference doses for all contaminants and for estimating hazards associated with dermal exposure results in an underestimation of the potential for adverse health effects based on the hazard indexes. If intake from dermal absorption of the organic indicator chemicals had been included, the total hazard indexes would have been approximately 2.4 and 18, respectively, for the two exposure cases. A hazard index greater than one indicates some potential for adverse health effects. For both the representative and plausible maximum cases, the major contributor to the noncarcinogenic hazard is exposure to 2,4,6-TNT; as shown in Table 6.7, the estimated compound-specific hazard indexes are 1.7 and 7.2, respectively (excluding exposure via the dermal route). This is not an unexpected finding given the presence of this contaminant at concentrations greater than 1% in surface soils at the quarry. In general, exposure to a compound at a level near the reference dose, as for the representative exposure case, would not be expected to result in significant health effects. The reference dose for 2,4,6-TNT was established based on the lowest dose at which detectable effects (trace to mild effects in the liver) were observed in experimental animals, divided by a factor of 1,000 to account for various uncertainties in the data and to ensure that the reference dose would be protective of human health (Gordon and Hartley 1989). However, the results indicate that the potential exists for the occurrence of adverse health effects to an unprotected individual frequently entering the quarry (as for the plausible maximum exposure case) and that access to the quarry should continue to be controlled.

6.3 TOTAL RADIOLOGICAL AND CHEMICAL RISKS

The total lifetime carcinogenic risks and noncarcinogenic hazard indexes for the two exposure scenarios considered in this baseline risk evaluation are presented in Table 6.8. The radiological risks are reported as fatal cancers whereas the chemical risks represent the induction of all cancers. The risk from radiation exposure exceeds that from chemical exposure for both scenarios. However, the chemical carcinogenic risk is a significant contributor to the overall risk for the trespasser scenario. The hazard indexes are based solely on exposure to chemical contaminants. The estimated carcinogenic risks and hazard indexes are based on the 5- and 10-year exposure periods (for the representative and plausible maximum cases, respectively) assumed for this baseline risk evaluation. Under current land-use conditions in which access to the quarry is restricted, the carcinogenic risks associated with potential exposures to the quarry bulk wastes in the near term are low. Noncarcinogenic hazards to individuals outside the quarry are also very low. However, the potential exists for adverse health impacts to unprotected individuals frequently trespassing the quarry. Although it is unlikely that under current site conditions an individual would routinely enter the quarry, the findings of this risk evaluation emphasize the need for strict control of access to the quarry in the near term and for implementation of remedial action to ensure the long-term protection of human health.

TABLE 6.7 Calculated Hazard Indexes for Noncarcinogenic Effects: Trespasser Scenario

Contaminant[a]	Representative Exposure Case: Average Daily Intake (mg/kg-d)	Oral Reference Dose[b] (mg/kg-d)	Hazard Index[c]
2,4,6-TNT[d]	8.5×10^{-4}	5.0×10^{-4}	1.7
1,3,5-Trinitrobenzene[d]	9.2×10^{-6}	5.0×10^{-5}	1.8×10^{-1}
Arsenic[e]	6.6×10^{-6}	1.0×10^{-3}	6.6×10^{-3}
Lead[e]	6.2×10^{-5}	6.0×10^{-4}	1.0×10^{-1}
Nickel[e]	2.0×10^{-5}	2.0×10^{-2}	1.0×10^{-3}
Selenium[e]	1.5×10^{-6}	3.0×10^{-3}	5.0×10^{-4}
Uranium[d]	3.4×10^{-5}	3.0×10^{-3}	1.1×10^{-2}
Total hazard index			2.0

Contaminant[a]	Plausible Maximum Exposure Case: Average Daily Intake (mg/kg-d)	Oral Reference Dose[b] (mg/kg-d)	Hazard Index[c]
2,4,6-TNT[d]	3.6×10^{-3}	5.0×10^{-4}	7.2
1,3,5-Trinitrobenzene[d]	3.8×10^{-5}	5.0×10^{-5}	7.6×10^{-1}
Arsenic[e]	2.7×10^{-5}	1.0×10^{-3}	2.7×10^{-2}
Lead[e]	2.6×10^{-4}	6.0×10^{-4}	4.3×10^{-1}
Nickel[e]	8.2×10^{-5}	2.0×10^{-2}	4.1×10^{-3}
Selenium[e]	6.3×10^{-6}	3.0×10^{-3}	2.1×10^{-3}
Uranium[d]	1.4×10^{-4}	3.0×10^{-3}	4.7×10^{-2}
Total hazard index			8.5

[a]The compounds 2,4-DNT, 2,6-DNT, PCBs, and PAHs are not listed because reference doses are not available. The carcinogenic risks associated with these compounds are given in Table 6.5.

[b]The oral reference dose was used to calculate the hazard index for the oral and inhalation pathways. Sources: 2,4,6-TNT, 1,3,5-trinitrobenzene, and uranium -- EPA (1989c); arsenic, nickel, and selenium -- EPA (1989b); lead, derived from the previously recommended maximum contaminant level of 20 μg/L -- EPA (1989c).

[c]The hazard index is the average daily intake divided by the reference dose; a hazard index of greater than one is considered to indicate a potential for adverse health effects.

[d]Intake from inhalation and ingestion averaged over exposure period (from Tables 4.8 and 4.9).

[e]Intake from ingestion averaged over exposure period (from Table 4.10).

TABLE 6.8 Total Risks and Hazard Indexes for the Passerby and Trespasser Scenarios

Exposure Scenario/Case	Carcinogenic Risk		Health Hazard Index for Noncarcinogenic Effects[c]
	Radiological[a]	Chemical[b]	
Passerby			
Representative	4.2×10^{-6}	1.0×10^{-9}	1.0×10^{-3}
Plausible maximum	1.2×10^{-5}	3.0×10^{-9}	1.6×10^{-3}
Trespasser			
Representative	6.0×10^{-6}	4.3×10^{-6}	2.0
Plausible maximum	8.7×10^{-5}	3.6×10^{-5}	8.5

[a]Risk of a fatal cancer; the rate of cancer induction will be higher.

[b]Rate of cancer induction. The EPA has recommended a range of 1×10^{-4} to 1×10^{-7} as acceptable for exposure to carcinogenic chemicals.

[c]A hazard index of less than one is considered to indicate a nonhazardous situation; a hazard index of greater than one is considered to indicate a potential for adverse health effects.

6.4 DISCUSSION

The evaluation of risks to human health presented in this baseline risk evaluation was, by necessity, based on a number of assumptions. In addition, many uncertainties are inherent to the risk assessment process. Sections 6.4.1 through 6.4.4 provide additional discussion of the rationale for the major assumptions used in this evaluation and for their impact on the results contained herein. Some of the more important sources of uncertainty are also identified.

6.4.1 Site Characterization Data

The currently available site characterization data are limited with regard to both the nature and extent of contamination and the pathways and mechanisms for contaminant migration at the quarry. Also, the nature of the bulk wastes makes additional characterization difficult (see Sections 1.3 and 3.1). Hence, this baseline risk evaluation

was based on historical characterization data. These data are considered to be sufficient for a quantitative assessment of the risks associated with the quarry bulk wastes in the near term.

The chemical and radioactive contaminants in the bulk wastes are highly non-homogeneous. However, for the selection of indicator contaminants and the determination of exposure point concentrations, the risks posed by these contaminants were estimated using the average contaminant concentrations in samples above detection limits (see Sections 3.2.1 and 4.3). This method was considered to result in the best estimates of the actual concentrations of contaminants in the bulk wastes. As available, monitoring data were used to minimize the need to model environmental transport processes. When environmental transport modeling was used, conservative approaches were developed to ensure that the actual concentrations in the environment would be less than those determined in this evaluation.

6.4.2 Selection and Use of Indicator Contaminants

The baseline risk evaluation considers a subset of the radioactive and chemical contaminants present at the quarry. Although the indicator contaminant selection process is designed to identify those contaminants that pose the greatest threat to human health, some uncertainty is inherent in this process and it is recognized that risk estimates would be higher if all compounds were included. However, with the exception of VOCs (see Section 3.2.2), the indicator contaminant selection process for the quarry was straightforward. In selecting the radionuclides for evaluation, all radionuclides in each of the uranium-238 and thorium-232 decay series were considered. The chemical contaminants selected for evaluation represent the major chemical classes present at the quarry (nitroaromatic compounds, PAHs, PCBs, and metals) and the most toxic or carcinogenic species within each class. Hence, those compounds not evaluated in this risk evaluation would not be expected to contribute significantly to the risk estimates.

6.4.3 Exposure Scenarios

Conservatism was built into this risk evaluation largely through the parameters used to define the exposure scenarios. For the passerby scenario and, in particular, for the trespasser scenario, it is unlikely that an individual would either walk by or enter the quarry as frequently as assumed for these scenarios. Conservative assumptions were used to estimate the risks to the passerby, i.e., no credit was taken for reduction in the gamma exposure rate or chemical concentrations with distance from the quarry, and the effects of atmospheric dispersion of radon gas were assumed to be offset by decay product ingrowth. Both assumptions result in overestimating the risk to a passerby. In addition, the doses from background sources of radiation were included in these dose estimates. For the trespasser scenario, no correction to the intake and risk estimates for the nitroaromatic compounds was made to account for the fact that these compounds are present in surface soils in only a small area of the quarry. Although the actual area within the quarry where an individual would spend the most time cannot be predicted, it is unlikely that the entire time would be spent in this one highly contaminated area. A

more reasonable estimate would be that an individual would be in contact with this area of the quarry approximately 10% of the time. This would indicate that the risk estimates and hazard indexes reported in Tables 6.5 and 6.7 for the nitroaromatic compounds are approximately tenfold too high.

6.4.4 Reference Doses and Carcinogenic Potency Factors

Reference doses and carcinogenic potency factors were used to estimate the potential noncarcinogenic and carcinogenic health effects from exposure to chemical contaminants at the quarry (see Section 6.2). Because these toxicity values are generally based on animal studies, extrapolation of the data to humans is a source of uncertainty. In extrapolating, the doses are divided by factors of 10 (usually 100 to 1,000) to account for the various uncertainties in the data and to ensure that the reference doses are protective of human health. The carcinogenic potency factors for estimating carcinogenic risks are derived using very conservative models; these factors are the upper 95% confidence limit on the probability of response. Thus, the values used to estimate the hazard indexes and carcinogenic risks are considered to be very protective.

The risk estimates for 2,4-DNT and 2,6-DNT were estimated based on a potency factor derived for mixtures of these compounds. However, because the relative concentrations of these isomers in the experimental studies used to derive the potency factor are not the same as the concentrations in the environmental media at the quarry, there is some uncertainty in the risk estimates for these compounds. Recent data indicate that 2,6-DNT is more potent than 2,4-DNT, suggesting that the potency factor may underestimate the risks associated with the mixtures of these compounds at the quarry. Also, the use of oral carcinogenic potency factors to estimate risks associated with the inhalation pathway introduces additional uncertainty into the risk estimates.

Radiation doses were converted to health risks using risk estimators of the ICRP (for exposure to external gamma radiation and incidental ingestion of soil) and the BEIR IV study (for inhalation of radon decay products). These risk estimators are generally accepted by the scientific community as providing realistic estimates of the potential health risks associated with radiation exposure. The health risks associated with the inhalation of radon decay products were evaluated separately from other exposure modes to take advantage of the data provided in the recently completed BEIR IV study. Although some uncertainty in the true risks is associated with radiation exposure, this uncertainty is much less than that associated with most other carcinogens.

6.4.5 Summary

By necessity, some of the procedures used and uncertainties inherent in the baseline risk evaluation process tend to underestimate potential risks. These include the use of indicator contaminants to represent all site contaminants, as well as the lack of appropriate methodology and toxicity constants to quantify risks for all indicator contaminants and routes of exposure. However, most of the assumptions built into this risk evaluation tend to overestimate potential risks — including conservative assumptions for the exposure scenarios (e.g., the number of times the trespasser would enter the

quarry), the uncertainty factors used to derive reference doses protective of human health, and the conservative models used to derive the carcinogenic potency factors. These procedures should ensure that the risks estimated in this evaluation are realistic, but conservative, estimates of the near-term risks posed by these materials under current site conditions. The results presented in this baseline risk evaluation should not be taken to represent absolute risk. Rather, they should be considered to represent the most important sources of potential risk at the quarry, which -- once identified -- may be dealt with effectively in the remedial action process.

7 ENVIRONMENTAL ASSESSMENT

This baseline risk evaluation includes assessment of potential risks to the environment from the quarry bulk wastes in addition to assessment of potential risks to human health. Potential health risks are discussed in Chapter 6. The environmental impacts that could result from leaving the bulk wastes in the quarry are addressed in Sections 7.1 through 7.4 in terms of water resources, soil resources, air quality, and vegetation and wildlife. This assessment was prepared prior to issuance of the recent EPA guidance document on performance of environmental risk assessments at NPL sites (EPA 1989d). Consistent with the scope of the human health evaluation, the environmental assessment was addressed qualitatively because comprehensive environmental data are not available. Additional information on the environmental setting and ecological resources at the quarry will be given in the FS report.

7.1 WATER RESOURCES

The bulk wastes in the quarry are not expected to result in any additional, direct adverse impacts to local surface water. Essentially all surface runoff at the quarry -- e.g., from precipitation and snowmelt -- is collected in the quarry pond. This pond has already been contaminated as a result of contact with the bulk wastes. Thus, incremental contamination from future surface runoff is not expected to significantly alter the existing water quality. Under a currently proposed response action at the quarry, the pond water and all water entering the quarry would be pumped, treated, and released off-site (MacDonell et al. 1989). Thus, no surface water would remain in the quarry if this action were implemented. Femme Osage Slough, to the south of the quarry, already contains radioactive contamination. This contamination may be the result of subsurface migration of uranium from north of the slough and/or of past pumping tests at the quarry pond (during the pumping tests, water from the pond was discharged directly into Little Femme Osage Creek, which then flowed into Femme Osage Creek and discharged into the Missouri River through what is now Femme Osage Slough).

Groundwater in the vicinity of the quarry has already been contaminated as a result of contaminant migration (MK-Ferguson Company and Jacobs Engineering Group 1989b). If the bulk wastes remain in the quarry, contaminants could progress farther into the surrounding environment via the fractured limestone of the Kimmswick Formation. Contaminant concentrations may increase in the vicinity of Femme Osage Slough. Studies reported by MK-Ferguson Company and Jacobs Engineering Group (1989b) indicate that the clay and silty alluvium at the slough may act as a groundwater barrier. Although there is currently no indication that groundwater flows through the alluvial material below the slough to the alluvial aquifer, groundwater may flow underneath the clay and silty material through fractured bedrock and contamination may ultimately reach the vicinity of the St. Charles County well field.

7.2 SOIL RESOURCES

No additional adverse impacts to soils within the quarry are expected to result from the continued presence of the bulk wastes because these soils have already been disturbed and contaminated as a result of past waste disposal activities. However, soils in the vicinity of the quarry could be adversely affected if the wastes remain in the quarry. Although the air and surface water pathways of contaminant release are not expected to be significant, the groundwater pathway may play an important role in the contamination of local soils.

The amount of exposed soil in the quarry is very small because most of the surface is either covered with vegetation or under water. Thus, the potential for wind resuspension and dispersal of contaminated soil is not expected to be significant. In addition, most of the surface runoff is retained within the quarry so the potential for surface water resuspension and dispersal of contaminants is also expected to be low. No significant impacts to nearby agricultural soils are expected to occur because the land immediately surrounding the quarry is primarily uncultivated wildlife area. However, the results of characterization studies have indicated that contaminants have migrated from the quarry into the local alluvium (Marutzky et al. 1988); continued migration could impact agricultural areas south of the quarry sometime in the future. Hence, if the bulk wastes remain in the quarry, contaminant migration into vicinity soils is expected to continue.

In summary, the presence of the bulk wastes in the quarry is not expected to result in significant adverse impacts to soil resources within the quarry. However, the migration of contaminants via groundwater into soils in the vicinity of the quarry is expected to continue and could increase over time.

7.3 AIR QUALITY

Areas of exposed soil in the quarry are limited, so the potential for particulate resuspension is low. In addition, no resuspension is expected to occur from other than natural forces because no activities are ongoing at the quarry. Thus, the potential for adverse impacts to air quality resulting from the quarry bulk wastes is negligible. The major impact that could result from gaseous releases, i.e., of radon, is addressed in the health assessment portion of this baseline risk evaluation (see Section 6.1).

7.4 VEGETATION AND WILDLIFE

Potential impacts to local vegetation and wildlife from exposure to the quarry bulk wastes are difficult to quantify because only limited relevant environmental data are available. The biotic uptake and ultimate impact of a contaminant are influenced by a variety of environmental and receptor-specific factors. These factors include the physical and chemical characteristics of the contaminant and of the medium in which it exists (e.g., soil or water); the mechanisms and pathways of contaminant release; the species, size, and age of the biotic receptor; the nature of the interactions (e.g., competition) between the receptor and other individuals or species; the method of nutrient

intake and the respiration/transpiration rates of the receptor; and the specific mechanisms of contaminant intake, internal transport, and assimilation. Because of the lack of a comprehensive data base regarding these factors, the following assessment of potential adverse impacts to plants and animals from exposure to current quarry contamination is qualitative.

In the absence of any remedial action, exposure of biota at the quarry area to site-associated contaminants would continue. If, in the future, the contamination were to spread to a larger area -- through leaching, biouptake, and/or ingestion -- the exposure of local biota could increase. The greatest potential impact would be to those species that are restricted to or heavily utilize the quarry area. In addition, the transport of contaminants to local surface waters could continue, and their subsequent biouptake could impact biota that utilize these water resources.

Most toxicity studies are focused on human health effects, not on impacts to plant or animal receptors. Thus, potential impacts to vegetation and wildlife from exposure to quarry contaminants are very difficult to quantify. However, some studies have been carried out in which plants and animals were analyzed for possible effects of exposure to such contaminants (e.g., PCBs, heavy metals, and radium) (see Eisler 1985, 1986, 1988a, 1988b). These effects include reduced reproductive output, survival of young, and growth rates; behavioral aberrations; and numerous biochemical and physiological abnormalities. The repeated exposure of local biota to contaminants from the quarry could potentially result in the manifestation of such adverse effects.

Several investigations have been conducted at the Weldon Spring site to assess the extent to which local biota may have become contaminated as a result of exposure to site wastes (deRoos 1984; Ryckman/Edgerley/Tomlinson 1978; MK-Ferguson Company and Jacobs Engineering Group 1988). These studies, which examined selected terrestrial and aquatic biota, identified limited biological uptake of contaminants as evidenced by low levels of contamination in some of the organisms. However, no mammals or fish were collected from the quarry for tissue analysis. Very low or negligible contaminant levels have been reported for fish and mammals collected from the chemical plant area and Femme Osage Slough (MK-Ferguson Company and Jacobs Engineering Group 1988). In addition, no external indications of negative impacts have been detected in biota at the quarry.

A variety of federal and state listed "species of concern" occur in the quarry area and could therefore be exposed to quarry contaminants. For example, the federally endangered bald eagle (*Haliaeetus leucocephalus*) is known to overwinter in the nearby Howell Island Wildlife Area and could therefore be exposed to migrated contaminants. In addition, the state endangered Cooper's hawk (*Accipiter cooperii*) and the state rare wood frog (*Rana sylvatica*) may utilize habitats occurring at the quarry during breeding and nesting and could therefore be directly exposed to quarry contaminants. However, no threatened or endangered species identified by the U.S. Fish and Wildlife Service (Nash 1988; Tieger 1988) or the Missouri Department of Conservation (Dickneite 1988) have been reported to occur in the quarry, and no significant adverse impacts to listed species due to the presence of the bulk wastes in the quarry are apparent at this time.

In summary, although no significant adverse impacts to vegetation and wildlife are currently evident in the area, such impacts could occur in the future if the bulk wastes remain in the quarry.

8 REFERENCES

Agency for Toxic Substances and Disease Registry, 1987a, *Toxicological Profile for Arsenic*, prepared by Life Systems, Inc., published by Oak Ridge National Laboratory, draft for public comment, Nov.

Agency for Toxic Substances and Disease Registry, 1987b, *Toxicological Profile for Nickel*, prepared by Syracuse Research Corporation, published by Oak Ridge National Laboratory, draft for public comment, Oct.

Agency for Toxic Substances and Disease Registry, 1987c, *Toxicological Profile for Selected PCBs (Aroclor-1260, -1254, -1248, -1242, -1232, -1221, and -1016)*, prepared by Syracuse Research Corporation, published by Oak Ridge National Laboratory, draft for public comment, Nov.

Agency for Toxic Substances and Disease Registry, 1987d, *Toxicological Profile for Benzo(a)pyrene*, prepared by ICF-Clement, published by Oak Ridge National Laboratory, draft for public comment, Oct.

Agency for Toxic Substances and Disease Registry, 1987e, *Toxicological Profile for Benz(a)anthracene*, prepared by ICF-Clement, published by Oak Ridge National Laboratory, draft for public comment, Oct.

Agency for Toxic Substances and Disease Registry, 1987f, *Toxicological Profile for Benzo(b)fluoranthene*, prepared by ICF-Clement, published by Oak Ridge National Laboratory, draft for public comment, Nov.

Agency for Toxic Substances and Disease Registry, 1987g, *Toxicological Profile for Dibenz(a,h)anthracene*, prepared by ICF-Clement, published by Oak Ridge National Laboratory, draft for public comment, Oct.

Agency for Toxic Substances and Disease Registry, 1988, *Toxicological Profile for Lead*, prepared by Technical Resources, Inc., revised by Syracuse Research Corporation, published by Oak Ridge National Laboratory, draft for public comment, Feb.

Anderson, E., et al., 1985, *Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments, Final Report*, EPA/600/8-85/010; PB85-242667, prepared by GCA Corporation, GCA/Technology Division, Chapel Hill, N.C., for U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Washington, D.C., Aug.

Bailey, R.G., 1978, *Description of the Ecoregions of the United States*, U.S. Forest Service, Intermountain Region, Ogden, Utah.

Bechtel National, Inc., 1983, *Weldon Spring Site (WSS) Environmental Monitoring Report, Calendar Year 1982*, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tenn., July.

Bechtel National, Inc., 1985, *Radiological Survey Report for the Weldon Spring Quarry, Weldon Spring, Missouri*, DOE/OR/20722-70, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tenn., Sept.

Bechtel National, Inc., 1987, *Hydrogeological Characterization Report for Weldon Spring Chemical Plant, Weldon Spring, Missouri*, DOE/OR/20722-137, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tenn., July.

Berkeley Geosciences Associates, 1984, *Characterization and Assessment for the Weldon Spring Quarry Low-Level Radioactive Waste Storage Site*, prepared for Oak Ridge National Laboratory, Oak Ridge, Tenn., Sept.

Berlin, M., and B. Rudell, 1986, *Uranium*, in Handbook on the Toxicology of Metals, Volume II: *Specific Metals*, L. Friberg et al., eds., 2nd ed., Elsevier, Amsterdam, pp. 623-637.

Cowherd, Jr., C., et al., 1985, *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*, EPA/600/8-85/002, prepared by Midwest Research Institute, Kansas City, Mo., for U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Washington, D.C., Feb.

deRoos, C., 1984, letter from C. deRoos (Missouri Department of Conservation, Jefferson City), plus attachments, to G. Turi (U.S. Department of Energy, Washington, D.C.), April 20.

Dickneite, D.F., 1988, letter from D.F. Dickneite (Environmental Administrator, Missouri Department of Conservation, Jefferson City) to I. Hlohowskyj (Argonne National Laboratory, Argonne, Ill.), Aug. 24.

Eisler, R., 1985, *Selenium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*, U.S. Fish and Wildlife Service Biological Report, *85*(1.5).

Eisler, R., 1986, *Polychlorinated Biphenyl Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*, U.S. Fish and Wildlife Service Biological Report, *85*(1.7).

Eisler, R., 1988a, *Arsenic Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*, U.S. Fish and Wildlife Service Biological Report, *85*(1.12).

Eisler, R., 1988b, *Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*, U.S. Fish and Wildlife Service Biological Report, *85*(1.14).

Etnier, E.L., 1987, *Water Quality Criteria for 2,4-Dinitrotoluene and 2,6-Dinitrotoluene*, ORNL-6312, prepared by Oak Ridge National Laboratory, Oak Ridge, Tenn., for U.S. Army Medical Research and Development Command, Fort Detrick, Frederick, Md., Final Report, Aug.

Gaines, E.P., 1988, letter from E.P. Gaines (Data Manager, Missouri Department of Conservation, Jefferson City) to I. Hlohowskyj (Argonne National Laboratory, Argonne, Ill.), Sept. 8.

Gilbert, T.L., et al., 1989, *A Manual for Implementing Residual Radioactive Material Guidelines*, ANL/ES-160; DOE/CH/8901, prepared by Argonne National Laboratory, Energy and Environmental Systems Division, Argonne, Ill., for U.S. Department of Energy, Assistant Secretary for Nuclear Energy, June.

Gordon, L., and W.R. Hartley, 1989, *Health Advisory on 2,4,6-Trinitrotoluene*, U.S. Environmental Protection Agency, Office of Drinking Water, Jan.

Hawley, J.K., 1985, *Assessment of Health Risk from Exposure to Contaminated Soil*, Risk Analysis, 5(4):289-302.

Hodge, H.C., J.N. Stannard, and J.B. Hursh (eds.), 1973, *Uranium-Plutonium Transplutonic Elements*, Springer-Verlag, New York.

Hwang, S.T., 1987, *Methods for Estimating On-site Ambient Air Concentrations at Disposal Sites*, Nuclear and Chemical Waste Management, 7:95-98.

International Agency for Research on Cancer, 1983, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Polynuclear Aromatic Compounds, Part 1, Chemical, Environmental and Experimental Data*, Volume 32, World Health Organization, Dec.

International Commission on Radiological Protection, 1975, *Report of the Task Group on Reference Man*, ICRP Publ. 23, prepared by a Task Group of Committee 2.

International Commission on Radiological Protection, 1977, *Recommendations of the International Commission on Radiological Protection (Adopted January 17, 1977)*, ICRP Publ. 26, Annals of the ICRP, *1*(3).

International Commission on Radiological Protection, 1979-1982, *Limits for Intakes of Radionuclides by Workers*, a report of Committee 2 of the International Commission on Radiological Protection, adopted by the Commission in July 1978, ICRP Publication 30, Part 1 (and Supplement), Part 2 (and Supplement), Part 3 (and Supplements A and B), and Index, Annals of the ICRP.

International Commission on Radiological Protection, 1981, *Limits for Inhalation of Radon Daughters by Workers*, Adopted March 1981, ICRP Publ. 32, Annals of the ICRP, 6(1).

Kaye, M.E., and J.L. Davis, 1987, *Chemical Characterization Report for the Weldon Spring Quarry, St. Charles County, Missouri*, DOE/OR/20722-176, prepared by Bechtel National, Inc., Oak Ridge, Tenn., for U.S. Department of Energy, Oak Ridge Operations Office, Aug.

Kleeschulte, M.J., and L.F. Emmett, 1986, *Compilation and Preliminary Interpretation of Hydrologic Data for the Weldon Spring Radioactive Waste-Disposal Sites, St. Charles County, Missouri — A Progress Report*, U.S. Geological Survey Water-Resources Investigation Report 85-4272.

Lenhard, J.A., F.H. Belcher, and J.N. Holt, 1967, *Weldon Spring Raffinate Pits and Quarry Task Force Report*, prepared for U.S. Atomic Energy Commission, Oak Ridge Operations Office, Oak Ridge, Tenn., June 1.

Lepow, M.L., 1975, *Investigations in Sources of Lead in the Environment of Urban Children*, Environmental Research, *10*:415.

MacDonell, M.M., J.M. Peterson, and I.E. Joya, 1989, *Engineering Evaluation/Cost Analysis, Proposed Management of Contaminated Water in the Weldon Spring Quarry*, DOE/OR/21548-039, prepared by Argonne National Laboratory, Energy and Environmental Systems Division, Argonne, Ill., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Jan.

Marutzky, S.J., R. Colby, and L.S. Cahn, 1988, *Radiologic Characterization of the Weldon Spring, Missouri, Remedial Action Site*, UNC/GJ-HMWP-4; DOE/ID/12584-22, prepared by UNC Geotech, Inc., Grand Junction, Colo., for U.S. Department of Energy, Weldon Spring Site Remedial Action Project, Weldon Spring, Mo., Feb.

Meyer, K., 1988, *Previous WSQ Soil Sampling*, inter-office correspondence from K. Meyer (MK-Ferguson Company, Weldon Spring, Mo.) to Distribution, Oct. 24.

MK-Ferguson Company and Jacobs Engineering Group, 1988, unpublished information, St. Charles, Mo.

MK-Ferguson Company and Jacobs Engineering Group, 1989a, *Evaluation of Radon Emissions and Potential Control Requirements*, DOE/OR/21548-082, Rev. 1, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Missouri, Aug.

MK-Ferguson Company and Jacobs Engineering Group, 1989b, *Remedial Investigations for Quarry Bulk Wastes*, DOE/OR/21548-066, Rev. 1, prepared for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Weldon Spring, Missouri, Dec.

Nash, T., 1988, personal communication from T. Nash (U.S. Fish and Wildlife Service, Columbia Field Office, Columbia, Mo.) to I. Hlohowskyj (Argonne National Laboratory, Argonne, Ill.), Aug. 10.

National Council on Radiation Protection and Measurements, 1984, *Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States*, Report No. 78, Washington, D.C.

National Council on Radiation Protection and Measurements, 1987, *Exposure of the Population in the United States and Canada from Natural Background Radiation*, NCRP Report No. 94, Bethesda, Md., Dec. 30.

National Research Council, 1980, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation*, BEIR III Report, report of the Advisory Committee on the Biological Effects of Ionizing Radiation, Washington, D.C.

National Research Council, 1988, *Health Risks of Radon and Other Internally Deposited Alpha Emitters*, BEIR IV Report, report of the Committee on the Biological Effects of Ionizing Radiation, Washington, D.C.

Occupational Safety and Health Administration, 1989, *Air Contaminants: Final Rule (29 CFR Part 1910)*, Federal Register, *54*(12):2332-2982, Jan. 19.

Pennak, A.F., 1975, *Weldon Spring Decommissioning Study, Quarry Supplement*, NLCO-1121 Sup. 1 (Special), prepared by National Lead Company of Ohio, Cincinnati, for U.S. Energy Research and Development Administration, Oak Ridge Operations Office, Oak Ridge, Tenn., Sept. 10.

Peterson, J.M., et al., 1988, *Work Plan for the Remedial Investigation/Feasibility Study-Environmental Impact Statement for the Weldon Spring Site, Weldon Spring, Missouri*, DOE/OR/21548-033, prepared by Argonne National Laboratory, Energy and Environmental Systems Division, Argonne, Ill., for U.S. Department of Energy, Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, St. Charles, Mo., Aug.

Porter, J.W., 1989, memorandum from J.W. Porter (Assistant Administrator, U.S. Environmental Protection Agency, Washington, D.C.) to Regional Administrators, Regions I-X, Subject: *Interim Final Guidance for Soil Ingestion Rates*, OSWER Directive 9850.4, Jan. 27 (stamped).

Rickert, D.E. (ed.), 1985, *Toxicity of Nitroaromatic Compounds*, Hemisphere Publishing Corporation, Washington, D.C.

Rickert, D.E., B.E. Butterworth, and J.A. Popp, 1983, *Dinitrotoluene: Acute Toxicity, Oncogenicity, Genotoxicity, and Metabolism*, Critical Reviews in Toxicology, *13*(3):217-234.

Roels, H., et al., 1980, *Exposure to Lead by the Oral and Pulmonary Routes of Children Living in the Vicinity of a Primary Lead Smelter*, Environmental Research, *22*:81-94.

Ryckman/Edgerley/Tomlinson & Associates, 1978, *Phase III Report: Assessment of Disposition Alternatives, Weldon Spring Chemical Plant, St. Charles County, St. Louis, Missouri*, Data Requirement A00B; Contract No. DAAK11-77-C-0026, prepared for Department of the Army, Aberdeen Proving Ground, Md.

Sax, N.I., 1984, *Dangerous Properties of Industrial Materials*, 6th ed., Van Nostrand Reinhold Company, New York.

Seiler, H.G., and H. Sigel (eds.), 1988, *Handbook on Toxicity of Inorganic Compounds*, Marcel Dekker, Inc., New York.

Sittig, M., 1985, *Handbook of Toxic and Hazardous Chemicals and Carcinogens*, 2nd ed., Noyes Publications, Park Ridge, N.J.

Strenge, D.C., and T.J. Bander, 1981, *MILDOS - A Computer Program for Calculating Environmental Radiation Doses from Uranium Recovery Operations*, NUREG/CR-2011; PNL-3767, prepared by Pacific Northwest Laboratory, Richland, Wash., for U.S. Nuclear Regulatory Commission, Washington, D.C.

Tidball, R.R., 1984, *Geochemical Survey of Missouri*, Geological Survey Professional Paper 954-H,I, U.S. Government Printing Office, Washington, D.C.

Tieger, J., 1988, letter from J. Tieger (U.S. Fish and Wildlife Service, Columbia Field Office, Columbia, Mo.) to I. Hlohowskyj (Argonne National Laboratory, Argonne, Ill.), Dec. 22.

United Nations Scientific Committee on the Effects of Atomic Radiation, 1977, *Sources and Effects of Ionizing Radiation*, Report E.77.IX.1, New York.

U.S. Department of Energy, 1987a, *Draft Environmental Impact Statement, Remedial Action at the Weldon Spring Site*, DOE/EIS-0117D, Office of Remedial Action and Waste Technology, Feb.

U.S. Department of Energy, 1987b, *U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites*, Revision 2, March.

U.S. Department of Energy, 1987c, *Water Quality Phase I Assessment*, DOE/OR/21548-003, prepared by MK-Ferguson Company, St. Charles, Mo., for Oak Ridge Operations Office, Weldon Spring Site Remedial Action Project, Oak Ridge, Tenn., Dec.

U.S. Department of Energy, 1988, *Annual Environmental Monitoring Report, Weldon Spring, Missouri, Calendar Year 1987*, DOE/OR/21548-015, prepared by MK-Ferguson Company and Jacobs Engineering Group, St. Charles, Mo., for Weldon Spring Site Remedial Action Project, May.

U.S. Environmental Protection Agency, 1980, *Ambient Water Quality Criteria for Dinitrotoluene*, EPA/440/5-80/045; PB81-117566, Office of Water Regulations and Standards, Washington, D.C., Oct.

U.S. Environmental Protection Agency, 1984a, *Health Effects Assessment for Arsenic*, EPA/540/1-86/020; PB86-134319, Office of Research and Development, Cincinnati, Ohio, and Office of Emergency and Remedial Response, Washington, D.C., Sept.

U.S. Environmental Protection Agency, 1984b, *Health Effects Assessment for Lead*, EPA/540/1-86/055; PB86-134665, Office of Research and Development, Cincinnati, Ohio, and Office of Emergency and Remedial Response, Washington, D.C., Sept.

U.S. Environmental Protection Agency, 1984c, *Health Effects Assessment for Nickel*, EPA/540/1-86/018; PB86-134293, Office of Research and Development, Cincinnati, Ohio, and Office of Emergency and Remedial Response, Washington, D.C., Sept.

U.S. Environmental Protection Agency, 1984d, *Health Effects Assessment for Polycyclic Aromatic Hydrocarbons (PAHs)*, EPA/540/1-86/013; PB86-134244, Office of Research and Development, Cincinnati, Ohio, and Office of Emergency and Remedial Response, Washington, D.C., Sept.

U.S. Environmental Protection Agency, 1984e, *Health Effects Assessment for Selenium (and Compounds)*, EPA/540/1-86/058; PB86-134699, Office of Research and Development, Cincinnati, Ohio, and Office of Emergency and Remedial Response, Washington, D.C.

U.S. Environmental Protection Agency, 1986a, *Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup*, EPA/600/6-86/002; PB86-232774, Office of Research and Development, Washington, D.C., May.

U.S. Environmental Protection Agency, 1986b, *Guidelines for Carcinogen Risk Assessment*, Federal Register, 51(185):33992-34003, Sept. 24.

U.S. Environmental Protection Agency, 1986c, *Superfund Public Health Evaluation Manual*, EPA/540/1-86/060 (OSWER Directive 9285.4-1), Office of Emergency and Remedial Response, Washington, D.C., Oct.

U.S. Environmental Protection Agency, 1988a, *Public Health Risk Evaluation Database*, Office of Emergency and Remedial Response, Feb. (Version 2.04).

U.S. Environmental Protection Agency, 1988b, *Superfund Exposure Assessment Manual*, EPA/540/1-88/001 (OSWER Directive 9285.5-1), Office of Remedial Response, Washington, D.C., April.

U.S. Environmental Protection Agency, 1989a, *Exposure Factors Handbook*, EPA/600/8-89/043, Office of Health and Environmental Assessment, Washington, D.C., July.

U.S. Environmental Protection Agency, 1989b, *Health Effects Assessment Summary Tables, Third Quarter, FY 1989*, July.

U.S. Environmental Protection Agency, 1989c, *Integrated Risk Information System*, Office of Research and Development (data base, accessed October).

U.S. Environmental Protection Agency, 1989d, *Risk Assessment Guidance for Superfund — Environmental Evaluation Manual*, EPA/540/1-89/001A; OSWER Directive 9285.7-01, Office of Emergency and Remedial Response, Washington, D.C., Interim Final, March.

U.S. Nuclear Regulatory Commission, 1982, *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material*, Division of Fuel Cycle and Material Safety, Washington, D.C., July.

U.S. Nuclear Regulatory Commission, 1988, *Radioactive Material in the West Lake Landfill, Summary Report*, NUREG-1308, Office of Nuclear Material Safety and Safeguards, Washington, D.C., April.

Weidner, R.B., and M.W. Boback, 1982, *Weldon Spring Storage Site, Environmental Monitoring Report for 1979 and 1980*, NLCO-1176 (Special), prepared by National Lead Company of Ohio, Cincinnati, for U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tenn., April 19.

Yuan, Y.C., J.H.C. Wang, and A. Zielen, 1989, *MILDOS-AREA: An Enhanced Version of MILDOS for Large-Area Sources*, ANL/ES-161, prepared by Argonne National Laboratory, Energy and Environmental Systems Division, Argonne, Ill., for U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tenn., June.

APPENDIX A:

METHODOLOGY FOR ESTIMATING AIR CONTAMINANT CONCENTRATIONS

APPENDIX A:

METHODOLOGY FOR ESTIMATING AIR CONTAMINANT CONCENTRATIONS

A.1 SOURCE TERM

Estimates of fugitive dust emissions resulting from wind erosion are estimated based on an approach developed by Cowherd et al. (1985) for evaluating particulate emissions from uncontrolled hazardous waste sites. Although this method was developed for preliminary site assessments and emergency evaluations, the *Superfund Exposure Assessment Manual* of the U.S. Environmental Protection Agency (EPA 1988) indicates that the degree of accuracy obtained with this method is consistent with simplified quantitative estimation procedures.

The method assumes that the contaminated surface is exposed to wind, is uncrusted, and is composed of finely divided particles. These conservative assumptions tend to overestimate wind-induced dust emissions. For dust particles less than 10 μm in mean aerodynamic diameter, the flux from such a surface is estimated by the expression:

$$E10 = 0.036\ (1 - V)\ (U_m/U_t)^3\ F(x) \qquad \text{(A.1)}$$

where:

E10 = total flux of particles <10 μm (g/m^2-h),

V = fraction of surface vegetative cover,

U_m = mean annual wind speed (km/h),

U_t = threshold wind speed (km/h), and

F(x) = function specific to this model (g/m^2-h).

The dust flux is converted to an emission rate by:

$$Q10 = \frac{(E10)\ (A)}{(Y)} \qquad \text{(A.2)}$$

where:

Q10 = emission rate of particles <10 μm (g/s),

A = area of contamination (m^2), and

Y = conversion factor (3,600 s/h).

A.2 AMBIENT AIR CONCENTRATIONS

Although Gaussian dispersion models are generally used to estimate ambient air concentrations of pollutants dispersed downwind of an emission source, they are generally not appropriate for the estimation of on-site air concentrations or of the concentrations at a receptor located within 100 m of the source area. The EPA (1986) has therefore developed a box-model approach for estimating on-site concentrations from an area source. Under the assumption that a contaminant present at a site will travel only a short distance before it is inhaled by a receptor, the box model considers mixing of the emitted contaminant with winds but ignores dispersion effects. The air concentrations of contaminants are estimated by:

$$C_{ai} = \frac{(Q10)\ (C_{si})\ (Z)}{(LS)\ (UR)\ (MH)} \qquad (A.3)$$

where:

C_{ai} = ambient air concentration of contaminant i (mg/m^3),

C_{si} = concentration of contaminant i in soil (mg/kg),

LS = equivalent side length of the site perpendicular to the wind direction (m),

UR = average wind speed in the receptor zone (m/s),

MH = mixing height (assumed to be one-half of the vertical distance between the floor and rim of the quarry in this analysis, i.e., MH = 10 m), and

Z = conversion factor (1×10^{-3} kg/g).

The results predicted by this model have been compared with a more detailed model in which a short-range dispersion equation was derived by integrating point-source modeling over the area of emission (Hwang 1987). Use of the box model resulted in more conservative estimates of the contaminant concentration in air by a factor of about 10.

A.3 REFERENCES

Cowherd, Jr., C., et al., 1985, *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*, EPA/600/8-85/002, prepared by Midwest Research Institute, Kansas City, Mo., for U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Washington, D.C. (Feb.).

Hwang, S.T., 1987, *Methods for Estimating On-site Ambient Air Concentrations at Disposal Sites*, Nuclear and Chemical Waste Management, 7:95-98.

U.S. Environmental Protection Agency, 1986, *Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup*, EPA/600/6-86/002; PB86-232774, Office of Research and Development, Washington, D.C. (May).

U.S. Environmental Protection Agency, 1988, *Superfund Exposure Assessment Manual*, EPA/540/1-88/001 (OSWER Directive 9285.5-1), Office of Remedial Response, Washington, D.C. (April).

APPENDIX B:

ENGLISH/METRIC - METRIC/ENGLISH EQUIVALENTS

TABLE B.1 English/Metric Equivalents

Multiply	By	To obtain
Acres	0.4047	Hectares (ha)
Cubic feet (ft^3)	0.02832	Cubic meters (m^3)
Cubic yards (yd^3)	0.7646	Cubic meters (m^3)
Degrees Fahrenheit (°F) − 32	0.5555	Degrees Celsius (°C)
Feet (ft)	0.3048	Meters (m)
Gallons (gal)	3.785	Liters (L)
Gallons (gal)	0.003785	Cubic meters (m^3)
Inches (in.)	2.540	Centimeters (cm)
Miles (mi)	1.609	Kilometers (km)
Pounds (lb)	0.4536	Kilograms (kg)
Square feet (ft^2)	0.09290	Square meters (m^2)
Square yards (yd^2)	0.8361	Square meters (m^2)
Square miles (mi^2)	2.590	Square kilometers (km^2)

TABLE B.2 Metric/English Equivalents

Multiply	By	To obtain
Centimeters (cm)	0.3937	Inches (in.)
Cubic meters (m^3)	35.31	Cubic feet (ft^3)
Cubic meters (m^3)	1.308	Cubic yards (yd^3)
Cubic meters (m^3)	264.2	Gallons (gal)
Degrees Celsius (°C) + 17.78	1.8	Degrees Fahrenheit (°F)
Hectares (ha)	2.471	Acres
Kilograms (kg)	2.205	Pounds (lb)
Kilometers (km)	0.6214	Miles (mi)
Liters (L)	0.2642	Gallons (gal)
Meters (m)	3.281	Feet (ft)
Square kilometers (km^2)	0.3861	Square miles (mi^2)
Square meters (m^2)	10.76	Square feet (ft^2)
Square meters (m^2)	1.196	Square yards (yd^2)