PUBLIC HEALTH ASSESSMENT

FEED MATERIALS PRODUCTION CENTER (USDOE)
(a/k/a FERNALD ENVIRONMENTAL MANAGEMENT PROJECT)

FERNALD, HAMILTON AND BUTLER COUNTIES, OHIO

EPA FACILITY ID: OH6890008976

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Table of Contents

List of Appendices iii

List of Tables iv

List of Figures vii

List of Abbreviations viii

Executive Summary EX-1

Background 1
- Purpose and Scope 1
- Site Description and History 1
- Demographics 9
- ATSDR Activities 12
- Other Group and Agency Activities 13

Environmental Contamination, Exposure Pathways and Potentially Exposed Populations 16
- Introduction 16
- Air Pathway and Direct Radiation 21
  - Background 21
  - Environmental Data 24
  - Estimated Exposure Doses 33
- Soil Pathway 45
  - Background 45
  - Environmental Data 46
  - Estimated Exposure Doses 50
- Surface Water Pathway 55
  - Background 55
  - Environmental Data 58
  - Estimated Exposure Doses 62

Groundwater Pathway 67
Background 67
Environmental Data 69
Estimated Exposure Doses 77
Biota Pathway 83
Background 83
Environmental Data 83
Estimated Exposure Doses 86

Public Health Implications 91
Introduction 91
Uranium 95
Pathways of Exposure 95
Properties Affecting the Chemical Toxicity of Uranium 97
Evidence for Uranium Toxicity and Health-Based Guidelines 98
Mechanisms of Uranium Toxicity 100
Radioactive Materials and Radiation Exposures 102
Pathways of Exposure 102
Radiological Effects of Radioactive Materials and Radiation Exposure 103
Arsenic 108
Manganese 109

Health Outcome Data 111

Community Concerns 116

Conclusions 118

Recommendations 119

Public Health Action Plan 120

For Additional Information 122

Preparers of Report 125

References 126

List of Appendices

Appendix A—Selection of Contaminants

Appendix B—Exposure Doses and Health-Based Guidelines

Appendix C—Community Concerns

Appendix D—Summary of the Fernald Dosimetry Reconstruction Project and the Fernald Risk Assessment Project

Appendix E—Comparison of ATSDR/NAREL and DOE Radon Monitoring Program Data

Appendix F—ATSDR's Glossary of Terms

Appendix G—Public Comments and ATSDR's Responses

List of Tables

Table 1A. Demographic characteristics of the population residing within 5 and 10 kilometers of the Fernald Site property boundary (based on the 1990 Census) 11

Table 1B. Summary of demographic characteristics of the population residing within 5 and 10 kilometers of the Fernald Site property boundary (based on the 1990 Census) 11

Table 2. Derived concentrations of off-site resuspended soil particulates from 1991 through 1993 and health-based comparison values 33

Table 3. Current and past airborne concentrations of uranium and estimated off-site exposure doses for a child and an adult farmer 35

Table 4. Estimated maximum committed effective (whole body) and committed equivalent (lung and bone surface) doses for current chronic exposure for 1 year to radioactive contaminants in air off site of the Fernald facility by a child and an adult farmer 40

Table 5. Summary of DOE's alpha-track monitoring results at fenceline and at potentially affected residences with background subtracted and reported in pCi/L (and in Bq/L) 42

Table 6. Approximate annual lung dose for an adult male exposed continuously to alpha concentrations (presumably radon and radon progeny) listed in Table 5 (with background subtracted) 43

Table 7. Annual average external exposure doses at fenceline air monitoring stations west of the silos and northeast of the site (with background subtracted) 44

Table 8. Summary of analytical data used for selecting chemical contaminants in the surface soil pathway 48

Table 9. Summary of analytical data used for selecting radioactive contaminants in the surface soil pathway (data from 1989 forward) 49

Table 10. Estimated past and current chemical exposure doses for ingestion of uranium in off-site surface soil at the Fernald facility by a small child 51

Table 11. Estimated current exposure doses and health-based guidelines for chemical (metal) contaminants in soil pathways 52

Table 12. Estimated current doses for a child from one year exposure to radioactive contaminants in soil east of the site 54

Table 13. Maximum past chemical uranium concentrations in off-site surface water 59

Table 14. 1964 estimated concentrations for radioactive contaminants in off-site surface water in picocuries per liter (and becquerels per liter) 59

Table 15. Maximum current chemical uranium concentrations in off-site surface water 60

Table 16. Maximum current radioactive contaminant concentrations in off-site surface water . 61

Table 17. Estimated maximum past uranium (chemical) exposure doses for hypothetical exposure scenarios for surface water pathways 63

Table 18. Estimated current uranium (chemical) exposure doses for hypothetical exposure scenarios for surface water pathways 64

Table 19. 1964 estimated exposure doses for radioactive contaminants in surface water for the hypothetical exposure scenarios 65

Table 20. Estimated current exposure doses for radioactive contaminants in surface water for the hypothetical exposure scenarios 66

Table 21. Summary of sampling programs and activities that include private off-site wells . . . 72

Table 22. Maximum yearly concentrations of uranium in private wells 12, 13, 15, and 17 off site of the Fernald facility from 1982 to 1997 73

Table 23. Private well sampling (non-radioactive) from 1986 through 1995 75

Table 24. Maximum concentrations and estimated chemical exposure doses for current and past exposure to uranium in water from private well 15 near the Fernald site 78

Table 25. Maximum estimated doses for current exposure to arsenic and manganese in off-site groundwater at the Fernald site 80

Table 26. Uranium concentrations and past and current estimated committed effective and committed equivalent doses from ingestion of off-site groundwater near the Fernald site 81

Table 27. Estimated and measured maximum past and current uranium concentrations in off-site biota near the Fernald site 85

Table 28. Measured maximum current radioactive contaminant concentrations in off-site biota in pCi/g (Bq/g) for vegetables, meat, and fish and in pCi/L (Bq/L) for milk 86

Table 29. Age-specific ingestion rates and percent of biota consumed by Fernald residents for two hypothetical exposure scenarios for the biota pathway 87

Table 30. Estimated maximum past uranium (chemical) exposure doses for hypothetical exposure scenarios for biota pathway 88

Table 31. Estimated maximum current uranium (chemical) exposure doses for hypothetical exposure scenarios for biota pathway 89

Table 32. Estimated maximum past (radioactive) uranium committed effective (whole body) and committed equivalent (bone surface) doses based on 1-year exposure for hypothetical exposure scenarios for the biota pathway 89

Table 33. Estimated maximum current doses based on 1-year exposure to radioactive contaminants for hypothetical exposure scenarios for biota pathway 90

Table 34. Estimated past uranium and radiation doses for all exposure pathways 92

Table 35. Estimated current chemical and radiation doses for all exposure pathways 93

Table 36. Estimated maximum total chemical uranium doses for persons living near the site . . 95

Table 37. Relative water solubility and kidney toxicity of various uranium compounds 98

Table 38. Estimated maximum total radiation doses from 1 year of exposure for persons living near the site 106

List of Figures

Figure 1. Location of the Fernald site and surrounding area 2

Figure 2. Layout of the Fernald site 3

Figure 3. Demographic characteristics of the population residing within 1 mile of the Fernald site 10

Figure 4. Pathways of exposure to contaminants from the Fernald site 17

Figure 5. Location of air monitoring stations from 1960 to 1970 and from 1970 to 1987 25

Figure 6. Location of air monitoring stations (AMS) from 1988 through 2002 27

Figure 7. Surface water discharge points from the Fernald site to Paddy's Run Creek and the Great Miami River 56

Figure 8. Location of privately owned sampled wells near the Fernald site 68

Figure 9. Location of on-site and off-site uranium groundwater contamination at the Fernald site 70

List of Abbreviations

AEC	U.S. Atomic Energy Commission
AMAD	Activity mean aerodynamic diameter
AT	Averaging time
ATSDR	Agency for Toxic Substances and Disease Registry
BW	Body weight
Bq	Becquerel(s)
C	Contaminant concentration
CDC	Centers for Disease Control and Prevention
CEL	Cancer effect level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Ci	Curie(s)
cm	centimeter
CPF	Cancer potency factor
CREG	ATSDR's Cancer Risk Evaluation Guide
CSF	Cancer slope factor
Conc (or conc)	Concentration
DHHS	US Department of Health and Human Services
DNA	Deoxyribonucleic acid
DOE	US Department of Energy
ED	Exposure duration
EF	Exposure frequency
EMEG	ATSDR's Environmental Media Evaluation Guide
EPA	US Environmental Protection Agency
ESADDI	Estimated safe and adequate daily dietary intake
FCAB	Fernald Citizens Advisory Board
FCHEC	Fernald Community Health Effects Committee, Inc.
FDRP	CDC's Fernald Dosimetry Reconstruction Project
FEMP	Fernald Environmental Management Project
FHES	Fernald Health Effects Subcommittee
FMMP	Fernald Medical Monitoring Program
FMPC	Feed Materials Production Center
FRAP	CDC's Fernald Risk Assessment Project
FRESH	Fernald Residents for Environmental Safety and Health, Inc.
FRL	Final Remediation Level
FWMMP	Fernald Workers Medical Monitoring Program
g	gram
GIS	Geographic information system
Gy	Gray(s)
hr	Hour(s)
ICRP	International Commission on Radiological Protection
IDLH	Immediately Dangerous to Life and Health
IEMP	Integrated Environmental Monitoring Plan
IR	Intake rate (ingestion or inhalation)
kg	Kilogram(s)
km	Kilometer(s)
L	Liter(s)
LOAEL	Lowest-Observed-Adverse-Effect-Level
MCL	EPA's Safe Drinking Water Act Maximum Contaminant Level

µg	Microgram(s)
m^3	Cubic meter
mi	Mile(s)
mCi	Millicurie(s)
mg	Milligram(s)
mGy	Milligray(s)
mrad	Millirad(s)
mrem	Millirem(s)
mSv	Millisievert(s)
MRL	Minimal Risk Level
NAAQS	National Ambient Air Quality Standards
NAREL	EPA's National Air and Radiation Environmental Laboratory
NCEH	National Center for Environmental Health
NCI	National Cancer Institute
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NOAEL	No-Observed-Adverse-Effect-Level
NO_x	Nitrogen Oxides
NPL	National Priorities List
NRC	National Research Council, National Academy of Sciences
ODH	Ohio Department of Health
OEPA	Ohio Environmental Protection Agency
OSDF	On-site disposal facility
OSHA	Occupational Safety and Health Organization
PAHs	Polyaromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PEL	OSHA Permissible Exposure Limit
pCi	picocurie(s)
ppb	Part(s) per billion (equivalent to µg/L or µg/kg)
RAC	Radiological Assessments Corporation
RCRA	Resource Conservation and Recovery Act
RfD	EPA's Reference dose
RMEG	ATSDR's Reference Dose Media Evaluation Guide
ppm	Part(s) per million (equivalent to mg/kg or µg/ml)
SED	Site-wide environmental database
SEER	Surveillance Epidemiology, End Result (NCI's data)
SIR	Standardized incidence rate
SMR	Standardized mortality ratio
SO_2	Sulfur dioxide
SSOD	Storm sewer outfall ditch
TLDs	Thermoluminescent dosimeters
TSP	Total suspended particulates
UF_4	Uranium tetrafluoride (green salt)
UF_6	Uranium hexafluoride
UO_2	Uranium dioxide
UO_3	Uranium trioxide (orange oxide)
U_3O_8	Triuranium octaoxide (yellowcake)
USDOE	US Department of Energy
yr	Year(s)

Executive Summary

The Fernald Environmental Management Project (FEMP), owned by the US Department of Energy (DOE), is a 1,050-acre complex located about 17 miles northwest of downtown Cincinnati, Ohio. From 1951 through 1988, the facility produced high-purity uranium metal products for the defense industry and was known as the Feed Materials Production Center (FMPC). (As of February 2003, this site is now known as the Fernald Closure Project.)

Disposal practices and operational deficiencies resulted in contamination of soil, groundwater, surface water, and air. The major sources of contaminants included the production area, six waste pits, three waste silos, a storm sewer outfall to Paddy's Run, and an effluent line discharging into the Great Miami River. The site was added to the US Environmental Protection Agency's Superfund National Priorities List (NPL) in 1989.

Remediation has been ongoing at the site since 1991. The majority of this work should be completed by December 2006, pending DOE funding. Presently, the three silos contain a large quantity of radioactive waste materials and other metal oxides. The K-65 silos (silos 1 and 2) store waste from processing Belgian Congo ore, which contains a significant quantity of radium 226. This waste also contains radon 222 (produced from radium 226), thorium 230, lead 210, and polonium 210. Silo 3 stores waste that contains the same radioactive constituents at much lower quantities and other metal oxides. As part of the remedial activities, the contents of the silos will be treated and/or temporarily stored at the site and will be ultimately transported to an off-site disposal facility. In addition, a large volume of contaminated soil and debris that meet approved waste acceptance criteria is being removed from the facility production areas and placed in on-site disposal cells. Other contaminated materials that do not meet the waste acceptance criteria are being transported to off-site disposal facilities.

After the scheduled closure date (December 2006), the site will remain under DOE's ownership and not available for unrestricted use. A long-term stewardship plan is being drafted; however, perpetual care and monitoring of the on-site disposal cells will be required, and groundwater remediation efforts will be continued until required groundwater concentrations are met.

In this public health assessment, ATSDR scientists evaluated environmental and health information and identified pathways through which people are currently being exposed, have been exposed in the past, or may be exposed in the future to chemicals or radioactive materials from the site. "Current exposures" occurred from the cessation of production operations in 1989 until the present. "Past exposures" occurred during production operations from 1951 through 1988. "Future exposures" are not anticipated but must be considered as long as remedial activities continue, the waste cells are located at the site, and the groundwater concentrations have not reached the desired limits. For each pathway, this assessment discusses whether residents in the area may be exposed to chemicals and radioactive materials at levels that pose a public health hazard, and the assessment provides a rationale in each case for ATSDR's

assignment of a public health hazard level. Very conservative assumptions are used to account for worst-case situations. The table below presents ATSDR's findings.

ATSDR Conclusion Category	Exposure Pathway
Public health hazard	Groundwater: past (uranium) Air: past (radon, radon decay products and other radionuclides)
Indeterminate public health hazard	Air: past (non-uranium chemicals)
No apparent public health hazard	Surface water: past, current Air: current* Biota: past, current Groundwater: current
No public health hazard	Soil: past, current, and future
* During the waste pit remedial activities, off-site airborne concentrations of certain non-uranium metal particles (i.e., beryllium) could not be determined; therefore, this pathway was temporarily indeterminate.	

According to data reviewed for this public health assessment, there are no known exposure pathways that pose a public health hazard to neighboring residents under current conditions at this site. Although residents near the site may be exposed to low levels of chemicals and radioactive materials in the environment, the concentrations of these substances do not appear to be at levels that would cause harm to humans. This conclusion takes into account cleanup activities that have been conducted and those in progress. During remedial activities involving the waste pits, the total suspended particulate matter concentrations at the site boundary do not exceed EPA's air quality standards; however, the concentrations for certain metal particles (i.e., beryllium) could not be determined. Given the distance to the nearest residence, ATSDR does not believe that off-site air concentrations would be at a level of health concern.

ATSDR considered historic chemical releases from the site and identified two off-site exposure pathways. *Past ingestion of uranium in groundwater* from privately owned wells in the South Plume caused exposures that *pose a public health hazard* for children and adults as a result of uranium's chemical toxicity. *Past exposure to airborne radioactive materials (e.g., radon, radon daughters, and uranium) poses a human health hazard* to individuals close to the site. Also, *past exposure to airborne chemicals poses an indeterminate human health hazard*, mainly due to lack of information, i.e., off-site concentrations or frequency and quantities of the releases. Several of the release sources were not process related, i.e., coal burning, open burning and incineration of waste, and fire training.

On-site cleanup operations include the storage, removal, and transport of radioactive materials and other metal oxides from the K-65 silos and silo 3. Because of the significant differences in the physical, chemical, and radioactive properties of the waste and the construction of the silos, the clean-up operations for the K-65 silos and silo 3 are different and are being treated separately

A *future air exposure pathway* could exist if a natural disaster or an accident caused the release of these waste materials in the silos into the environment. .

The health data evaluated for neighboring residents support the conclusions made in this public health assessment and indicate that continued evaluation of the site should be considered. The results of the Centers for Disease Control and Prevention's Fernald Dosimetry Reconstruction Project (FDRP) and Fernald Risk Assessment Project (FRAP) indicate that while FMPC was operating, neighboring residents were exposed to radioactive materials from the site that resulted in a higher than expected risk for lung cancer. Results from ATSDR's and the state's off-site radon monitoring and DOE's site boundary monitoring have indicated that there are no current abnormal off-site radon concentrations. Continued monitoring by the state and DOE until the silo waste is removed from the site should determine if radon will pose an off-site health hazard in the future. Results of the FDRP also suggest that neighboring residents may have elevated kidney burdens of uranium from past exposure, primarily from consumption of contaminated water in privately owned wells in the South Plume. Preliminary analyses of residents participating in the University of Cincinnati's Fernald Medical Monitoring Program (FMMP) suggest a higher than expected occurrence of adverse effects on the urinary and kidney/renal systems. It is unknown whether these excesses are related to chemicals and radioactive releases from this site. A more in-depth assessment of site-related past exposures to contaminants in these wells is needed, as well as further evaluation of other possible risk factors among the participants.

Over several years, ATSDR representatives collected information from members of the community about their concerns related to health and environmental issues. Many persons expressed concerns about cancer and other illnesses from exposures to contaminants from the site. Community concerns are documented and addressed in Appendix C of this document.

The U.S. Department of Health and Human Services (DHHS) sponsored the Fernald Health Effects Subcommittee (FHES) as part of the Citizens' Advisory Committee on Public Health Service Activities and Research at DOE Sites through fiscal year 2001. Following the FHES recommendations, ATSDR co-sponsored three educational workshops for health care providers in the Fernald and Cincinnati areas, which were held in November 1998, February 2000, and January 2003. The main body of this report briefly discusses these workshops.

Considering the data and information reviewed for this public health assessment, ATSDR recommends the following: (1) analyze boundary air monitoring filters for site-related chemicals and particle diameters; (2) continued monitoring of groundwater for potential site-related contaminants along the east site boundary and in the South Plume and include analyses for contaminants that may be drawn into the South Plume from other sources as a result of groundwater remedial activities at this site; (3) a more in-depth assessment of *past* exposure to airborne non-uranium chemical contaminants and chemical contaminants in privately owned residential wells near this site if pertinent information becomes available; and (4) continued monitoring for radon and radon daughters in the neighboring off-site area during remedial activities at the site, especially those involving the K-65 silos.

The interpretation, conclusions, and recommendations provided in this public health assessment are based on the data and information referenced herein. Additional data could alter these conclusions and recommendations. The conclusions and recommendations are site-specific and are, therefore, not applicable to any other situation.

Background

Purpose and Scope

This public health assessment for the Fernald Environmental Management Project (FEMP)[1], formerly the Feed Materials Production Center (FMPC), addresses the human health hazards from past, current, and potential future exposure to chemical and radioactive materials released to the environment and transported to off-site communities. It does not address exposures of FEMP or FMPC workers to radioactive or hazardous materials on the site. Concerns about occupational exposures and workplace safety should be addressed by the National Institute for Occupational Safety and Health (NIOSH). A contact person for NIOSH is identified in the For Additional Information section of this report.

The Centers for Disease Control and Prevention's (CDC's) Fernald Dosimetry Reconstruction Project and the Fernald Risk Assessment Project analyzed the community's past exposures to radioactive materials when the facility was operating — from 1951 through 1988 (Killough 1998b; CDC 1998; CDC 2000). ATSDR scientists reviewed these documents. The methodology used and the outcomes reported in these documents will be mentioned in various sections throughout this public health assessment.

Site Description and History

The FEMP site is a 1,050-acre complex owned by the U.S. Department of Energy (DOE) near Fernald, Ohio, about 17 miles northwest of downtown Cincinnati (DOE 1972–1999). The area surrounding the site is mainly residential and rural, and the land is chiefly used for farming and raising cattle. There is some light industry within 3.2 kilometers (2 miles). The towns of Fernald, Ross, New Baltimore, and New Haven are within 10 kilometers (6.2 miles) of the site. FEMP's location and the surrounding area are shown on the map in Figure 1.

The plant facilities produced high-purity uranium metal products and feed material for the former Atomic Energy Commission and, more recently, DOE. Construction of the site began in 1951. Production began in 1953 and ended in 1988/1989. Throughout its process operations history, the site was called the *Feed Materials Production Center* (FMPC). The former production facilities occupied 136 acres of the site complex. Waste disposal areas surrounded the production area. The layout of the site is shown in Figure 2 (Killough et al.1998b).

[1]This site has been renamed the *Fernald Closure Project* as of February 2003; however, to minimize confusion, ATSDR has retained the name Fernald Environmental Management Project (FEMP) for this report (DOE 2003a).

Figure 1. Location of the Fernald Site and Surrounding Area
(Reference: ATSDR 1999a)

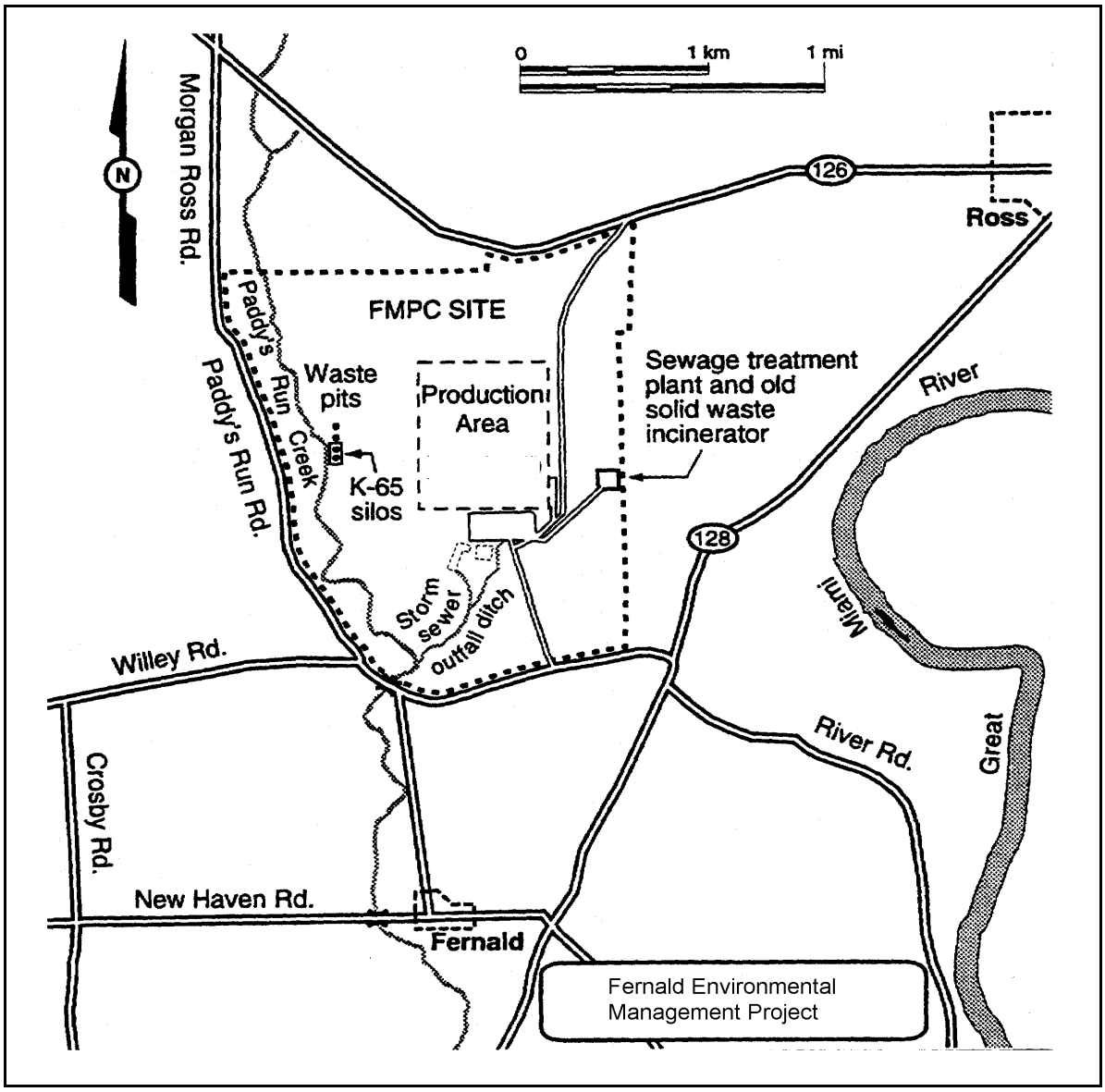


Figure 2. Layout of the Fernald site
(Reference: Killough et al. 1998b)

FMPC manufacturing processes chemically and physically purified a variety of feed materials for gaseous diffusion plants, converted uranium compounds into uranium metal, cast metal into various shapes, and machined castings to specified dimensions. FMPC mainly shipped and received a variety of uranium compounds to and from other DOE sites; however, relatively small amounts of thorium metal were also produced during the mid 1950s and from 1964 until 1980. The uranium came from ores and materials recycled from other DOE facilities. Uranium trioxide (UO_3 or orange oxide) and uranium tetrafluoride (UF_4 or green salt) were processed in the greatest quantities. Approximately 54% of the material received and shipped was natural

uranium, 20% was enriched uranium, and 26% was depleted uranium. Recycled materials were processed beginning in 1962 (Voilleque et al. 1995).

In this report, "*on-site contamination and releases*" describes contamination and releases of material within the fenced security area of the site or in areas for which public access is restricted. "*Off-site contamination*" describes materials leaving the site and are no longer being controlled by FEMP. On-site sources are considered only as sources of off-site contamination or for their impact on the community. Contamination in environmental media at this site and surrounding area is attributed to process operations and waste management practices. Historical sources of contaminants from *major process operations* included (DOE 1994):

- Plant 1 (Sampling/Preparation Plant): Beginning in 1953, this plant received large quantities of natural, enriched, and depleted uranium (feed material). The feed materials were dried, crushed, milled, ground, and digested in nitric acid. This process produced waste that included uranium and thorium progeny (radioactive waste), non-radioactive metal oxides, and nitrate compounds. This plant had 15 dust collectors but released some uranium ore dust and U_3O_8 to the air. (It was on the west side of the production area.)

- Plants 2/3 (Refineries): Beginning in 1953, these plants converted uranium to uranyl nitrate through acid digestion and then to uranium trioxide (UO_3) by evaporation and denitration. From 1953 to 1955, these plants also processed pitchblende ore that contained elevated levels of radium. Later, these plants used UO_2, uranyl nitrate hexahydrate, scrap from Plant 1, and uranium oxides from Plant 8. Plants 2/3 had four dust collectors and two scrubbers but still were a source of some uranium ore dust, U_3O_8, UO_3, uranyl nitrate hexahydrate, nitrate compounds, and radium 226 released to the atmosphere. (They were on the west side of the production area.)

- Plant 4 (Green Salt Plant): Beginning in 1953, this plant reduced UO_3 to UO_2 . In 1954, this plant converted UO_2 to UF_4 by reaction with anhydrous hydrogen fluoride, but the process was discontinued because of mechanical problems. Plant 4 had 12 dust collectors but still was a source of some U_3O_8, UF_4, UO_2F_2, and UO_3 released to the atmosphere. (It was in the center of the production area.)

- Plant 5 (Metals Production): Beginning in 1953, this plant reduced UF_4 to uranium metal through high temperature reaction with magnesium, creating uranium metal derbies that were recast to form ingots. Graphite crucibles were machined and magnesium fluoride slag was milled for reuse in reduction pots. This plant had 17 dust collectors, but some magnesium fluoride slag dust contaminated with UF_4 and U_3O_8 was still released. (It was in the center of the production area.)

- Plant 6 (Metals Fabrication Plant): Beginning in 1952, billets were made from ingots, heat-treated in neutral salt and salt-oil baths, and shipped off-site to be made into a product. The returned products were machined into final form and pickled in nitric acid.

Chips and lathe turnings were crushed, pickled, rinsed, dried, briquetted, and recycled. This plant had an exhaust stack that ventilated the pickling tank, wash tanks, and briquetting operations. (It was on the east side of the production area.)

- Plant 7: This plant was designed to convert UF_6 to UF_4 but operated only from 1954 to 1956. (It was in the center of the production area south of Plant 4.)

- Plant 8 (Scrap Recovery Plant): Beginning in 1953, this plant processed impure metals and residues. High-grade scrap was oxidized in an oxidation furnace or a box furnace, both of which were vented to wet scrubbers before the gases were discharged to the atmosphere. This plant also produced thorium hydroxide from thorium tetrafluoride for six months in 1966 by heating it in a reverter tube with hydrofluoric acid. The off-gas was neutralized in a caustic scrubber. The thorium hydroxide was sent to the pilot plant. (This plant was on the southwest side of the production area south of Plant 3.)

- Plant 9 (Special Products Plant): Beginning in 1954, this plant originally cast and cropped ingots as well as drilled and machined billets. From 1961 to 1963, a process was used to dissolve rejected co-extrusion sections from the cladding operation at Hanford by using dilute nitric acid to remove copper from uranium cores. This process was also used to remove other metals. Later it was used to pickle derbies to remove potassium and lithium carbonates left by the salt-cleaning process. The acid tanks were exhausted through a stack with a blower. In 1954 and 1955, thorium metal was also produced and machined in this plant. Airborne uranium releases were not significant from this plant compared to the other plants; however, unmonitored thorium emissions occurred from the dissolution of thorium nitrate tetrahydrate, which vented to the atmosphere; the precipitation of thorium tetrafluoride, which vented to an absorber; and the acid wash, which vented through a dust collector. (This plant was on the east side of the production area north of Plant 6.)

- Pilot Plant: Beginning in 1951, this plant converted gaseous diffusion plant UF_6 tails to UF_4 by heating it in an autoclave. The off-gases included hydrogen, nitrogen, hydrogen fluoride, uranium tetrafluoride particulate, and traces of uranium hexafluoride. The off-gases were passed through two cyclones and two sintered metal filters, a carbon trap, a two-stage refrigerated condenser, and a water scrubber. However, on February 16, 1966, an unmonitored release of approximately 1,195 kilograms of uranium as UF_6 occurred during a one-hour period when the winds were out of the north/northwest. From 1964 until 1980 several processes were used involving thorium ores, pellets, and other thorium materials. Thorium metal was produced from 1969 to 1971 through a process that used hydrofluoric acid, calcium metal, zinc fluoride, zinc chloride, and argon gas. Thorium oxalate was produced in this plant from 1971 to 1976. The precipitation tanks were vented to a packed tower water scrubber. (This plant was in the southwest corner of the production area.)

These processes generated large quantities of chemical and radioactive wastes, which resulted in contaminated wastewater and stormwater discharges directly to surface water streams. Also, before 1984, solid and slurried wastes from plant operations were disposed of on-site (DOE 1994). Potential contaminants may have been released from some of these locations, such as underground storage tanks, waste storage pits, landfills, and sludge ponds. The waste storage pits and landfills were in the northwest corner of the site outside the production area. The lime sludge ponds were just west of the production area. Combustible wastes were burned in several on-site incinerators and open-burn areas. From 1966 until 1990, a fire training facility located north of the production area and less than a half mile south of the closest residence was used approximately 60 days per year for fire training exercises. Waste oils, kerosene, gasoline, wooden pallets, straw, damaged furniture and vehicles, rubber tires, metallic sodium, magnesium, and waste solvents were some of the items burned (DOE 1993a). The coal burning plant located in the north central part of the production area generated a significant amount of fly ash that was stored in piles in the southwest corner of the site. A contaminated oil/graphite burn pad was also located near the coal-burning steam plant (DOE 1994).

A large quantity of radioactive waste materials and other metal oxides have been stored in Silos 1, 2, and 3 on-site since the 1950s. The K-65 silos (silos 1 and 2) contain waste from processing Belgium Congo ore, which had a high concentration of radium 226. The K-65 silos also contain radon 222 (produced from radium 226), thorium 230, lead 210, and polonium 210. Silo 3 contains similar radioactive constituents at much lower concentrations and other metal oxides; however, the predominant radionuclide of concern is thorium 230. Silo 4 is empty and never was used (DOE 1998).

Disposal practices and operational deficiencies resulted in contamination of air, soil, surface water, and groundwater (EPA 2001a). Major sources of contaminants included the production area, six waste pits, three waste silos, a storm sewer outfall to Paddy's Run (an intermittent stream), and an effluent line discharging to the Great Miami River. As early as 1981, the State of Ohio found radioactive contamination in the Buried Valley Aquifer south of the site. In December 1981, this contamination was identified as uranium by National Lead of Ohio (the operator of the plant) and confirmed by the US Geological Survey in August 1982, eventually resulting in the closure of a private well down-gradient from the site (USGS 1984). In 1985, elevated concentrations of uranium, technetium 99, and hexavalent chromium were detected in the effluent line discharging to the Great Miami River (EPA 2001a). In April 1986, elevated concentrations of radon were detected by on-site air monitors. In November 1989, the site was placed on the US Environmental Protection Agency's (EPA's) National Priorities List (NPL).

For the FEMP Remedial Investigation, sampling began in and around the source areas in July 1987. The primary radioactive contaminant was uranium; however, thorium and several fission and activation products, including technetium 99 were found (DOE 1994). The predominant inorganic chemicals associated with production processes included magnesium fluoride, nitric acid, hydrochloric acid, hydrofluoric acid, magnesium metal, calcium hydroxide, calcium-magnesium carbonate, and ore impurities, e.g. arsenic, calcium, iron, magnesium, molybdenum,

phosphorus, silicon dioxide, sodium, sulfate, thorium, and vanadium. Organic compounds used during production included kerosene; tributyl phosphate; various oils used as lubricants, cutting oils, and coolants; degreasers and paint solvents (which contained polychlorinated biphenyls); PAHs from flyash, incinerator ash, and fuel oil; pesticides; herbicides; and other various solvents (e.g., acetone and benzene).

Although some protective and remedial actions were performed in the 1980s, most remedial activities did not begin until the 1990s (DOE 1994). In 1991, DOE officially announced the end of the production mission for the *Feed Materials Production Center,* and the site was renamed the *Fernald Environmental Management Project* (DOE 1972–1999). In February 2003, the site name was changed again to the *Fernald Closure Project* (DOE 2003a). In this public health assessment, ATSDR will use the terms *Fernald site* and *Fernald facility* to refer to the site in both the past and present, without regard to name distinction or to a particular time frame.

In August 1993, a group of concerned citizens formed the Fernald Citizens Task Force to provide DOE, EPA, and the Ohio Environmental Protection Agency (OEPA) with recommendations regarding cleanup (remediation) and future use of the site and disposal of waste materials associated with the cleanup. Their first public meeting was held October 14, 1993 (DOE 1993b). In July 1995, this group completed its first series of formal recommendations by issuing a report titled *Fernald Citizens Task Force Recommendations on Remediation Levels, Waste Disposition, Priorities, and Future Use.* This report recommended that the Fernald property be used for a variety of purposes but that residential and agricultural uses of the land be prohibited. It also recommended that an on-site disposal facility be constructed to dispose of low-level radioactive waste materials that met site-specific waste acceptance criteria and that a portion of the site be used as a natural resource area. The task force's recommendations were accepted by DOE, EPA, and OEPA and were instrumental in forming the overall approach to remediating the site. In 1997, this group became the Fernald Citizens Advisory Board (FCAB).

All current activities at FEMP involve remediating the site and nearby contaminated areas in accordance with agreements between DOE, EPA, and OEPA. These activities include monitoring for chemical and radioactive materials in on-site and off-site environmental media (e.g., air, groundwater, soil) and the following specific projects:

(1) Silos 1 and 2 Project: 8,900 cubic yards of high-activity low-level waste, including radon gas, will be removed from the two concrete silos, treated, and shipped off-site for disposal;
(2) Silo 3 Project: 5,100 cubic yards of low-level waste will be removed from the concrete silo and shipped off-site for disposal;
(3) Waste Pits Remedial Action Project: Six very large waste pits are being remediated, with the waste water being treated at the Waste Water Treatment Plant before discharge and the dry waste being shipped off-site for disposal;
(4) Decontamination and Demolition Project: 225 former production plants, support buildings, and associated structures are being dismantled, with some debris placed in the

on-site disposal facility (OSDF) and some shipped off-site for disposal;

(5) Nuclear Material Disposition Project: The off-site disposition of 31 million pounds of nuclear product has been completed;

(6) Soil and Disposal Facility Project: Contaminated soil is being shipped both off site for disposal and placed in the OSDF (if it meets the required limits). There are seven planned disposal cells for the OSDF. Substantial natural resource restoration is being performed. (More than 80 percent of the site will be restored to native forest, wetlands, and prairie);

(7) Waste Management Project: waste is characterized, sampled, packaged, and disposed appropriately as radioactive, hazardous, or mixed waste; and

(8) Aquifer Restoration and Waste Water Treatment Project: contaminated portions (~ 170 acres) of the Great Miami Aquifer are being remediated to reduce uranium concentration to EPA cleanup standards. In 1991, a groundwater extraction system was installed to contain the spread of off-site groundwater contamination. Since 1998, extraction and injection wells have been installed to shorten the time required to remove and treat contaminated groundwater from 25 years to 10 years (EPA 2001b). More wells have been installed recently, and the anticipated completion of this project is now 2006. However, groundwater will continue to be treated, no matter how long it takes, until the desired levels are reached for all four seasons of the year (FCAB 2002).

In 1998, DOE initiated the Accelerated Waste Retrieval Project for Silos 1 and 2 to address increasing radon concentrations in the silos' head space, issues with the silo integrity, and heterogenicity of the waste for final treatment. This project was delayed but began again in November 2002. A Radon Control System was installed in the silos and was first "hot" tested on December 6, 2002. It proved to be successful in substantially reducing the radon concentration in the head space (DOE 2003b). This phase of the project should reduce the risk associated with current storage of the waste and is the first step in the final remediation of the silos. Additional information about this project can be obtained by contacting EPA Region V's representative for the Silos Project or the OEPA representative identified in the For Additional Information section of this report.

The scheduled site closure date is December 2006, pending DOE funding. After closure, the site will not be available for unrestricted use, DOE will retain ownership, long-term monitoring of the OSDF will be required, and groundwater remediation efforts will continue until the limits set by DOE, EPA, and OEPA are met. A long-term stewardship plan is being drafted (FCAB 2002).

The primary DOE contractor for the site is Fluor Fernald, Inc. Other contractors during the plant's history include Fluor-Daniels Fernald, Fernald Environmental Restoration Management Corporation (a subsidiary of Fluor-Daniel), Westinghouse Environmental Management Company of Ohio, and the first contractor to operate the facility, National Lead of Ohio (DOE 1972–1999).

Demographics

Demographic information characterizing the communities surrounding the site is used to evaluate human exposure pathways and health outcome data. Delineating the number of children, elderly, and women of child-bearing age is important, because these persons tend to be more sensitive to environmental exposures than the general population (ATSDR 1992; Klaassen 1996). Information about racial and ethnic characteristics can help identify sub-populations that have increased sensitivities or that may be underserved and require additional attention.

The majority of the Fernald site is in the northern end of Hamilton County, Ohio; a smaller portion is in the southern end of Butler County. Several farms are within 1.6 kilometers (km), or 1 mile (mi), of the site boundary. The nearest farm is adjacent to the site's southeastern boundary; this farm has been active since the Fernald facility was in operation.

Figure 3 summarizes demographic data from the 1990 US Census for persons residing within 1.6 km (1 mi) of the site boundary (ATSDR 1999a). The 1990 data are being used because they reflect the population composition close to the facility closure. According to these data, 922 persons resided in 333 housing units in this area; 110 persons (12% of the total) were 6 years old or younger, 57 persons (6% of the total) were 65 years old or older, and 215 females (23% of the total) were between the ages of 15 and 44. Most residents within 1.6 km (1 mi) of the site were white (99.5%); a small percentage of the population (1.2%) was composed of persons who are either black, American Indian/Native Alaskan, or Asian/Pacific Islander. Hispanic origin is listed separate but is an ethnic subgroup and not a racial subgroup. People of Hispanic origin would also be counted in one of the racial subgroups.

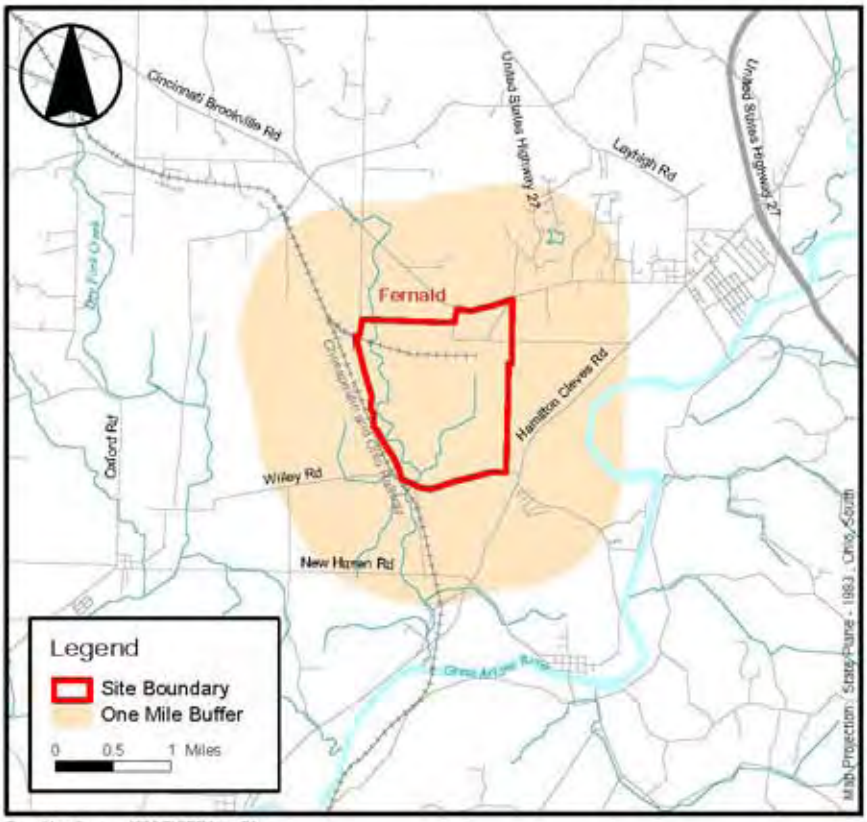
Tables 1A and 1B present demographic data for persons residing within 5 km (3.1 mi) and 10 km (6.2 mi) of the site. These data are similar to the data for persons residing close (within 1.6 km) to the site. There was a slightly higher percentage of non-white persons residing within 10 km (4.9%), as compared to 5 km (0.8%) or 1.6 km (0.5%), of the site. This increase reflects a greater number of black persons residing within 10 km of the site. Ross, New Baltimore, and New Haven are the largest townships within 10 km (6.2 mi) of the Fernald site.

Fernald (Fernald Environmental Management Project)

INTRO MAP

Fernald, Ohio

EPA Facility ID OH6890008976



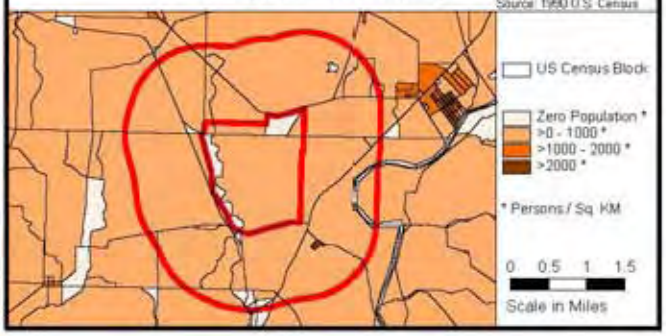
Base Map Source: 1995 TIGER/Line Files

Butler & Hamilton Counties, Ohio

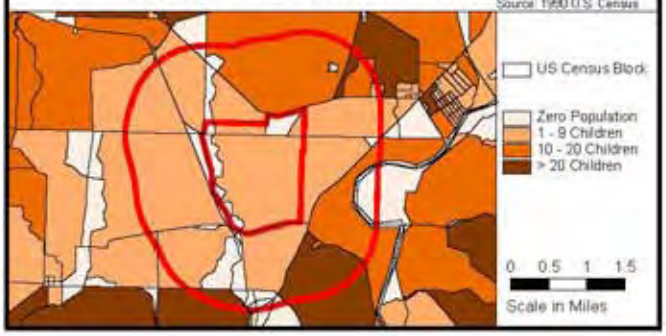
Demographic Statistics Within One Mile of Site*	
Total Population	922
White	917
Black	0
American Indian, Eskimo, Aleut	1
Asian or Pacific Islander	4
Other Race	0
Hispanic Origin	6
Children Aged 6 and Younger	110
Adults Aged 65 and Older	57
Females Aged 15 - 44	215
Total Housing Units	333

Demographics Statistics Source: 1990 US Census
*Calculated using an area-proportion spatial analysis technique

Population Density



Children 6 Years and Younger



Adults 65 Years and Older

Females Aged 15 - 44

JVA000299

Table 1A. Demographic characteristics of the population residing within 5 and 10 kilometers of the Fernald Site property boundary (based on the 1990 Census)*

Characteristic	@ 5 kilometers			@10 kilometers		
	Butler Co.	Hamilton Co	Total Pop.	Butler Co.	Hamilton Co.	Total Pop.
Total Population	5,032	4,094	9,126	30,098	55,225	85,323
Total Area (in miles^2)	22.4	28.1	50.5	74.1	85	159.1
Pop./miles^2	224.6	145.6	180.7	406.1	649.7	536.2
White	4,989	4,062	9,051	29,593	51,548	81,141
Black	10	6	16	210	2,883	3,093
American Indian	5	5	10	28	84	112
Asian	6	8	14	116	280	396
Hispanic Origin†	21	10	31	118	333	451
Other Race	1	3	4	33	97	130
<6 Years of age	550	437	987	2498	6,501	8,999
>65 Years of age	372	349	721	1845	4,012	5,857
Women 15–44 Years of age	1,181	943	2,124	5,785	13,457	19,242

Key: Pop. = population; total number of persons
* Based on the 1990 Census for Butler and Hamilton Counties (ATSDR 1999a)
† Hispanic origin is an ethnic subgroup and also counted within racial subgroups

Table 1B. Summary of demographic characteristics of the population residing within 5 and 10 kilometers of the Fernald Site property boundary (based on the 1990 Census)*

Characteristic	Percent of Population Residing Within 5 Kilometers of Site	Percent of Population Residing Within 10 Kilometers of Site
Total Percent Population	100.0	100.0
White	99.2	95.1
Black	0.2	3.6
American Indian/Native Alaskan	0.1	0.1
Asian	0.2	0.5
Hispanic Origin†	0.3	0.6
Other Race	< 0.0	0.1
<6 Years of age	10.8	10.5
>65 Years of age	7.9	6.9
Women 15–44 Years of age	23.3	22.6

* Based on the 1990 Census for Butler and Hamilton Counties (ATSDR 1999a)
† Hispanic origin is an ethnic subgroup and also counted within racial subgroups

ATSDR Activities

Site Visits and Public Availability Sessions

ATSDR conducted an initial visit to the Fernald site in May 1992. DOE staff and their contractors provided ATSDR representatives with a site tour and information about cleanup activities at the site. Since this initial visit, ATSDR staff have made numerous trips to the site to attend or participate in meetings held by DOE, local organizations such as the Fernald Residents for Environmental Safety and Health, Inc. (FRESH), and site-specific advisory boards. Both DOE and the US Department of Health and Human Services (DHHS) had sponsored site-specific advisory boards. DOE sponsors the currently active Fernald Citizens Advisory Board (FCAB). DHHS sponsored the Fernald Health Effects Subcommittee (FHES) through the fiscal year 2001. ATSDR holds an *ex officio* position on the FCAB and co-sponsored the FHES with CDC's National Center for Environmental Health (NCEH) and the National Institute for Occupational Safety and Health (NIOSH). Additional information about these organizations and advisory boards is provided below.

In 1993, ATSDR held public availability meetings in Ross and Crosby townships. ATSDR representatives invited community members to meet with them one-on-one or in small groups to discuss the community members' health concerns related to the site. Staff from CDC and Boston University assisted ATSDR in meeting with the community during these sessions. Staff from Boston University also assisted ATSDR by consolidating these concerns. Community concerns expressed in these and other meetings are documented and addressed in the Community Concerns section of this report.

Environmental Sampling and Health Consultations

Beginning in 1993, ATSDR staff visited the Fernald area numerous times to collect samples of environmental media, such as soil, air, water, and home-grown vegetables, and to monitor radon levels in private residences near the site and in ambient (outdoor) air. Through an Interagency Agreement, EPA's National Air and Radiation Environmental Laboratory (NAREL) in Montgomery, Alabama assisted ATSDR in collecting and analyzing these samples. Because this work was initiated largely in response to community concerns, sampling and analysis workplans were designed to address questions about releases of radioactive materials from the site and their impact on the surrounding environment and the health of the community. ATSDR has not noted any major discrepancies in environmental concentrations of radioactive materials in its data and the data generated by DOE.

Except for results of some radon measurements in off-site ambient air and early measurements of private residences' air, the results from the ATSDR/NAREL environmental sampling program were previously reported in four health consultations prepared by ATSDR (ATSDR 1995a, 1995b, 1996a, 1996b). This document briefly describes these health consultations in the Environmental Contamination, Exposure Pathways, and Potentially Exposed Population section.

A consultation on ATSDR's ambient radon measurements will be issued separate from this document. (The final radon monitors were collected from the Fernald vicinity in September 2003.) This radon monitoring program is discussed in the above mentioned section, as well as in Appendix E of this document.

Health Education

In response to recommendations from the health care providers' workgroup of the FHES, ATSDR co-sponsored three educational workshops for health care providers in the Cincinnati area. The University of Cincinnati College of Medicine and Mercy Health Partners were also sponsors. The workshops were held in November 1998, February 2000, and January 2003. They were open to all health care providers in the Cincinnati (and Fernald) area. Representatives from ATSDR, NIOSH, the University of Cincinnati College of Medicine, and Fluor-Daniel Fernald presented information on exposures to chemicals and radioactive materials from the Fernald site and related health effects, the Fernald Medical Monitoring Program (FMMP) and Fernald Workers Medical Monitoring Program (FWMMP), and sources of medical and health information. A description of FMMP and FWMMP is given in the next section of this report. Additional information can be obtained by contacting ATSDR's Division of Health Education and Promotion representative identified in the For Additional Information section of this report.

Other Group and Agency Activities

Fernald Health Effects Subcommittee (FHES)

DHHS sponsored the FHES through the fiscal year 2001 as part of the Citizens' Advisory Committee on Public Health Service Activities and Research at DOE Sites. The mission of the FHES was to provide community-based advice and recommendations to CDC and ATSDR concerning the agencies' public health activities at the site. The FHES was composed of members from the Fernald community, labor representatives, and technical experts. Officials from OEPA, the Ohio Department of Health (ODH), and the Hamilton County General Health District served as *ex officio* members. FHES met several times per year, and meetings were open to the public.

Fernald Citizens Advisory Board (FCAB)

The FCAB, formerly the Fernald Citizens Task Force, is sponsored by DOE. The FCAB mission is to provide recommendations to involved governmental agencies regarding specific concerns about remediation and future use of the Fernald site and disposal of waste materials associated with cleanup. The FCAB consists of approximately 15 members representing various elements of the local community. Officials from DOE, EPA, OEPA, and ATSDR serve as non-voting *ex officio* members. Additional information about the FCAB can be obtained by contacting the FCAB representative identified in the For Additional Information section of this report.

Centers for Disease Control and Prevention (CDC)

National Center for Environmental Health (NCEH)

In response to community health concerns related to the Fernald site, the CDC's NCEH conducted several investigations to estimate the amount of radioactive materials released from the site during its years of operation (1951 through 1988) and to assess what health effects might be expected from exposure to this material. These efforts began with the Fernald Dosimetry Reconstruction Project (FDRP) and continued with Phases I and II of the Fernald Risk Assessment Project (FRAP). The FDRP estimated past releases of radioactive materials from the Fernald site, transport of these materials in the environment, and doses to individuals living near the site. Additional information about the FDRP is provided in Appendix D of this report.

The FRAP built on the information produced in the FDRP to estimate population-level risks for the entire community surrounding the site. Phase I evaluated lung cancer mortality risk, and Phase II provided screening-level risk estimates for incidence of kidney cancer, female breast cancer, bone cancer, and leukemia. These investigations are discussed in more detail in the Health Outcome Data section of this report.

National Institute for Occupational Safety and Health (NIOSH)

NIOSH, part of CDC, has conducted (or initiated) several investigations involving Fernald workers. These projects are mentioned briefly in the Health Outcome Data section of this report. Additional information about NIOSH activities at the Fernald site can be obtained by contacting the NIOSH representative identified in the For Additional Information section of this report.

The Fernald Medical Monitoring Program (FMMP) and the Fernald Workers Medical Monitoring Program (FWMMP)

In January 1985, Fernald area residents filed a class action lawsuit against National Lead of Ohio (the Fernald site manager from 1954 to 1985) and DOE. These legal actions resulted in a Settlement Fund and the establishment of a medical monitoring program for neighboring residents. Another legal action resulted in a similar medical monitoring program for workers.

The focus of FMMP is on residents of the neighboring community. The objectives of FMMP are to (1) provide a complete medical evaluation of the current health status of eligible persons, (2) provide a comprehensive evaluation of risk factors for illnesses or diseases of participants, (3) provide education to participants on how to modify risk factors for illness or disease, and (4) establish a good baseline database that may be useful for subsequent epidemiological research (Pinney 1999a). Additional information about FMMP is provided in the Health Outcome Data section of this report.

FWMMP is similar to FMMP, but its focus is on site workers and on occupational exposure histories. FWMMP has about 3,000 participants, and participants are administered medical examinations annually. To date, data collected for FWMMP are not computerized. This health assessment focuses on potential off-site exposure to neighboring residents, and therefore it does not discuss FWMMP in detail. Additional information about FMMP and FWMMP can be obtained by contacting representatives identified in the For Additional Information section of this report.

Fernald Residents for Environmental Safety and Health, Inc. (FRESH)

FRESH is a local community group that advocates cleanup of the Fernald facility, works to educate the surrounding communities, and promotes responsible environmental restoration and public health and safety. Funding for FRESH is provided by the W. Alton-Jones Foundation, public contributions, and membership dues. FRESH holds monthly open meetings to provide residents with an update on Fernald-related issues. FRESH also publishes a newsletter five to six times per year. A representative from FRESH also served on the FHES. Additional information about FRESH can be obtained by contacting the representative identified in the For Additional Information section of this report.

Fernald Community Health Effects Committee, Inc. (FCHEC)

After 2001, when the FHES was disbanded, a non-profit community organization was formed that is concerned about adverse health effects on the local community potentially caused by this site. In the spring of 2004, this group performed a survey of homes within a five-mile radius of the site to determine how area residents have used and maintained their cisterns. This project is being conducted in partnership with the University of Cincinnati Environmental Health Foundation with funding from the Citizens' Monitoring and Technical Assistance Fund. Additional information about FCHEC and its projects can be obtained by contacting the representative identified in the For Additional Information section of this report.

Environmental Contamination, Exposure Pathways and Potentially Exposed Populations

Introduction

This section discusses the various chemicals and radionuclides (contaminants) evaluated in various media for the Fernald site, how people may come into contact with them, and what off-site populations are potentially exposed.

Evaluating Environmental Contamination

Contaminants Evaluated
Contaminants evaluated are those chemicals at levels that exceed media-specific comparison values and all radioactive contaminants found in off-site environmental media. Not all contaminants are at levels that pose a health hazard. The potential for exposure to contaminants of health concern in each pathway is evaluated in this section.

A release of a chemical or a radionuclide into the environment does not always mean that this substance will be a contaminant of health concern to an off-site population. ATSDR scientists first determine if a chemical or radioactive substance in water, air, soil, or biota (plants and animals) should be considered a *"contaminant of concern."* The criteria used include (1) environmental levels exceeding media-specific comparison values, (2) noted community health concerns, and (3) the quality and extent of the sampling data with which to evaluate potential exposure and human health hazard. For inorganic compounds (metals) and radionuclides, background values may also be considered, because some of these substances occur naturally. Also, unlike chemicals, the presence of radionuclides at high enough concentrations in the environment can result in external (or direct) radiation exposures to persons who are close to the material. For chemicals, the highest environmental concentration detected off-site is compared with media-specific comparison values to determine if further evaluation is warranted. Media-specific comparison values are contaminant concentrations in specific environmental media (e.g., water, soil, air) that are considered "safe" under conservative assumptions about exposure. They are *not* thresholds of toxicity. While concentrations at or below comparison values may be considered safe, it does not automatically follow that environmental concentrations that exceed a comparison value would produce adverse health effects. Generally, if a contaminant's concentration exceeds one or more media-specific comparison values, the contaminant is evaluated further in this section and in the public health implications section. (Refer to Appendix A for a description of the media-specific comparison values.)

Determining Exposure Pathways

A release of a chemical or radionuclide into the environment does not always result in *human exposure*. For an exposure to occur, a *completed exposure pathway* must exist. Exposure pathways are characterized as *complete, potential, or not complete.* The five elements of a

completed exposure pathway are (1) a source of chemical or radioactive contamination, (2) an environmental medium or media (e.g., groundwater, surface water, air) through which contaminants are transported from on-site to off-site locations, (3) a point of exposure or place where human exposure is likely to occur, (4) a route of human exposure (e.g., eating, breathing), and (5) an exposed population. A *potential exposure pathway* exists when one or more of the elements is missing but could become present, and available information indicates that human exposure is possible. Also, an exposure pathway is considered potential when modeled data are used to predict human exposure. An exposure pathway that is *not complete* is missing at least one of the elements that most likely will never be present, and it is therefore unlikely that human exposure would occur (ATSDR 1992). Figure 4 illustrates the necessary components of an exposure pathway.

A simple example will illustrate the concept of an exposure pathway. Chemicals or radionuclides may be released from a facility onto the ground (soil) during routine operations or an accident (the *contaminant source*). These substances may then dissolve in rainwater that percolates down through the soil to the underlying groundwater (the *environmental media*). If the contaminated

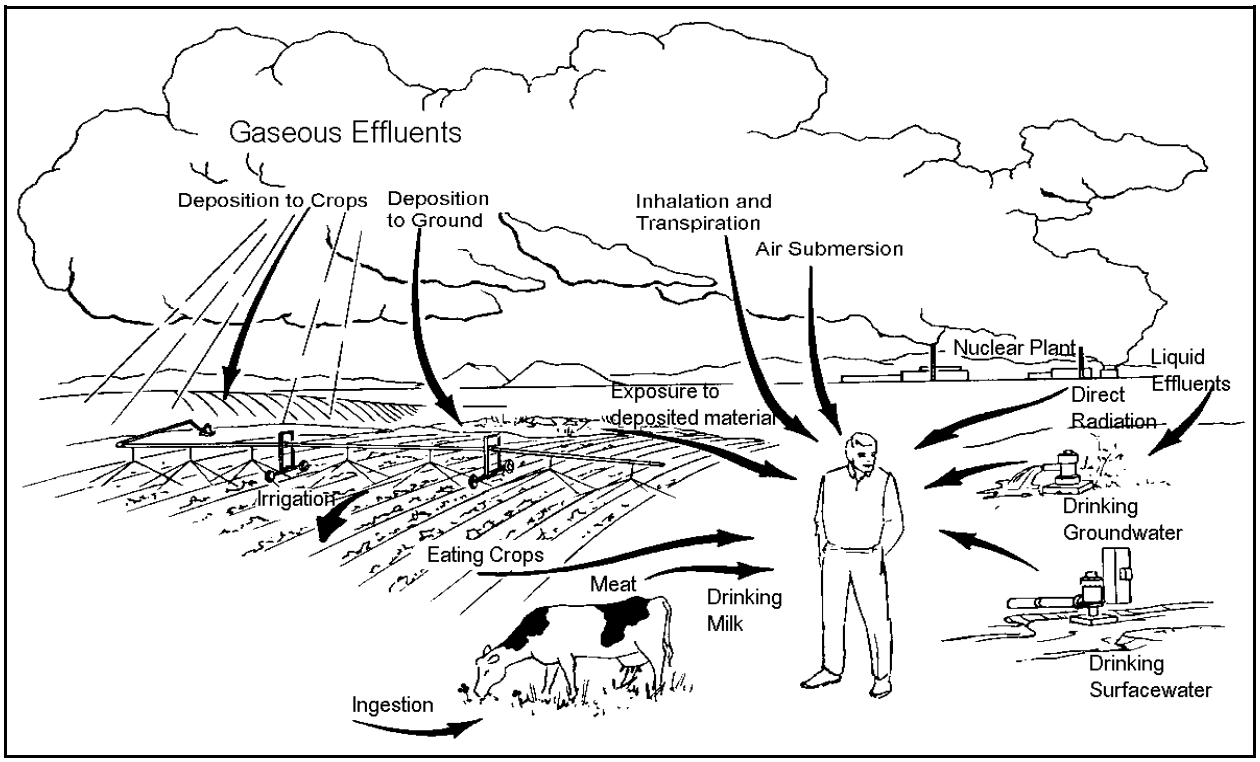


Figure 4. Pathways of exposure to contaminants from the Fernald site

groundwater is being used as a drinking water source (the *point of exposure* and *exposed population*), then people may be drinking and bathing in this water (the *routes of exposure*).

As discussed in the Background section, FMPC released various chemical and radioactive materials to the off-site environment during the production years mainly by air and surface water releases. These releases had potential effects on other off-site media as demonstrated below:

Air releases: Off-site air
Off-site soil from deposition
Food crops and animal forage
Off-site surface water from deposition

Surface water releases: Off-site surface water
Groundwater from migration
Soil, food crops, and animal forage from irrigation
Fish

Storage of chemicals and radioactive materials: Off-site gamma radiation levels
Off-site air from leaks
Groundwater from seepage and migration

ATSDR evaluated the potential for contaminants to be transported off-site by reviewing off-site environmental sampling data from DOE, DOE contractors, the United States Geological Survey (USGS), OEPA, Southwestern Ohio Air Pollution Control Agency, and ATSDR as well as by modeling past releases. Contaminants evaluated further are those found in off-site environmental media at levels exceeding media-specific comparison values. (Media-specific comparison values are concentrations in specific environmental media that are considered "safe" under default assumptions. The fact that a concentration exceeds a comparison value does not mean that a health concern exists but that the contaminant needs to be evaluated further. See Appendix A.)

ATSDR scientists then considered if humans could be exposed to determine completed and potential exposure pathways and to determine potentially exposed populations.

Identifying Potentially Exposed Populations

Current and Past Exposure
Environmental data collected while the facility was in operation were used to estimate **past** exposure to nearby residents. Environmental data collected after the facility stopped operating were used to estimate **current** exposure to nearby residents.

The focus of the ATSDR public health assessment is on *past, current, and potential future* exposure to chemicals and on *current and potential future* exposure to radioactive materials from the site. *Past* exposure to radioactive materials was described in the Fernald Dosimetry Reconstruction Project (Voillesque et al 1995; Killough et al 1998a, 1998b). ATSDR reviewed the documents from this project and will indicate under each pathway section if ATSDR has any comments or a different approach than the methodology used in this project. For the purposes of this health assessment, *current exposure* refers to the period from 1989, when the facility had stopped

process operations, to the present. *Past exposure* refers to the period from 1951 to 1988, when the facility was under construction and operating. When applicable, ATSDR scientists also evaluated *potential future exposure* to chemical and radioactive materials released from the site to the environment.

The exposure pathways analysis is essentially a *screening step* to identify rapidly which pathways and contaminants are *unlikely* to cause adverse health effects requiring no further evaluation and which pathways and contaminants need further evaluation. Using conservative assumptions about exposure, ATSDR scientists estimate exposure doses for chemicals and radioactive materials in completed or potential exposure pathways. For *chemicals*, the estimated exposure doses are compared to a variety of health-based guidelines. Methods and assumptions used by ATSDR scientists to calculate exposure doses are discussed in Appendix B—Exposure Doses and Health-Based Guidelines. When the estimated chemical exposure dose exceeds an appropriate health guideline, a more in-depth, "weight-of-evidence" approach is used to evaluate the health hazard (Weis and Susten 1999). The "weight-of-evidence" evaluation involves a thorough evaluation of the quality and relevance of scientific information that is the basis of health guidelines. For *radioactive* contaminants, ATSDR scientists evaluate all exposure pathways for the site that contribute to radiological doses (committed effective doses to the whole body and equivalent doses to target organs). In the Public Health Implications section, ATSDR adds the doses that a maximally exposed individual could receive from all pathways and determines whether these combined doses indicate an increased likelihood of an individual developing cancer.

Special Consideration of Women and Children

Women and children may sometimes be affected differently from the general population by contaminants in the environment. Both are generally physically smaller than men and are therefore affected by smaller quantities of the contaminants. In addition, the effect of hormonal variations, pregnancy, and lactation can change the way a woman's body responds to some substances. Exposure during pregnancy and lactation can expose the fetus or infant if contaminants cross the placenta or get into the mother's milk. Depending upon the stage of pregnancy, exposure of the fetus could result in death (miscarriage or stillbirth) or birth defects. If the mother is exposed during lactation, her milk may concentrate certain contaminants, increasing the exposure to her infant.

ATSDR recognizes that a developing young person, whether fetus, infant, or child, has unique vulnerabilities. For example, some exposures would affect children more than adults because of their lower body weight and higher ingestion rate, resulting in an increased dose or amount taken into the body compared to their body weight. In addition, because children are shorter than adults, their breathing zones are closer to the ground and thus closer to soil contaminants and low-lying layers in the air. Different behavioral characteristics for children include more hand-to-mouth behavior, thus tending to increase the ingestion of soil or dust contaminants.

Furthermore, children's metabolic pathways are less developed than those of adults, especially in the first months after birth. In some instances, children are better able to deal with environmental toxins, but in others, they are more vulnerable. Moreover, some chemicals that are not toxic to adults are highly toxic to infants.

Children grow and develop rapidly in their first months and years of life. Some organ systems, especially the nervous and respiratory systems, may experience permanent damage if exposed to high concentrations of certain contaminants during this period. Because of rapid growth and development, a child's genetic material (deoxyribonucleic acid, or DNA) is more likely to be exposed than later in life, making it more vulnerable to damage.

In addition, children have more future years than adults, giving more time for the development of illnesses that require many years to progress from the earliest initiation to the manifestation of the disease.

Finally, young children have less ability to avoid hazards because of their lack of knowledge and their dependence on adults for decisions that may affect children but not adults.

In this document, ATSDR takes into consideration whether women and children were, are, or may be exposed to chemical and radioactive contaminants of concern in the completed and potential exposure pathways for the site. In the Public Health Implications section, ATSDR discusses the public health hazard from exposures via these pathways.

Air Pathway and Direct Radiation

Background

Air exposure pathways include chemicals and radioactive materials released *directly* to air, as particles or gases, and direct radiation (e.g., x-rays and gamma rays). They also include *indirect* releases from resuspension of particles deposited on the ground surface.

As described previously in this document, the most important sources of *past airborne releases* from the site are the dust collectors in Plants 1, 2/3, 4, 5, 6, 7, 8, 9, and the Pilot Plant; the scrubbers in Plants 2/3 and 8; and other monitored and unmonitored sources (e.g., the coal-burning steam plant, waste incinerators and burn pads, waste pits, waste silos, and waste processing operations). Releases from these sources occurred continually throughout the operating history of the facility (Voilleque et al.1995; DOE 1994).

There were also several *past accidental releases of uranium* to the atmosphere when the Fernald facility was operating (Voilleque et al.1995). Two of these events, one in 1953 and another in 1966, involved releases of large quantities of uranium hexafluoride (UF_6) to the atmosphere. The 1966 accident released the largest quantity of UF_6, lasted an hour, and involved a release of UF_6 from a 10-ton cylinder that was under pressure. A leak occurred when a valve unscrewed from the cylinder, expelling the pressurized gas. The escaping gas was vented to the atmosphere through a removable hood and was carried by wind in a southeasterly direction over the Laboratory and Administration Buildings, which were evacuated (Voilleque et al.1995). This incident and the resulting off-site air concentrations are evaluated further on page 30.

The largest sources of *past radon 222 gas* (referred to as “radon” in this report) and *past direct radiation* exposures to nearby residents are the K-65 Silos (Silos 1 and 2), located on the western portion of the Fernald property. These silos contain residues left after extraction of uranium from pitchblende ores from the Belgian Congo. The residues, which were the property of the African Metals Corporation (an agency of the Belgium government), were placed in the silos from 1953 until 1955 (Boback et al.1987). An agreement was made between the African Metals Corporation and the US Atomic Energy Commission (AEC): the AEC was to store the residues separate from other materials for eventual return to the owner. However, in 1983 the lease agreement ended, and DOE assumed full ownership and responsibility for them (Boback et al.1987). The residues contain high concentrations of radium 226, the parent of radon 222. Although the silos had 4-inch concrete domes, radon gas built up in the head spaces and was released to the atmosphere, especially through vents and other dome penetrators such as piping and manholes. In 1964, earthen berms were built around the silos helping to reduce the radiation levels but not the release of radon from the head space. In 1979, major openings were sealed, and pipes removed which significantly reduced the radon release. In 1987, an exterior foam layer was added to the silo domes. Because no direct measurements of radon releases were made until the 1980s, CDC’s Fernald Dosimetry Reconstruction Project (FDRP) used models to estimate past releases. The

results indicate that the majority of the estimated radiation doses were from breathing radon decay products, and that these doses would lead to an increased risk of lung cancer mortality. The FDRP also reviewed measurements of direct radiation levels made on the outside of the silos from 1959 through 1987 (Voillesque et al.1995). The most frequent and consistent measurements were made on the surface of the center of the domes; therefore, the FDRP used these results in their dose estimations for the off-site community. Past releases of radon gas (before 1989), past direct radiation from the silos, and potential health effects from the resulting radiation exposures are extensively discussed in the FDRP and CDC's Fernald Risk Assessment Project (FRAP) (Voilleque et al.1995; Shleien et al.1995; Killough et al.1998a, 1998b; CDC 1998, 1999). For more details on this subject, see Appendix D. ATSDR scientists reviewed the FDRP and FRAP documents and agree with the methodology and conclusions of these reports concerning *past* effects of radon releases and radiation exposures from the silos. The highest direct radiation levels would have occurred just west of the site between 1953 and 1964 and between 1979 and 1988, with the maximum radiation doses received between 1958 and 1963. The highest lung doses from radon progeny would have occurred between 1952 and 1979, with the maximum lung dose received in 1959/1960 by the closest resident to the west side of the site near the silos.

The boilers in the coal-fired steam plant at the western end of the production area were sources of *airborne emissions of particulate matter, sulphur dioxide (SO_2), and nitrogen oxides (NO_x).* Although the plant has now been demolished, it was a source of particulate matter, SO_2, and NO_x releases after the manufacturing plants discontinued operations (DOE 1972–1999). These releases are evaluated further in the environmental data section.

Other *past* non-processing sources of airborne releases included a graphite burner that operated from November 1, 1965 to September 14, 1984, an oil burner that operated from March 31, 1962 to June 15, 1979, an old solid waste incinerator that operated from November 16, 1954 to December 31, 1979, a new solid waste incinerator that operated from January 2, 1980 to April 1986, and a liquid organic waste incinerator that operated from April 1, 1983 to 1984 (HCES 2004). These sources released uranium as well as various chemicals to the atmosphere and are evaluated further in the environmental data section.

Not much is known about the materials that were burned on the burn pad in the Production Area or in the burn pit in the Waste Pits area. Mainly contaminated petroleum products were burned on the burn pad. Chemicals identified during waste pit remedial activities give a clue to the identify of materials burned in the burn pit. Two waste pits were covered by water which cut down on fugitive dust emissions; however, about 30% was not covered at times (DOE 1998b). One pit had a synthetic cap and the other pits had soil covers (OEPA 2001). The contents of the waste pits and burn pit include various organic compounds, organic nitrogen, phosphorus, and metal salts and oxides (predominantly calcium hydroxide, magnesium fluoride, and uranium oxides). No estimate of airborne releases could be made from these sources; therefore, *exposure to airborne releases from these potential sources is indeterminate*.

Current and potential future releases are occurring (or are likely to occur) until remedial activities on site are completed (DOE 1972–1999). Most airborne emissions from the site have decreased significantly since the process operations ceased in 1989; however, radon releases and fugitive emissions could increase as contaminated materials are treated and removed.

Radon and direct radiation releases are occurring from the K-65 silos. Radon concentrations and radiation levels on- and off-site are being monitored. In 1991, a bentonite (clay) layer was added to the top of the K-65 silos, decreasing the radon release rate and direct radiation levels. By 1998, radiation levels were increasing near the K-65 silos (DOE 1972–1999). In December 2002, a radon control system was first tested and substantially reduced the radon concentration in the head space of these silos (DOE 2003b). Continuous operation of the Radon Control System (RCS) began in May 2003, which produced a significant decrease in radiation levels in the vicinity of the K-65 silos and at the western fenceline; however, a potential for radon releases now exists from the RCS stack and the waste pit dryer stack (DOE 2003c).

Also, on-site and site boundary air monitoring is being performed during remediation to measure concentrations of total suspended particles, uranium, and other radioactive particles (DOE 1994, 1972–1999). Monitoring of emission sources has varied some during the course of remedial activities and site closure. During 2002 and the first half of 2003 stacks for Building 71 (waste packaging operations) and the Silos RCS were monitored for these emissions (DOE 2003c). The RCS was also monitored for radon 220/222. The stacks for the Waste Pits Project (WPP) dryer and pugmill were monitored for radioactive particles, and the WPP dryer stack was also monitored for radon 220/222 (DOE 2003c). No air monitoring for chemicals is being performed; however, the WPP dryer has a gas cleaning system to alleviate chemical releases.

Other potential sources that were permitted by the Southwestern Ohio Air Pollution Control Agency beginning in 1985 include storage tanks (mainly for nitric acid and sodium hydroxide), laboratory exhaust systems, flyash piles (particles only), furnace stacks, drum coating operations, WPP dryers, laundry facility dryers, and emissions from railroad car loading and waste preparation building. No incidents or significant releases were reported for most of these permits. One incident notification was received in April 2001 concerning a ruptured disk in one of the WPP dryers which caused a steam release 1-inch in diameter and 10 feet high which did not go through the gas cleaning system and lasted about 7 minutes. Estimates of the contaminant concentrations and potential exposures were later submitted and will be discussed on page 31. (Another WPP dryer incident occurred on June 5, 2004, during a power failure.)

Environmental Data

ATSDR scientists used measurements and estimates of uranium particulate emissions from scrubber and dust collector systems in processing plants on-site and routine air monitoring and estimates for chemical and radioactive contaminants on and off site to evaluate off-site conditions.

In the mid-1950s, continuous stack sampling was performed to check the operational efficiency for controlling FMPC's product. The accuracy of the sampling was not the best. The filters were analyzed mainly for uranium and occasionally for other radioactive materials (Boback et al.1987). According to International Technology Corporation's Interim Report on Air, Soil, Water, and Health Risk Assessment in the Vicinity of the FMPC (IT 1986), the largest total annual emission of uranium occurred in 1955 and was six times greater than the average annual uranium emissions for all other years before 1986. Their *estimated average* annual uranium concentration at the site boundary for 1955 was 0.83 $\mu g/m^3$ (0.56 pCi/m^3). Computer models were used in the FDRP to predict past uranium airborne concentrations using the best known quantities of uranium emissions from stacks and vents and from knowledge of the process operations (Voilleque et al.1995; Shleien et al.1995; Killough et al.1998a,1998b). The *highest estimated* off-site uranium concentration is 3.7 $\mu g/m^3$ (2.5 pCi/m^3) for the area east of the facility in 1955 (Killough et al.1998b). This concentration represents overall site emissions from both direct and indirect airborne uranium releases. Both of the above estimates exceed ATSDR's most conservative comparison value for chronic exposure to airborne uranium of 0.3 $\mu g/m^3$. *Therefore, past exposure to airborne uranium will be discussed further in the Estimated Exposure Dose section for this pathway.*

Routine ambient air monitoring for *uranium* particles began in 1960. From 1960 through 1970, continuous, high-volume samplers were located at the four corners of the *production* area. (Refer to Figure 5.) The majority of air samples collected at the site were analyzed for uranium, radon, and radon daughters. Composites of samples were analyzed for other radionuclides, including radium 226 and 228, neptunium 237, plutonium 238 and 239, technetium 99, cesium 137, and thorium 228, 230, and 232, which were released from the site in such small amounts that they are estimated to have contributed very little to overall releases (Voilleque et al.1995). Annual average uranium concentrations at these monitoring locations were highest in the early 1960s. The highest uranium concentration measured at these monitors is 0.518 $\mu g/m^3$ at the southwest corner of the *production area* in 1960. Although the uranium concentration exceeded ATSDR's most conservative CV at this location, it is unlikely that it would have exceeded it at the southwestern *property boundary*. These *production area* monitors were decommissioned after 1970 and six monitoring stations were established along the fenced *property* boundary. In 1981, an additional monitor was installed near the northwest corner of the property line (IT 1986).

During the period from 1972 to 1984, the highest annual average uranium concentrations measured at the *property boundary* were found at monitoring stations BS-1, BS-2, and BS-3 located north, northeast, and east of the facility, respectively. (Refer to Figure 5.) The highest

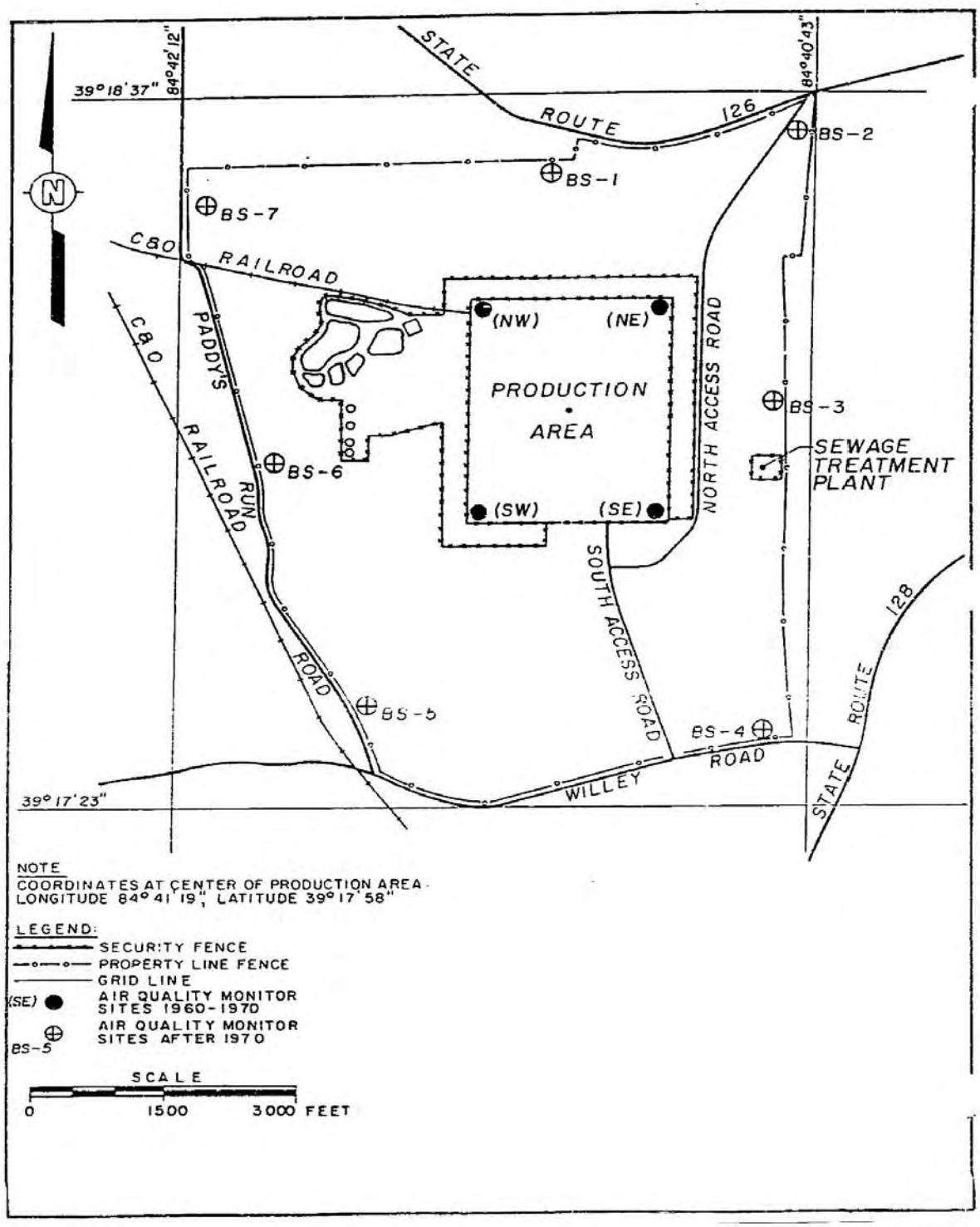


Figure 5. Location of Air Monitoring Stations from 1960 to 1970 and from 1970 to 1987

annual average uranium concentration measured at these locations is 0.037 µg/m^3 in 1983, at monitoring station BS-3, located on the eastern property boundary (IT 1986). This location also had the highest annual average uranium concentrations for 1972 and all years between 1975 and 1984, but none of these concentrations exceeded ATSDR's CV. However, *because off-site air concentrations of uranium prior to 1960 appear to have exceeded ATSDR's CV, all past off-site airborne exposures to uranium will be discussed further in the Estimated Exposure Dose section.*

In 1984, the site began reporting total suspended particulate (TSP) concentrations at the air monitoring stations. In 1984 and 1985 only the average annual TSP concentrations were reported. In some years only radioactive particulate concentrations were reported. From 1986 through 1988 and from 1996 through 2002, maximum, minimum, and average TSP concentrations were reported in the annual environmental reports. Some stations were added or deleted during these time periods, and designations changed to AMS-#. (Refer to Figure 6.) The highest *current maximum* TSP concentration (159 µg/m^3) was reported for AMS-3 (east side of site) in 1997. The highest *current annual average* TSP concentration (52 µg/m^3) was reported for AMS-27 (directly west of the waste pit area) in 2002 (DOE 1972-1999, 2000, 2001, 2002). There are no current standards for total suspended particles, but the highest *current annual average* TSP concentrations at AMS-27 exceed EPA's National Ambient Air Quality Standards for annual concentrations of particulate matter with 2.5 and 10 micron size diameters. From February through November of 1998, DOE measured the activity median aerodynamic diameter (AMAD) of airborne U^{238} and Th^{232} particles from their fence-line air samples and found that ~70% or more of these particles had AMADs of greater than 15 micron (Leifer et al.2002), which means that EPA's standards for all particulate matter were probably not exceed for 1998. The AMADs measured for 1998 are indictive of resuspended soil particles but appear to have been measured for only $U^{238}$and Th^{232} particles. The waste pits remedial activities began in late 1999, and the highest current annual average TSP was reported in 2002 at the northwest boundary near the pits (DOE 1972–1999, 2003d). A supplemental particle size study was done on air filters from the waste pit remedial activity project waste handling facilities from December 11 through December 13, 2000 and from February 6 through February 8, 2001 (DOE 2001c). This study showed a comparison of AMADs for beta and alpha particles versus the total activity on the filters and a comparison of AMADs for alpha and particle weight versus total percentage of particles on the filters. By far the largest percentage of total particles were greater than 9 microns (non-respirable), as were most of the alpha particles in the material handling building. *Therefore, concentrations of total suspended particles do not appear to exceed EPA's air quality standards and will not be discussed further.*

However, waste pits 1, 2, and 4 are known to contain some beryllium. ATSDR scientists reviewed information collected by Fluor Daniel Fernald in 2000 through April 2003 concerning the use and potential contamination from prior use of beryllium at the site. Although documentation shows that 3,000,000 pounds of beryl ore were sent to the site between 1952 and 1961, there are no records indicating if the ore was used, where it was used, or how it was disposed of, and no verbal recollection of the ore from former employees (Fluor Daniel Fernald 2000). It was reported that approximately 3,000 pounds of beryllium used as a coating on

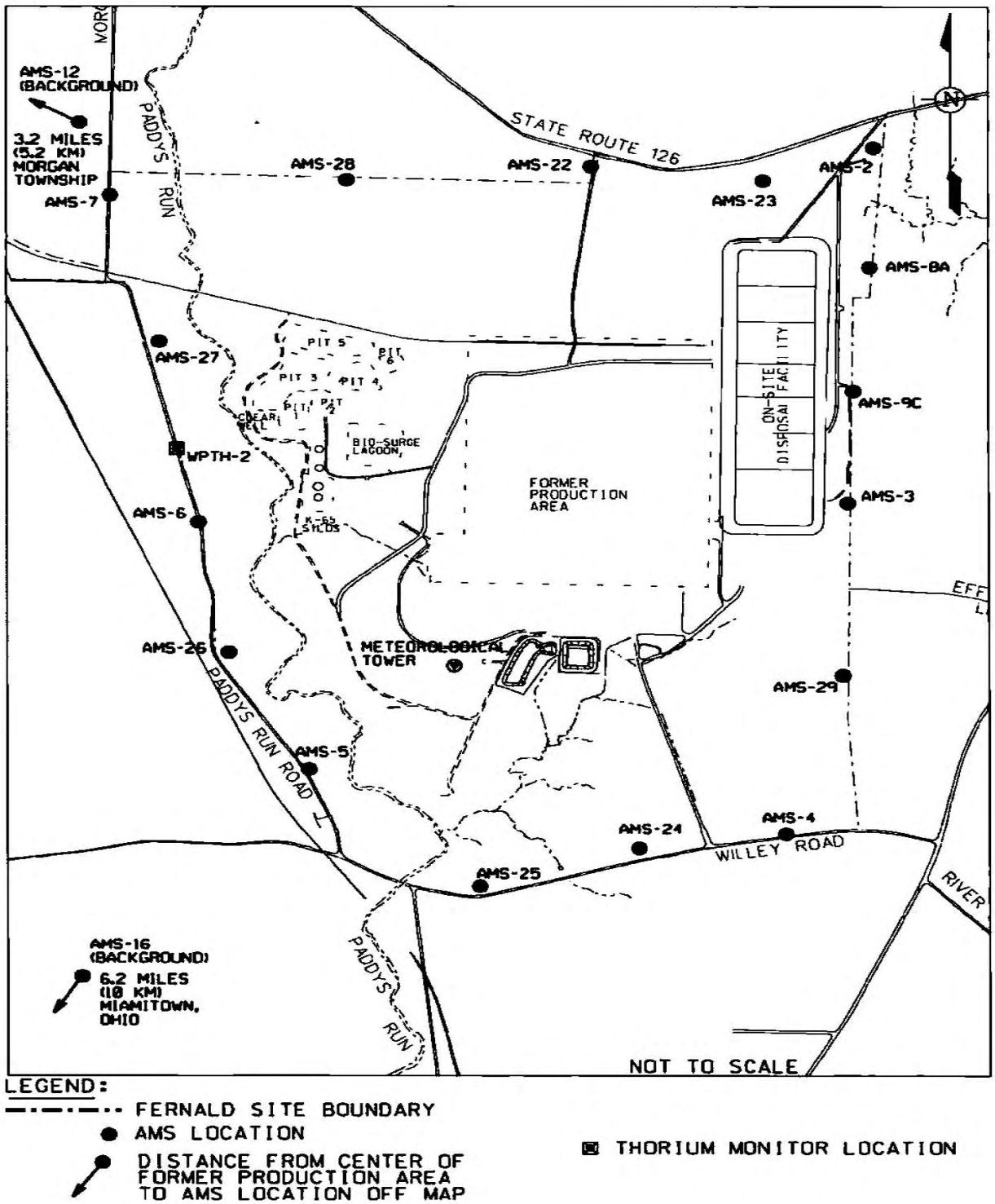


Figure 6. Location of Air Monitoring Stations (AMS) from 1988 through 2002

crucibles were buried in Waste Pit 1 in 1956 and in Waste Pit 4 between 1964 and 1969. Approximately 200 to 300 pounds of beryllium contaminated waste were buried in Waste Pits 1 and 2 in 1958 (Fluor Daniel Fernald 2000). In 1999, DOE adopted a rule concerning worker exposure to beryllium. The rule established an 8-hour time-weighted average beryllium concentration of 0.2 µg/m^3 which triggers the necessity for workplace precautions and controls (DOE 1999). ATSDR's comparison value for chronic exposure to airborne beryllium is 0.02 µg/m^3 (chronic inhalation RMEG). From DOE's measurements at the fenceline, the potential hazard from off-site concentrations of airborne beryllium during the remedial activities for the waste pits cannot be determined. *As a result, current off-site airborne exposure to beryllium is indeterminate.*

By 1990, 16 air monitoring stations were operating on and off the Fernald property: 7 at the property fenceline, 2 on-site, and 7 off-site. Weekly analyses for total uranium and suspended radioactive particles were performed. A fraction of each sample was composited for yearly analyses of several radionuclides, including strontium 90, radium 226 and 228, neptunium 237, plutonium 238 and 239/240, technetium 99, cesium 137, and thorium 228, 230, and 232 (DOE 1972–1999). By 1994, 21 air monitoring stations were established on and off the Fernald property: 7 at the property fence, 4 near the waste pits, 3 at other on-site locations, and 7 off-site. The maximum annual concentrations for radioactive particles in off-site air and *potential current exposures to all airborne radioactive particles will be discussed in the Estimated Exposure Doses section for this pathway.*

The Fernald facility began routine *radon* (gas) monitoring in July 1980. Alpha-track etch detectors (radon cups) had been used until the end of 1998 to collect airborne radon measurements at the site boundary and at various locations on and off the Fernald facility property. These detectors measure total radon concentration over an extended period and are returned to the manufacturer's laboratory for analysis. Originally, the Fernald facility exchanged these detectors every three months; in later years, the facility exchanged them every six months. In 1991, the facility installed real-time monitors (alpha scintillation detectors) to continuously record radon concentrations at some air monitoring stations on-site, at the perimeter of the K-65 silo berm, in the head space of the silos, at the boundary of the site, and at two background locations. Real-time monitors operate continuously to provide radon concentration data in set time intervals, such as every hour. In 1992, ATSDR and EPA's National Air and Radiation Environmental Laboratory (NAREL) entered into an interagency agreement to monitor environmental radon concentrations in the vicinity of the FEMP site. Data were collected from 1993 and 1994 and were presented in ATSDR's health consultation in May 1995. ATSDR continued to monitor for off-site radon concentrations until September 2003. (For more details about the ATSDR/NAREL and DOE Radon Monitoring Comparison, refer to Appendix E.) As mentioned earlier, two additional sources of radon 220/222 releases have been added during remedial activities: the WPP dryer stack and the Silos RCS stack. The current alpha-track monitoring results at the fenceline and *potential current exposures from radon will be discussed in the Estimated Exposure Doses section for this pathway.*

The largest source of *direct radiation* (gamma rays and x-rays) at the site is the waste material stored in Silos 1 and 2. As stated previously, FDRP reviewed direct radiation measurements and determined potential *past* exposures for five scenarios which are extensively discussed in the FDRP and FRAP documents. The individual described in scenario 2 (a person living 1.2 miles west of the center of the site for 38 years) received the highest external radiation dose from the silos (Killough et al.1998b). ATSDR scientists reviewed the calculations and assumptions for this determination and agree with the estimated doses for this individual. For the closest resident to the site who was in this area 24 hours per day for 350 days a year between 1957 and April 1964, the maximum *past* external doses were estimated to be 84 millirem (0.84 millisievert) per year. For most of the residents that live to the west of the site, the doses during this time period would have been approximately one-tenth this estimate or less. After the berms were added next to the silos in 1964, the direct radiation levels were ten percent lower for the closest resident. After the silo openings were sealed in 1979, the direct radiation levels again increased up to approximately 75 millirem (0.75 millisievert) in 1988 for the closest resident to the silos (Killough et al.1998b). By 1990, integrated direct radiation measurements were taken quarterly at the site boundary and at on-site and off-site locations by use of thermoluminescent detectors (TLDs). The TLDs are collected quarterly, and the data are reported in the annual Site Environmental Reports (DOE 1972–1999). In 1990, the maximum fenceline measurement was 28 millirem (mrem) per quarter (qtr) (approximately twice background) to the west of the silos and the waste pits. In 1991 the bentonite cap was added to the silos, and the maximum western fenceline measurement dropped to 17 mrem/qtr. In 1998, an increasing trend in radiation levels was identified at on-site locations near the K-65 silos. (The western fenceline levels were approximately 22 mrem/qtr.) By 2002, the maximum quarterly radiation level (at the western fenceline) was approximately 24 mrem/qtr (DOE 2003d). The radon control system (RCS) was first tested in December 2002. The fenceline radiation level at the monitor closest to the silos was 20 mrem/qtr, and the fenceline level at the monitor closest to the waste pits was 21 mrem/qtr for the first quarter of 2003. Continuous operation of the RCS began in May 2003. The fenceline radiation level at the monitor closest to the silos was 17 mrem/qtr, and the fenceline level at the monitor closest to the waste pits was 18 mrem/qtr for the second quarter of 2003. Because TLDs measure constant radiation exposure (24 hours/day) at the fence and radiation levels would be significantly less at any of the neighboring residences, *no one off-site would have received an exposure dose that would cause an adverse health effect from direct radiation before or after the plant ceased operation in 1989.*

Air sampling data are not available for *chemicals* (other than uranium) that may have been transported off site to locations where human exposure could occur. During the Remedial Investigation for Operable Unit 5 (DOE 1994), the non-radioactive predominant chemicals of concern (other than total uranium) that were identified for the air pathway based on *past* operational use at the site, included arsenic, barium, cobalt, manganese, thallium, indeno(1,2,3-cd)pyrene, and polychlorinated biphenyls (PCBs). Other chemicals used on site in large quantities included nitric acid, sodium hydroxide, hydrochloric acid, hydrofluoric acid, kerosene, tributyl phosphate, calcium hydroxide (lime), calcium-magnesium carbonate (dolomite), and various oils and oily materials. Some waste materials were incinerated or burned on the burn pad

or in the burn pit. Because no ambient air monitoring was available for potential chemicals released during plant operations or waste burning, their concentrations in off-site media (e.g. soil, surface water, vegetation) were reviewed in other pathway sections to determine qualitatively if these contaminants reached off-site locations via the air pathway. (Grass samples analyzed for fluoride will be discussed in the biota section.) ATSDR also used modeling and estimates of airborne concentrations for the 1966 accidental release of UF_6 (largest accidental release), for SO_2 and NO_x chronic releases from the steam plant, for concentrations released during a current incident with a waste pit project dryer, and for concentrations of metals in re-suspended soil particles, which are discussed below.

On February 14, 1966, a valve was inadvertently removed from a heated cylinder of UF_6. Approximately 1,195 kg U as UF_6 were released about 6 feet above the ground. It was vented to the atmosphere through a removable hood. The release lasted 1 hour with the wind from the north at approximately 5 miles per hour, the temperature at 33 to 35 degrees F, and the humidity at 90% with no precipitation (Boback et al.1987). Because fire hoses and water spray were used quickly to try to control the release and cool the cylinder, the release estimates were later modified to 750 kg U released to the atmosphere and 910 kg U released to the Great Miami River via Manhole 175. Airborne UF_6 hydrolyzes rapidly with the moisture in the air to form a soluble uranium compound, uranyl fluoride (UO_2F_2), and a gas, hydrogen fluoride (HF). During the FDRP, contractors for the CDC used models to predict the concentrations of HF released to the atmosphere and to estimate the kidney dose from UO_2F_2 exposure to a hypothetical individual located 1.3 km downwind of the release (Killough et al.1998b). ATSDR scientists have reviewed these calculations and agree with the methodology and estimated exposures for this incident. The radiation dose and uranium intake by this hypothetical individual would have been approximately 1.5 mrem (15 µSv) effective dose and 4.2 mg U inhaled. The maximum kidney concentration for the 1966 episodic release and hypothetical scenario was estimated to be 0.75 µg U per gram of kidney tissue. The widely used toxic threshold for renal damage in animals is 3 µg U per gram of kidney tissue; however, some mild effects have been seen at levels as low as 0.1 to 0.5 µg U per gram of kidney tissue. Therefore, renal damage would not be expected but some mild, transient effects on the kidney may have been experienced. No adverse health effects from the radiation dose would be expected. The estimated median HF concentration at this location was 0.6 mg/m^3, with a 95^{th} percentile concentration of 1.5 mg/m^3 (Killough et al.1998b). ATSDR does not have a comparison value (CV) for short-term HF releases. The Occupational Safety and Health Administration (OSHA) has set a permissible exposure level (PEL) of 3 ppm (or 2.5 mg/m^3) for HF exposure to workers. The PEL represents a time-weighted average concentration for an 8-hour work day, 40-hour work week. The PEL is intended to protect workers from irritation effects of HF on the respiratory system, skin, and eyes. The National Institute for Occupational Safety and Health (NIOSH) has established an air concentration of 30 ppm (or 25 mg/m^3) for HF that is considered immediately dangerous to life or health (IDLH). Air concentrations should not exceed the IDLH for a period of more than 30 minutes. CDC's estimated air concentration of HF is below the OSHA PEL and the NIOSH IDLH. Therefore, *ATSDR would not expect any adverse public health effects from this exposure to HF and will not further evaluate exposures to HF resulting from this or any other past accidental releases*.

ATSDR scientists estimated off-site concentrations of *SO_2 and NO_x* from the coal-fired steam plant in the Fernald production area by using the US Environmental Protection Agency's (EPA's) SCREEN3 air dispersion model (EPA 2000b). ATSDR selected inputs (e.g., wind speed, terrain, emission rates) that produced the highest (worst-case) downwind concentrations at the nearest residence, located 2,500 feet (760 meters) north-northeast of the facility. Emission rates were available for only 1 year, 1988, under *past* conditions at the site. Using peak operational years of the facility and the possibility of past use of coal with higher sulfur and nitrogen content, the 1988 emission rate was most likely much less than the maximum rate for *past* conditions at the site. Also, the 1988 emission rates were equal to or lower than the highest emission rates reported for the *current* years (after production ceased): 410,000 kg of SO_2 per year (yr) for 1991 and 160,000 kg/yr of NO_x for 1994 (DOE 1972–1999). The coal-burning plant was permitted by the Southwestern Ohio Air Pollution Control Office but not until 1985. Using the *current* emission rates and assuming worst-case conditions of air dispersion, ATSDR estimated that the maximum 1-hour SO_2 concentration at the nearest residence, located 2,500 feet from the stack, was 227 $\mu g/m^3$. The estimated maximum 1-hour NO_x at this residence was 89 $\mu g/m^3$. ATSDR compared these concentrations to EPA's National Ambient Air Quality Standards (NAAQS). The estimated maximum 1-hour SO_2 concentration at the nearest residence (227 $\mu g/m^3$) is less than the 3-hour average (1300 $\mu g/m^3$) and 24-hour average (365 $\mu g/m^3$) NAAQS. The estimated maximum 1-hour NO_x concentration (89 $\mu g/m^3$) is less than the NAAQS for NO_x (100 $\mu g/m^3$ annual arithmetic mean concentration) (EPA 2002). Although it is possible that past releases were also within these limits, *ATSDR found that past SO_2 and NO_x releases were indeterminate based on a lack of release data during the peak years of operation. However, current releases were not at a level of health concern and will not be further evaluated.*

ATSDR also reviewed incident reports that may have caused unplanned releases and *estimated* current off-site air concentrations of metals in re-suspended soil particles by using the maximum *measured* concentrations of total suspended particles in the off-site air and *measured* surface soil concentrations for metals. No estimates of past off-site air concentrations for re-suspended metal particles could be made due to insufficient information.

One *current* incident report was reviewed: a crack in the rupture disk for a WPP dryer on April 3, 2001, involved a steam release (1-inch in diameter and 10 feet high) lasting 7 minutes (DOE 2001d). The estimated chemical constituents of the release were based on extrapolation from an Event Basis Accident 5 for a similar scenario; however, the release involved a measured amount of thorium 230 in lieu of uranium oxide. The site's estimated radiation exposure and chemical concentrations at 40 meters from the source (which is an *on-site* location) are listed below:

Committed effective dose equivalent from the thorium 230 — 0.035 mrem (0.35 µSv)
Benzo-a-pyrene (B(a)P) — 6.3E-06 mg/m^3
Benzo-b-fluoranthene (B(b)F) — 5.8E-06 mg/m^3
Dibenzo-(a,h) anthracene (DB(ah)A) — 8.4E-07 mg/m^3
Arsenic (inorganic) — 1.6E-04 mg/m^3
Lead (inorganic) — 3.2E-05 mg/m^3
Beryllium — 1.3E-06 mg/m^3

Although ATSDR does not have CVs for B(a)P, B(b)F, and DB(ah)A, the concentrations listed above for B(a)P and DB(ah)A are significantly less than guidelines established by some states. The arsenic and beryllium concentrations exceed ATSDR's CVs; however, the CVs are based on chronic exposure for 70 years. When they are adjusted for an acute 7-minute exposure, the estimated concentrations are significantly less than the adjusted CVs. Also, because the closest site boundary is over 400 meters from the dryers, *this incident would not have been a health concern to persons off site. (Another similar incident occurred on June 5, 2004 because of a sudden loss of power which resulted in approximately a 13-minute release from the gas cleaning system and a steam release from the dryers. Although release quantities were not reported in the notification reviewed by ATSDR, due to the duration of the release and the distance to the boundary, it does not appear to have been an off-site health concern.) (DOE 2004)*

ATSDR scientists assumed that off-site suspended particles were generated only by resuspension of surface soil, an unrealistic but conservative assumption. Also, not all re-suspended particles would be respirable; however, ATSDR assumed that they were since this method is being used only as a screening tool. The *derived* airborne concentration for each metal was estimated by using the following equation:

Air conc (mg/m^3) = soil conc (mg/kg) x (1 $kg/10^9$ μg) x particulate conc ($\mu g/m^3$)
where: conc = concentration
mg/m^3 = estimated number of milligrams of metal per cubic meter of air
mg/kg = measured number of milligrams of metal per kilogram surface soil (off site)
1 $kg/10^9$ μg = a conversion factor (to convert from kilograms to micrograms)
$\mu g/m^3$ = measured number of micrograms of total suspended particles per cubic meter of air

Surface soil chemical concentrations were measured on a few occasions from 1991 through 1993, and prior to and following remedial activities. Although the soil sampling data were limited, metals (other than uranium) selected as contaminants of concern for the soil pathway are arsenic, barium, and manganese. (For further information, refer to the Soil Pathway section of this report.) Other metals detected in off-site surface soil for which ATSDR has health-based comparison values for air are beryllium, cadmium, cobalt, and nickel. As discussed previously in this section, total suspended particles (TSP) were routinely measured at sampling stations located at the fenceline and within 4 miles of the Fernald production center during this time period. The yearly average suspended particulate concentrations ranged from 30.0 to 39.6 $\mu g/m^3$ from 1991 through 1993 (DOE 1972–1999). The highest annual average (39.6 $\mu g/m^3$) was used to calculate airborne concentrations of metals. No off-site soil sampling data for chemicals other than uranium are available for the period when the facility was operating; however, unless additional soil was deposited on an area or the area was tilled, metal concentrations in surface soils would have remained the same or increased over time. Other current soil sampling data (collected prior to and after remedial activities or for release of an area) were also reviewed; however, the data did not specify if the samples were from the surface or subsurface (SED 1998, updated 2004). The derived maximum and mean air concentrations are in Table 2 along with the health-based comparison values. In the table an asterisk indicates that soil samples results reported for remedial activities were higher than the surface soil sample results from 1991 through 1993.

Table 2. Derived Concentrations of Off-Site Resuspended Soil Particles from 1991 through 1993 and Health-Based Comparison Values

Metal	Maximum/Mean Surface Soil Concentrations (mg/kg)	Derived Maximum/Mean Air Concentrations (µg/m^3)	Comparison Value (µg/m^3)
Arsenic*	9.2/ 5.8	0.00036/ 0.00023	0.0002
Barium	331/ 143	0.013/ 0.006	11.4
Beryllium*	1.4/ 1.1	0.00006/ 0.00004	0.02
Cadmium	1.9/ 1.2	0.00008/ 0.00005	0.0006
Cobalt	31.6/ 13.4	0.0013/ 0.0005	0.1
Manganese	4,850/ 1,873	0.192/ 0.074	0.04
Nickel	18.2/ 10.7	0.0007/ 0.0004	0.09

Key:
mg/kg = milligram per kilogram
µg/m^3 = microgram per cubic meter
* - indicates that unspecified depth samples collected during remedial activities were higher
Note: The air concentrations are very conservative since this screening technique assumes that all suspended particles are generated by resuspension of soil.

The derived mean and maximum air concentrations of arsenic and manganese exceed the CVs. (Refer to Appendix A for a description of ATSDR's CVs.) ATSDR's CV for **arsenic** is a CREG (0.0002 µg/m^3), which is based on *continuous* exposure for a 70-year life span (ATSDR 1998). ATSDR's CV for **manganese** is an EMEG/MRL of 0.04 µg/m^3, which is based on continuous exposure (ATSDR 1997). *Exposure to airborne arsenic and manganese as well as uranium will be discussed further in the Estimated Exposure Doses section.*

ATSDR does not have a CV for **barium** in air; therefore, ATSDR scientists used NIOSH's recommended exposure limit (REL) and OSHA's permissible exposure limit (PEL) for occupational exposure (500 µg/m^3) and adjusted this value for full-time exposure of the general public (11.4 µg/m^3). Maximum and mean concentrations of barium were less than this value. Maximum and mean concentrations of beryllium, cadmium, cobalt, and nickel were less than ATSDR's CVs. Therefore, *ATSDR will not further evaluate exposure to barium, beryllium, cadmium, cobalt, and nickel in re-suspended soil particles.*

Estimated Exposure Doses

ATSDR scientists evaluated *past*, *current*, and *potential future* exposure to *chemicals* in air off the Fernald site. Uranium, arsenic, and manganese are the only chemicals evaluated for this pathway; however, due to the lack of information on chemical emissions when the plant was operating, most *past* chemical exposures for the air pathway are indeterminate.

ATSDR scientists also evaluated *past, current,* and *potential future* exposure to *radioactive* contaminants in air and direct radiation off the Fernald site. Uranium, radon, and radon daughters are the primary radioactive contaminants. Strontium 90, technetium 99, cesium 137, radium 226, radium 228, thorium 228, thorium 230, thorium 232, neptunium 237, plutonium 238, and plutonium 239 are secondary radioactive contaminants evaluated for this pathway. Collectively, the term used to refer to all radionuclides evaluated is "radioactive contaminants." Because exposures to radon and radon decay products are evaluated differently from the other radioactive airborne contaminants, ATSDR evaluated them as separate contaminants for this pathway.

In estimating chemical and radiological doses, ATSDR evaluated two *hypothetical* exposure scenarios. The first assumes exposure to a child 1 to 6 years old and weighing 13 kg who inhales the above mentioned airborne contaminants while playing near the Fernald site. ATSDR assumed this child breathes 5 cubic meters of air per day (5 m^3/day) while playing near the site for 10 hours a day, 351 days a year, for 6 years (EPA 1999). ATSDR estimated exposure to a child because children, with immature or developing systems, may have increased sensitivity to toxic effects of uranium. ATSDR does not have direct evidence that shows whether children play or have played close to the facility boundary. However, 1990 Census data for Butler and Hamilton Counties indicate that 922 persons live within 1 mile of the Fernald facility. Of these, an estimated 110 persons were 6 years of age or younger. The closest residence to the production area was directly east of the site. Access to off-site contaminated areas was not restricted. Therefore, ATSDR scientists made conservative assumptions in estimating inhalation (and ingestion) exposure doses of airborne contaminants for children playing near the site. The second hypothetical exposure scenario assumes exposure to an adult farm worker who weighs 70 kg and inhales (and ingests) maximum concentrations of the airborne contaminants while working near the facility. ATSDR assumed that this farmer breathes 51 m^3/day while doing heavy work for 10 hours a day, 351 days a year, for 10 years (from 1989 through 1998) (EPA 1999). Because several active farms are located near the site, these scenarios are realistic ones but also conservative considering adverse weather conditions.

Chemicals

In calculating exposure doses for chemical effects of *uranium*, ATSDR used *estimated* and *measured* airborne concentrations of uranium. These uranium doses are for past and current exposures. In calculating exposure doses for chemical effects of *arsenic* and *manganese*, ATSDR used derived airborne concentrations of re-suspended soil particles. Exposure doses for these metals are only for 1991 through 1993. These doses were compared to health-based guidelines to determine if further evaluation of a potential public health hazard was warranted.

Past Exposure

The *estimated* airborne uranium concentration for 1955 was used for screening purposes; however, this concentration was approximately six times higher than concentrations estimated for all other years prior to 1989. As Table 3 shows, the estimated 1955 airborne uranium

concentration (3.7×10^{-3} mg/m^3) is lower than the health-based guideline (8×10^{-3} mg/m^3) for intermediate inhalation exposure to *insoluble* uranium in air, but higher than the health-based guideline (3×10^{-4} mg/m^3) for chronic inhalation exposure to *soluble* uranium in air. The *insoluble* uranium guideline is more relevant for Fernald, because the majority of releases from the site involved insoluble forms of uranium (Voilleque et al. 1995). For past years other than 1955, the estimated concentration would have been lower. Although past airborne uranium would not be a contaminant of concern by itself, ATSDR scientists evaluated the public health hazard of uraium from this pathway together with other exposure pathways (i.e., groundwater, soil, surface water, and biota) that contribute to total uranium exposure to nearby residents in the Public Health Implications section of this report.

Table 3. Current and past airborne concentrations of uranium and estimated off-site exposure doses for a child (scenario #1) and an adult farmer (scenario #2)

Scenario	Maximum Exposure Concentration (in mg/m^3)	Estimated Exposure Dose (in mg/kg/day)	Health-Based Guidelines
#1: Child			8×10^{-3} mg/m^3 (ATSDR int inhalation MRL — insoluble uranium) 3.4×10^{-4} mg/m^3 (ATSDR chr inhalation MRL — soluble uranium)
Past exposure (1955)*	3.7×10^{-3}	1.5×10^{-3}	
Current exposure	6×10^{-7}	2×10^{-7}	
#2: Adult Farmer			
Past exposure (1955)*	3.7×10^{-3}	2.5×10^{-3}	
Current exposure	6×10^{-7}	4×10^{-7}	

Key:
mg/m^3 = milligrams of uranium per cubic meter of air
mg/kg/day = milligrams of uranium per kilogram of body weight per day
int = intermediate; chr = chronic; MRL = Minimum Risk Level
* Past exposure for 1955 is approximately six times higher than for all other past years.

Current Exposure

Uranium emissions have been reduced drastically since the facility stopped operating in 1988 (Voilleque et al. 1995; DOE 1972–1999). The highest yearly average uranium concentration measured in off-site air since 1988 is 0.000562 µg/m^3 (or 6×10^{-7} mg/m^3). This concentration was *measured* at the eastern boundary in 1993 and represents overall site emissions from both direct and indirect air releases of uranium (DOE 1972–1999). This airborne uranium concentration is lower than the health-based guideline (8×10^{-3} mg/m^3) for intermediate-inhalation exposure to insoluble uranium in air, and lower than the health-based guideline (3×10^{-4} mg/m^3) for intermediate-chronic inhalation exposure to soluble uranium in air. ATSDR scientists used this maximum concentration to estimate exposure doses for chemical uranium, and for committed effective doses (whole body) and committed equivalent doses (lungs and bone surface) for radioactive uranium, for both hypothetical exposure scenarios. ATSDR's estimated exposure doses are presented in Tables 3 and 4.

Although the current uranium concentrations are more than 500 times lower than ATSDR's CVs, ATSDR scientists evaluated the public health hazard of uranium for this pathway together with

other exposure pathways (i.e., groundwater, soil, surface water, and biota) that contribute to total uranium exposure to nearby residents in the Public Health Implications section of this report.

As shown in Table 2, the derived maximum and mean concentrations for arsenic and manganese as re-suspended soil particles exceed the comparison values. ATSDR scientists used the maximum derived concentrations to estimate inhalation exposure doses for arsenic and manganese in air for both scenarios described previously. The maximum estimated inhalation exposure doses for a child to arsenic is 1.4×10^{-7}mg/kg/day. The maximum estimated inhalation exposure dose for an adult farmer to arsenic is 1.9×10^{-7} mg/kg/day. *ATSDR will further evaluate the potential for public health effects from exposure to airborne arsenic along with other pathways in the Health Implications section of this report*. For manganese, the maximum estimated inhalation doses for a child is 7×10^{-5} mg/kg/day and for the adult farmer is 1×10^{-4} mg/kg/day. Because manganese is essential in the human diet, the National Research Council has established a range of "estimated safe and adequate dietary intakes" (ESADDIs) for manganese, which are 0.3 to 2.0 mg/day for children less than 6 years old and 2 to 5 mg/day for persons over 11 (NRC1989). The estimated exposure doses are much lower than ATSDR's interim guideline and the National Research Council's recommendations. Therefore, *ATSDR will not further evaluate the potential public health effects from exposure to airborne manganese*.

Radiation

In evaluating radiation effects, the whole body, lungs, and bone surface are the major target organs for inhaled uranium and most other site-related airborne radioactive contaminants. ATSDR scientists calculated committed effective doses (whole body) and committed equivalent doses (lung and bone surface) for airborne radioactive contaminants other than radon and radon decay products for both hypothetical exposure scenarios described previously. (A different approach is used for exposure to radon and radon decay products.) ATSDR's calculations are very conservative due to assuming a small particle size. ATSDR also calculated a range of maximum external doses for current years, because the addition of the bentonite cap has changed (decreased) the potential for off-site exposure.

Past Exposure

As discussed previously, *past* exposures to radioactive contaminants in air and to direct radiation were addressed in the FDRP and FRAP (Voilleque et al. 1995; Shleien et al. 1995; Killough 1998a, 1998b; CDC 1998, 1999). Contractors for CDC predicted total radiation doses and risk to residents using nine scenarios. A description of these projects is provided in Appendix D of this report. Scenario 1 was a "realistic maximum inhalation exposure northeast of the site" (Killough et al.1998b). This individual lived within 1 mile of the site center for 38 years beginning when the plant went into operation. The median cumulative estimated effective dose for scenario 1 for 38 years of exposure to *only uranium* is 6.1 rem (or 0.061 sievert) with a possible range of 2 to 18 rem (0.02 to 0.18 sievert). Because the maximum uranium concentration at the site boundary was to the east, ATSDR scientists estimated doses for an individual living to the east of the site

using the maximum estimated uranium concentration for 1955 and approximately one-sixth these concentrations for the other 37 years, which resulted in very similar doses as those in the FDRP. Although ATSDR believes that the maximally exposed individual lived to the east of the site instead of to the northeast, ATSDR agrees with the FDRP's estimated doses from *past* airborne releases of uranium and radon for the nearby community.

ATSDR estimated that the maximum whole body dose (committed effective dose) for 1 year of exposure for an *adult* living to the *east/northeast* of the site in 1955 would have been approximately 0.85 rem (0.0085 sievert) with all other past years being approximately 0.14 rem (0.0014 sievert). The corresponding 1955 lung and bone surface doses (committed equivalent doses) would have been approximately 6.6 rem (0.066 sievert) and 1 rem (0.01 sievert), respectively. For all other past years, the adult lung and bone surface doses would have been approximately 1.1 rem (0.011 sievert) and 0.17 rem (0.0017 sievert), respectively. ATSDR estimated that the maximum whole body dose (committed effective dose) for one year of exposure for a five-year old *child* living *east/northeast* of the site in 1955 would have been approximately 1.7 rem (0.017 sievert) with all other past years being approximately 0.28 rem (0.0028 sievert). The corresponding 1955 lung and bone surface doses (committed equivalent doses) would have been approximately 13.7 rem (0.137 sievert) and 1.5 rem (0.015 sievert), respectively. For all other past years, the child lung and bone surface doses (committed equivalent doses) would have been approximately 2.3 rem (0.023 sievert) and 0.27 rem (0.0027 sievert), respectively.

FDRP's highest estimated committed equivalent dose to the epithelium of the tracheobronchial portion of the lung from *past* radon releases was 360 rem (3.6 sieverts) for 38 years of exposure (Killough et al.1998b). The FDRP estimated that a 38-year median dose for a person living northeast of the site would be approximately the same as a 38-year median dose for a person living west of the site. If radon exposure was consistent over the entire 38-year period, the past estimated committed equivalent dose to the lung from 1 year of exposure would be approximately 9.5 rem (0.095 sievert). However, the dose estimate for 1 year of exposure should be lower for the years following the corrective actions in 1979. For children, radon doses from 1 year exposure for very small children is similar to an adult but by the time they are 10 years of age the dose can be approximately 1.6 times higher. Although a child may receive a higher dose from the same amount of radon, the probability of developing lung cancer from radon exposure increases with age. After 30 years of exposure the probability of developing lung cancer from radon is approximately equal for a person first exposed as an adult and one first exposed as a child (NCRP 1984). This will be discussed further in the Health Implications section of this report.

Current Exposure

The current estimated committed effective (whole-body) and committed equivalent (lung and bone surface) doses for site-related radioactive contaminants in the air pathway are in Table 4. Further *evaluation of human exposure to radioactive contaminants in off-site air, including a*

determination of whether these estimated doses present an increased likelihood of developing cancer, is discussed in the Public Health Implications section of the report.

For current dose estimates from *radon and radon decay* products from the K-65 silos (Silos 1 and 2) and from direct radiation from Silos 1, 2, and 3, ATSDR scientists reviewed DOE alpha-track monitoring and external exposure data from 1989 to 1999. FEMP discontinued the use of alpha-track detectors and off-site monitoring except for background locations at the end of 1998 and now uses alpha scintillation continuous monitors for detecting radon (DOE 1972–1999). Results from all alpha-track fenceline monitors and those closest to the K-65 silos are shown in Table 5. Since FEMP began using 16 fenceline continuous monitors, the annual average concentrations for all monitors have ranged from 0.31 to 0.49 pCi/L (0.011 to 0.018 Bq/L). The annual average range for the four monitors closest to the silos has been from 0.4 to 0.53 pCi/L (0.015 to 0.020 Bq/L) (DOE 2000c, 2001b, 2002, 2003d). Results are averaged over a year, although concentrations can vary significantly with the seasons of the year and the time of day (Merrill 1998). Silo 3 does not contain waste with high radium concentrations like Silos 1 and 2, but its waste contributes to direct radiation levels. The current radon concentrations and direct radiation levels are not at a level of health concern; however, they will be included in the radiation discussion in the Public Health Implications section of this report.

In 1992, ATSDR entered into an interagency agreement with EPA's National Air and Radiation Environmental Laboratory (NAREL) to monitor radon at residences neighboring the Fernald site. An ATSDR health consultation presented the results of ATSDR/NAREL's sampling from December 1993 through June 1994 and concluded that radon released during this period did not pose a public health hazard (ATSDR 1995b). However, some issues related to DOE's monitoring program were highlighted: DOE's continuous monitors were unreliable when used outside their operational temperature range, DOE did not obtain duplicate hourly radon measurements, and backup continuous monitors were not maintained to replace inoperable detectors. Since then, DOE uses thermal jackets for the monitors and has adequate back-up and procedures for response to inoperable monitors. During this period, NAREL's E-PERM[2] monitors also experienced some erroneously high readings that were not confirmed by duplicate monitors in the same location. In 1995, an ATSDR/NAREL decision was made to employ three alpha track detectors[3] at each location along with the E-PERMS. As expected, the alpha track detectors were

[2] An E-PERM consists of a shell and an electrically charged plate that is measured before exposure. The shell is opened at a set time, allowing radon gas to enter and pass through a filter. The radon and its decay products decay by alpha, beta, and gamma emissions, causing ionizations in the air near the plate. These ionizations cause a reduction in the electrical charge proportional to the concentration of radon entering the device. The reduction in electrical charge is measured at the end of the exposure period. Thermoluminescent detectors (TLDs) are placed next to these devices to measure gamma dose from other sources. From these measurements, radon concentrations can be determined; however, errors can occur if anything touches the plate before the electrical charge is measured.

[3] An alpha track detector consists of a casing with filters and detector plates (a small piece of special plastic). At the beginning of the exposure period, the device is opened and radon is allowed to enter, passing through a filter. When the alpha particles from the decay of radon and its decay products strike the plate, they leave "tracks"

determined to be more reliable, and radon measurements were subsequently determined by using three detectors at each location. The monitoring data collected by NAREL and DOE in 1995 and 1996 were compared. NAREL's alpha-track detector data from 1995 were slightly biased toward higher readings, and DOE's alpha-track detector data from 1996 were slightly biased toward higher readings; however, for the 2 years combined, there was no difference in long-term measured concentrations. A more thorough discussion can be found in Appendix E.

as each particle impacts with the plastic. At the end of the exposure period, the casing is closed, and the device is sent to the manufacturer for analysis. The number of "tracks" per unit area on the plate indicates the radon concentration in the ambient air.

Table 4. Estimated maximum committed effective (whole body) and committed equivalent (lung and bone surface) doses for current exposure for 1 year to radioactive contaminants in air off-site of the Fernald facility by a child (scenario #1) and an adult farmer (scenario #2)*

	Max. Annual Average Conc. in pCi/m^3 (Bq/m^3)†	Committed Effective Dose (whole body) in mrem (mSv)††		Committed Equivalent Doses (lungs and bone surface) in mrem (mSv)††			
		Child	Adult	Child		Adult	
				Lung	Bone Surface	Lung	Bone Surface
Total Uranium	3.8E-04 (1.4E-05)	2.5E-02 (2.5E-04)	2.1 (2.1E-02)	2.1 (2.1E-02)	0.22 (2.2E-03)	17.7 (0.177)	2.27 (2.3E-02)
Strontium 90	9.5E-06 (3.5E-07)	1.0E-04 (1.0E-06)	1.0E-03 (1.0E-05)	8.2E-04 (8.2E-06)	1.7E-04 (1.7E-06)	8.2E-03 (8.2E-05)	2.3E-03 (2.3E-05)
Technetium 99	1.4E-04 (5.2E-06)	1.3E-04 (1.3E-06)	1.2E-03 (1.2E-05)	1.1E-03 (1.1E-05)	4.8E-07 (4.8E-09)	1.0E-02 (1.0E-04)	2.3E-06 (2.3E-08)
Cesium 137	3.5E-05 (1.3E-06)	9.7E-05 (9.7E-07)	9.2E-04 (9.2E-06)	7.2E-04 (7.2E-06)	4.3E-06 (4.3E-08)	7.0E-03 (7.0E-05)	1.1E-04 (1.1E-06)
Radium 226	2.7E-06 (1.0E-07)	2.0E-03 (2.0E-05)	1.7E-02 (1.7E-04)	1.3E-02 (1.3E-04)	2.2E-03 (2.2E-05)	0.14 (1.4E-03)	2.9E-02 (2.9E-04)
Radium 228	1.4E-04 (5.2E-06)	0.18 (1.8E-03)	1.5 (1.5E-02)	1.5 (1.5E-02)	0.56 (5.6E-03)	12.4 (0.124)	2.77 (2.8E-02)
Thorium 228	1.3E-05 (4.8E-07)	4.2E-02 (4.2E-04)	0.34 (3.4E-03)	0.34 (3.4E-03)	1.36 (1.4E-02)	2.8 (2.8E-02)	10.3 (0.103)
Thorium 230	4.8E-05 (1.8E-06)	0.26 (2.6E-03)	3.2 (3.2E-02)	0.28 (2.8E-03)	10.7 (0.107)	2.5 (2.5E-02)	189.1(1.89)
Thorium 232	8.7E-06 (3.2E-07)	5.5E-02 (5.5E-04)	0.64 (6.4E-03)	8.5E-02 (8.5E-04)	2.08 (2.1E-02)	0.93(9.3E-03)	33.1 (0.33)

	Max. Annual Average Conc. in pCi/m^3 (Bq/m^3)†	Committed Effective Dose (whole body) in mrem (mSv)††		Committed Equivalent Doses (lungs and bone surface) in mrem (mSv)††			
		Child	Adult	Child		Adult	
				Lung	Bone Surface	Lung	Bone Surface
Neptunium 237	3.8E-06 (1.4E-07)	8.9E-03 (8.9E-05)	0.13 (1.3E-03)	2.4E-02 (2.4E-04)	0.28 (2.8E-03)	0.2 (2.0E-03)	6.56 (6.6E-02)
Plutonium 238	3.8E-07 (1.4E-08)	2.1E-03 (2.1E-05)	2.8E-02 (2.8E-04)	2.7E-03 (2.7E-05)	4.5E-02 (4.5E-04)	2.4E-02 (2.4E-04)	0.91 (9.1E-03)
Plutonium 239	7.6E-07 (2.8E-08)	4.4E-03 (4.4E-05)	6.0E-02 (6.0E-04)	5.0E-03 (5.0E-05)	0.10 (1.0E-03)	4.4E-02 (4.4E-04)	2.01 (2.0E-02)
TOTALS		0.58 (5.8E-03)	8.0 (8.0E-02)	4.3 (4.3E-02)	15.4 (0.154)	36.7 (0367)	246.9 (2.47)

Key: Max = maximum
Conc. = concentration
pCi/m^3 = picocuries per cubic meter
Bq/m^3 = becquerels per cubic meter
mrem = millirems
mSv = millisieverts
* Scenario 1 - child with 6 years of chronic exposure; Scenario 2 - adult farmer with 10 years of chronic exposure
† Concentrations of radioactive contaminants are based on percentage of each isotope reported in the 1993 annual composite analyses and annual average uranium concentration from weekly collection of samples (DOE 1972–1999).
†† Most conservative chemical form(most conservative conversion factors) used for calculation (ICRP 1995b).

Table 5. Summary of DOE's alpha-track monitoring results at fenceline and at potentially affected residences with background subtracted and reported in pCi/L (and in Bq/L)

Year	Average of 21 Property Fenceline Locations	Average of 6 Boundary Stations Closest to silos*	Max. Concentration at Residences on West Side of Site†	Concentration Near Residence Northeast of Site‡
1989	0.24 ± 0.15 (0.009 ± 0.006)	0.28 ± 0.10 (0.010 ± 0.004)	0.4 (0.015)	0.2 (0.007)
1990	0.23 ± 0.28 (0.009 ± 0.010)	0.28 ± 0.07 (0.010 ± 0.003)	0.2 (0.007)	0.1 (0.004)
1991	0.31 ± 0.30 (0.011 ± 0.011)	0.34 ± 0.11 (0.013 ± 0.004)	1.0 (0.042)	0.1 (0.004)
1992	Less than background	0.17 ± 0.10 (0.006 ± 0.004)	0.4 (0.015)	Equal to background
1993	Less than background	Less than background	Less than background	Less than background
1994	Less than background	Less than background	Less than background	Less than background
1995	0.17 ± 0.10 (0.006 ± 0.004)	0.10 ± 0.10 (0.004 ± 0.004)	0.2 (0.007)	0.2 (0.007)
1996	0.20 ± 0.10 (0.007 ± 0.004)	Not reported	0.2 (0.007)	0.2 (0.007)
1997	0.40 ± 0.10 (0.015 ± 0.004)	0.30 ± 0.10 (0.011 ± 0.004)	0.2 (0.007)	Equal to background
1998	0.30 ± 0.20 (0.011 ± 0.007)	0.30 ± 0.10 (0.011 ± 0.004)	0.2 (0.007)	0.1 (0.004)

Key: pCi/l = picocuries per liter
Bq/l = becquerels per liter

* These locations were picked because of their close proximity to the silos; however, the prevailing wind direction is to the northeast or southeast from the silos.

† Ohio EPA's Office of Federal Facilities Oversight has used continuous radon monitors at three locations west of the site since 1996.

‡ This location was picked because a dose from other airborne radionuclides was calculated near this area.

Source: DOE 1972–1999

Because NAREL's data did not cover the entire current time period (beginning in 1989), ATSDR used DOE's data for the earlier years to calculate potential maximum exposures. Table 6 presents the approximate upper lung doses from one year of exposure, calculated from concentrations shown in Table 5 for the fenceline near the silos, a residence west of the site, and a residence northeast of the site. These concentrations occurred in different years, because of differences in

wind direction and activity occurring on the site. In calculating the doses, ATSDR assumed the indoor and outdoor concentrations averaged over the year would be the same. ATSDR also assumed that the adult male's exposure would be continuous, taking into consideration 8 hours of rest each night. The formula used is as follows and is based on NCRP Report 78's methodology (NCRP 1984):

Approximate male adult annual dose (in mrads) = 0.30 (16 hours/24 hours)(concentration of Rn^{222} in pCi/m^3) + 0.20 (8 hours/24 hours)(concentration of Rn^{222} in pCi/m^3)

Table 6. Approximate annual lung dose for an adult male exposed continuously to alpha concentrations (presumably, radon and radon progeny) listed in Table 5 (with background subtracted)

Location	Year	Approximate Annual Lung Dose in mrad/yr (mGy/yr)
Average of six boundary stations closest to silos	1991	91 ± 29 (0.91 ± 0.29)
Maximum annual concentration at residence west of silos	1991, after 1991	267 (2.67), 107 (1.07)
Maximum annual concentration near residence northeast of site	1989, 1995, and 1996	53 (0.53)

Key: mrad/yr = millirads per year
mGy/yr = milligrays per year
For purposes of uniformity in the health implications discussion, the annual lung doses in this table were converted to committed equivalent doses in millirem/year (and millisievert/year).
Source: NCRP 1984

In 1991, before bentonite (clay) caps were added inside the K-65 silo domes, the approximate annual lung dose for someone continuously present at the residence west of the silos was 267 millirad per year (mrad/yr) or 2.67 milligray per year (mGy/yr). After the bentonite caps were added in 1991, the direct radiation levels and radon releases from the silos decreased. The average annual lung dose after the caps were added is estimated at 60 mrad/yr (0.60 mGy/yr) for someone continuously present at a residence west of the silos. By 1998, there were indications that the direct radiation levels at the exclusion fence near the silos had increased although the levels at the western fenceline had not increased significantly (DOE 1972–1999). The silo domes were resealed in 1999 as an interim control measure. The Radon Control System (RCS) was first tested to reduce radon in the silos' headspace in December 2002 and started continuous operation in May 2003 (see Table 7 for changes in direct radiation levels). These radiation levels were determined by using quarterly thermoluminescent detector (TLD) readings averaged over the year.

Further evaluation of human exposure to radon and radon decay products in off-site air, including a determination of whether these estimated doses present an increased likelihood of developing lung cancer, appears in the Public Health Implications section of this report.

Table 7. Annual average external exposure doses at fenceline air monitoring stations west of the silos and northeast of the site (with background subtracted)

Year	Annual Average Dose at AMS-6 West of Silos in mrem/yr (mSv/yr)	Annual Average Dose at AMS-2 Northeast of Site in mrem/yr (mSv/yr)
1989	59 (0.59)	13 (0.13)
1990	59 (0.59)	11 (0.11)
1991	48 (0.48)	12 (0.12)
1992	7 (0.07)	12 (0.12)
1993	8 (0.08)	12 (0.12)
1994	8 (0.08)	11 (0.11)
1995	8 (0.08)	8 (0.08)
1996	11 (0.11)	7 (0.07)
1997	14 (0.14)	8 (0.08)
1998	17 (0.17)	7 (0.07)
1999	15 (0.15)	9 (0.09)
2000	16 (0.16)	7 (0.07)
2001	18 (0.18)	7 (0.07)
2002	22 (0.22)	8 (0.08)
1st & 2nd qtr - 2003	6 (0.06)	4 (0.04)

Key: mrem/yr = millirems per year
mSv/yr = millisieverts per year
Source: DOE 1972–1999, 2000c, 2001b, 2002, 2003d, 2003c.

Potential Future Exposure

Chemical and radioactive materials may be released from storage and processing areas during *future* remedial activities at the site. Radon emissions will continue until the silo waste is treated, removed from the silos, and sent off-site for disposal (DOE 1972–1999). By January 2000, contracts were awarded for remediation of Silo 3 and for Accelerated Waste Retrieval for Silos 1 and 2 (DOE 2000a). The Silo 3 remedial project should be completed in 2005. The waste retrieval project for Silos 1 and 2 should be completed in 2006. The community is particularly concerned about future activities involving removal and transport of the silo waste. Radon monitoring should be continued until all radon sources are no longer present at this site.

If additional information becomes available indicating that concentrations of chemicals or radioactive contaminants have increased, the air exposure pathways should be re-evaluated.

Soil Pathway

Background

Off-site soil near the Fernald site has become contaminated with uranium and potentially other chemicals and radioactive contaminants through several possible mechanisms. These include (1) releases to air as particulate emissions during production, episodic releases and waste incineration followed by deposition on soil, and (2) spills or leaks to soil from production processes, transport systems, or improper storage or disposal of uranium wastes.

Modeling of past *air particulate* releases from the Fernald facility indicates that cumulative uranium deposition on soil was highest in the 1960s and remained steady or declined slightly until production operations stopped in 1988 (Shleien et al. 1995; Killough et al. 1998a). Maximum soil deposition occurred in areas east, northeast, and south-southwest of the production area (Shleien et al.1995; Killough et al.1998a). Facility records indicate that the majority of the uranium released from the Fernald site to the atmosphere was relatively insoluble (Shleien et al.1995; Killough et al.1998a). The soluble fraction deposited on soil would have been dissolved in rain and surface water and then would have leached rapidly into deeper soils or would have been transported in surface runoff to Paddy's Run and the storm sewer outfall ditch (DOE 1994). Essentially none of the soluble uranium released during the peak of operation in the 1950s and the early 1960s is likely to have remained in soil in the 1980s and 1990s (Killough et al.1998a). Less soluble forms of uranium (e.g., uranium oxides) may have remained in soil longer; however, even insoluble uranium compounds could have been removed from surface soil over time or covered by new layers of topsoil. Chemical forms of uranium remaining in the surface soil after years of deposition are likely to have been uranium compounds of low solubility but may not be at peak concentrations if the soil was disturbed.

Uranium released as *spills or leaks* during process operations was likely to have been mixed with acids from cleaning operations (Voilleque et al.1995). The presence of acid increases the mobility of uranium in water. Soluble uranium salts would have leached into deeper soils, been dissolved in rain and surface water and transported off site, or been converted to insoluble uranium compounds over time and remained predominantly in the local soils.

Although very little data are available for *past* releases of non-uranium chemicals or radioactive materials, it was assumed that use of these materials during various processes also resulted in releases. More data is available to describe *current* soil concentrations of chemicals and other radioactive materials. Since 1989, several soil removal actions have been performed. These removal actions were based on uranium contamination, but other potential contaminants were also removed resulting in sampling data for pre- and post-removal *current* soil concentrations.

Environmental Data

Contractors for the Fernald site began routine soil monitoring for total uranium at the boundaries in 1971. Sample depths for routinely collected samples changed over time. From 1971 to 1983, the sample depth was 0 to 10 centimeters (cm) from the surface. From 1983 to 1985, the sample depth was 0 to 5 cm. After 1986, samples were taken at 0 to 5 cm and 5 to 10 cm (Killough et al.1998a). *Routine* boundary and off-site soil sampling was discontinued in 1996.

Additional soil sampling events have been conducted at the site from 1986 to the present as a result of litigation, removals, and remedial investigation/feasibility studies (DOE 1972–1999; DOE 1994; Killough et al.1998b). A 1986 study consisted of independent sampling by IT Corporation to access the regional distribution of uranium within a 5-mile radius of FEMP (IT 1986). The majority of these samples were analyzed for total uranium and uranium 234, 235, and 238; however, some were analyzed for total thorium, thorium 232, and radium 226. More sampling and analyses were performed in 1987 and 1988; some of these samples were also analyzed for thorium 228 and 230, technetium 99, strontium 90, ruthenium 106, radium 228 and 224, plutonium 238 and 239/240, neptunium 237, and cesium 137. By 1991, the analyses also included gross alpha and beta counts and by 1992, radium 224, protactinium 231, potassium 40, lead 210, and actinium 227. However, uranium was the primary radioactive contaminant.

Most of the off-site uranium was found along the northeastern and eastern boundary and along the outfall line leading from the site to the Great Miami River. Some of the *past* off-site samples exceeded both the media-specific comparison values (CVs) for *chemical* and *radioactive* uranium. A few *current* off-site samples exceeded the CV for *radioactive* uranium. In general, uranium levels were higher close to the site boundary, decreasing with increasing distance from the site (DOE 1972–1999; SED 1998). Although most of these areas have been excavated, *uranium was selected as a chemical and radioactive contaminant of concern for this pathway.*

The amount of information on concentrations of *chemicals* in off-site surface soils (except uranium) is limited. From 1991 to 1993, off-site soil samples collected on a few occasions were analyzed for *metals and organic compounds* (e.g., polyaromatic hydrocarbons) as well as for radionuclides mentioned above (SED 1998). These samples were collected at depths of 0 to 6 inches below the ground surface from five or six locations east and northeast of the facility boundary. One organic compound, benzo(a)pyrene, and two radioactive contaminants, technetium 99 (Tc-99) and radium 226 (Ra-226), were positively detected above ATSDR's CVs in one off-site soil sample (#SS-58). *Although the levels of benzo(a)pyrene and Tc-99 were slightly above the CVs, they were not selected as contaminants of concern for this pathway*, because this location represents the only sample with above CV concentrations, and any exposure to this concentration would be limited in frequency and duration. The concentration of Ra-226 in this same sample exceeded ATSDR's CV although it did not significantly exceed the Ra-226 background concentration. The Ra-226 concentration in another sample (#D-2) exceeded both. From 1993 through 1994, the area where D-2 was located was excavated during Removal Action 14, which removed uranium-contaminated soils associated with the sewage treatment plant on

the east side of the site. However, *Ra-226 was retained as a current contaminant of concern*. In 1997, three off-site soil borings were collected in this area as part of the sewage treatment plant remedial investigation. Although the samples did not exceed the site's final remediation level (FRL) and ATSDR's CV for uranium, two samples contained beryllium (0.91 mg/kg and 0.62 mg/kg) above the FRL but below ATSDR's CV. In 2001, five soil samples were collected in this area and analyzed for radioactive contaminants; none were above the site's FRLs or ATSDR's CVs. In November 2002, the presence of Ra-226, Th-232, and total uranium were detected but only Ra-226 was slightly elevated. No further soil removals are planned for this area.

In 1992, a greater number of samples, considered representative of background conditions, were collected approximately 3 to 6 miles northwest of the site boundary at select depth intervals and analyzed for radioactive and chemical constituent concentrations (DOE 1993c). The results were used in developing the FRLs as well as in delineating the extent of contamination on-site. In 2000, supplemental soil sampling was conducted in the same area northwest of the site to determine background levels of *inorganic constituents and radionuclides* at depths not previously evaluated. The majority of inorganic constituent concentrations were highest in the subsurface level (12–36 inches), and the majority of the radioactive constituent concentrations were highest in the surface soil (0–6 inches) (DOE 2001a).

Several metals have been found in off-site surface soils at concentrations above their CVs; however, none of these concentrations exceeded background values for this area. They include arsenic, barium, manganese, and thallium. A summary of environmental data used to evaluate *chemicals* in the soil pathways is presented in Table 8. Of these, thallium was not evaluated further for soil pathways because (1) it was detected infrequently, (2) the maximum concentration was just above the lower limit of analytical detection, and (3) the maximum concentration was similar to (or lower than) the background soil concentration. *Estimated exposures to arsenic, barium, and manganese will be discussed further in the Estimated Exposure Dose section*.

Since 1989, several radioactive contaminants were detected off-site above media-specific comparison values and background concentrations: *uranium 234 and 238, radium 226 and 228, technetium 99, and thorium 228, 230 and 232*. As mentioned previously, some of the affected areas have been excavated, but uranium 234 and 238, radium 226 and 228, and thorium 228, 230, and 232 will be retained as contaminants of concern and discussed further in this section. A summary of environmental data used to evaluate *radioactive materials* in the soil pathways is presented in Table 9. As demonstrated in this table, some of the maximum area background values for radioactive materials also exceed ATSDR's CVs. *Technetium 99 was not selected as a contaminant of concern for the soil pathway because an elevated technetium 99 concentration was only found in one sample.*

Table 8. Summary of analytical data used for selecting chemical contaminants in the surface soil pathway

Contaminant*	Sample with Maximum Concentration	Maximum Concentration (mg/kg or ppm)	Mean Concentration† (mg/kg or ppm)	Sample Year	Range of Contamination off site	Freq. of Detection	Media-Specific Comparison Value (mg/kg or ppm)
Uranium—Past Exposure‡	BS-3 (eastern facility boundary)	137		1973	2.9–136.5		
Current Exposure	C-2 (off site, east, excavated) C-5 (off site, east, excavated) C-10 (off site, east, excavated)	100 - 118		1992	1.1-120	NA	100 (ATSDR EMEG)
	SP-11 (off site, east)	120					
PAH—Benzo(a)pyrene	SS-58 (just off site, NE)	0.110	NA	1993	ND–0.110	1/6	0.1 (ATSDR CREG)
Arsenic	SS-58 (just off site, NE) 1873 (NW of site)	5.3 9.2	5 (n=31)	1993 1992	1.9–5.3 ND(2.9)–9.2	5/5 22/26	0.5 (ATSDR CREG)
Barium	SS-56 (just off site, east) 1873 (NW of site)	237 331	77 (n=35)	1993 1992	14.3–237 31–331	5/5 30/30	100 (ATSDR RMEG)
Manganese	SS-56 (just off site, east) 1873 (NW of site)	3,420 4,850	921 (n=35)	1993 1992	400–3,420 189–4,850	5/5 30/30	300 (ATSDR EMEG)
Thallium	SS-58 (just off site, NE) 1827 (NW of site)	0.42 0.58	0.4 (n=35)	1993 1992	ND(0.24)–0.42 ND(0.48)–0.58	2/5 1/30	

Key
mg/kg = milligrams of substance per kilogram of soil
ppm = parts per million
PAH = polyaromatic hydrocarbon
NW = northwest
NE = northeast
Range of Contamination = analytical range of contaminant concentration off site
ND = not detected
NA = not available or not analyzed
Freq. of Detection = frequency of analytical detection, i.e., number of positive detections/total number of samples
Media-specific comparison value, as described in introduction to Appendix A—Selection of Contaminants
* Contaminants were selected using all surface soil samples collected from 1971 to the present, and reported in the following sources: DOE 1972–1999; Killough et al. 1998; SED 1998; and DOE 2001b. **Only contaminants listed in bold were selected as contaminants of concern in soil pathways.**
† Mean concentrations were calculated from all off-site samples with reported concentrations above analytical detection levels.
‡ Past exposure was evaluated for only one contaminant of concern, uranium, because analytical data are not available for any other contaminants.

Table 9. Summary of analytical data used for selecting radioactive contaminants in the surface soil pathway (data from 1989 forward)

Contaminant*	Sample with Maximum Concentration	Maximum Concentration in pCi/g (Bq/kg)	Sample Year	Range of Contamination Off Site in pCi/g (Bq/kg)	Media-Specific Comparison Value (CV) in pCi/g (Bq/kg)	Maximum Area Background in pCi/g (Bq/kg)
Uranium 234	SP-11 (off site, east)	44 (1.63E03)	1992	0.1–44 (3.7-1.63E03)	25.9 (9.6E02) (RV)	NA
Uranium 238	SP-11 (off site, east)	40 (1.48E03)	1992	0.2-40 (7.4-1.48E03)	21.9 (8.1E02) (RV)	3.0 (111)
Technetium 99	SS-58 (off site, NE)	1.8 (66.7)	1993	0.1-1.8 (3.7-66.7)	0.59 (22) (RV)	0.9 (33.3)
Radium 226	All results > CV; max at D-2 (off site, NE) excavated 1993/94 [at SS58-not excavated]	13.8 (511) [1.9(70.4)]	1992 [1993]	0.3-13.8 (11.1-511)	0.11 (4.1) (RV)	1.7 (63)
Radium 228	All results > CV	1.4 (51.9)	1992	0.5-1.4 (18.5-51.9)	0.07 (2.7) (AG)	1.3 (48.1)
Thorium 228	Most results > CV; max at C-7 (off site, NE) excavated 1993/94 [at MH-180-36-not excavated]	2.1 (77.8) [1.9 (70.4)]	1992 [1989]	0.8-2.1 (29.6-77.8)	0.68 (25) (RV)	1.4 (51.9)
Thorium 230	Most results > CV; max at D-2 (off site, NE) excavated 1993/94 [at 2558 - not excavated]	24 (889) [3.52 (130.4)]	1992 [1991]	0.3-24 (25.9-889)	0.30 (11) (RV)	2.0 (74.1)
Thorium 232	All results above CV; max at C-7 (off site, NE) excavated 1993/94 [background]	2.7 (100) [1.52(56.3)]	1992 [1992]	0.3-2.7 (11.1-100)	0.06 (2.3) (AG)	1.5 (55.6)

Key

pCi/g = picocurie(s) per gram; Bq/kg = becquerel(s) per kilogram = 0.027 pCi/g

Range of Contamination = analytical range of contaminant concentration off site

CV = media-specific comparison value; soil screening values from NCRP Report No. 129 (NCRP 1999)

(RV) = heavily vegetated rural land use; (AG) = primarily food production for humans, no dwellings

NA = not available or not analyzed

NE = northeast

> = greater than

max = maximum value

* Contaminants were selected using all surface soil samples collected from 1989 to the present, and reported in the following sources: DOE 1972–1999; SED 1998; and DOE 2001b. **Only contaminants listed in bold were selected as contaminants in soil pathways**

Estimated Exposure Doses

ATSDR scientists evaluated *past*, *current*, and *potential future* exposure to uranium (*as a chemical*) in off-site soil at the Fernald site. Arsenic, barium, and manganese are additional chemicals evaluated for *current* exposures for this pathway.

ATSDR scientists also evaluated *past, current* and *potential future* exposure to *radioactive* contaminants in soil pathways. The *radioactive* contaminants include uranium 234 and 238; thorium 228, 230 and 232; and radium 226 and 228. *Past* exposures to radioactive contaminants were addressed in the Fernald Dosimetry Reconstruction Project (FDRP) and the Fernald Risk Assessment Project (Voilleque et al. 1995; Shleien et al. 1995; Killough 1998a, 1998b; CDC 1998, 1999). ATSDR scientists have reviewed these documents and agree with the methodology and conclusions for *past* radioactive contaminant concentrations estimated and measured in off-site surface soils. The soil pathway was a major contributor to *past* off-site radiation exposures. For a description of the exposure scenarios used in the FDRP, refer to Appendix D.

ATSDR assumed that incidental ingestion is the primary route of exposure to soil contaminants in estimating exposure doses. Although contaminated soils may become suspended in air and be a source of inhalation exposure, this exposure route is discussed in the Air Pathway and Direct Radiation section of this report. ATSDR scientists evaluated a *hypothetical* exposure scenario for a child 1 to 6 years of age who weighs 13 kg and who ingests maximum concentrations of potential contaminants in surface soils while playing near the Fernald site. ATSDR assumed exposure to a child because children may have increased sensitivity to the toxic effects of these contaminants and would ingest more soil than an adult. ATSDR does not have direct evidence that children currently play or have played near the facility boundary. Demographic data for Butler and Hamilton Counties indicate that 922 persons live within 1 mile of the Fernald facility. Of these, an estimated 110 persons are 6 years of age or younger. (Refer to the Demographics section of this report). The closest residence to the production area in the past was directly east and currently is southeast of the site. Off-site contaminated areas were not restricted from public access. Therefore, children may have played near the site in areas potentially contaminated.

Most children ingest soil occasionally during play because of frequent hand-to-mouth activity and reliance on care-givers, rather than themselves, for hygiene. However, children vary greatly with respect to soil ingestion behavior (Calabrese and Stanek 1998). An individual child's daily soil ingestion activities vary, ingesting relatively little soil one day and large amounts the next day. Under the hypothetical exposure scenario for this pathway, ATSDR assumed that a child ingests 200 mg of soil per day, on a total of 35 days a year, for 4 consecutive years. These conservative assumptions are based on information from a review of soil ingestion studies (Calabrese and Stanek 1998). In this review, it was estimated that 72% of children ingest 200 mg or more of soil for a total of 7 to 10 days a year, while 42% of children ingest this amount daily for 35 to 40 days a year.

Chemicals

ATSDR scientists calculated the *past and current chemical* exposure dose from *uranium* in soil for this hypothetical scenario. ATSDR also estimated a *current chemical* exposure dose to *metals* in soil via incidental ingestion. No data, other than for uranium concentrations, were available for past chemical soil concentrations; therefore, *past exposures to chemicals (other than uranium) in soil are indeterminate.*

Past Exposure

Past exposure to uranium *as a chemical* was evaluated by use of environmental sampling data collected while the facility was operating. Historically, the highest uranium concentrations have been found just outside the eastern boundary of the facility. The maximum uranium soil concentration detected in this off-site area was 137 mg/kg in a sample (BS-3) collected at the eastern facility boundary in 1973 (DOE 1972–1999; Killough et al. 1998a). Because this area was accessible to the public, ATSDR scientists assumed that human exposure to this concentration could occur and used this concentration to estimate an exposure dose to a small child. This estimated exposure dose is 10 times lower than the health-based guideline for ingested uranium, despite the fact that ATSDR scientists used conservative assumptions about the amount and rate of soil ingestion and uranium solubility. (Refer to Table 10.) If more realistic assumptions were used, the estimated dose would have been considerably lower. Although *past exposure to uranium in off-site soils does not present a public health hazard,* ATSDR scientists used this estimated chemical dose when evaluating the public health hazard from exposures to uranium from other pathways. (Refer to the Public Health Implications section of this report.)

Table 10. Estimated past and current chemical exposure doses for ingestion of uranium in off-site surface soil at the Fernald facility by a small child

Exposure Route and Time	Maximum Exposure Concentration (mg/kg)	Estimated Exposure Dose (mg/kg/day)*	Health-based Guideline (mg/kg/day)
Current ingestion	120	2×10^{-4}	2×10^{-3} (ATSDR Chronic Oral MRL)
Past ingestion	137	2×10^{-4}	

Key:
mg/kg = milligrams of uranium per kilogram of soil
mg/kg/day = milligrams of uranium per kilogram of body weight per day
MRL = minimal risk level
* Equations used to estimate doses are described in Appendix B

Current Exposure

Contractors at the Fernald facility have been removing contaminated soils on site and off site since 1989. Consequently, there are very few sources of *current* human exposure to off-site surface soil contaminants.

In estimating current exposure doses for *chemical uranium* in soil pathways, ATSDR scientists used the current maximum uranium concentration (120 mg/kg) found in any off-site surface soil sample. This concentration was detected in a sample collected just outside the eastern facility boundary (in 1992). As shown in Table 10, ATSDR's estimated exposure doses for *ingestion* of *chemical uranium* in off-site surface soil are 10 times *lower* than the health-based guideline, despite the fact that ATSDR used conservative assumptions to estimate dose. Although *current uranium in the soil pathway does not present a health hazard*, ATSDR scientists evaluated the exposures from this pathway together with exposures from other pathways (i.e., groundwater, air, surface water, and biota) that may contribute to total uranium exposure to Fernald area residents. (Refer to the Public Health Implications section of this report.)

ATSDR's estimated exposure doses for ingestion of *metals* in off-site surface soil, and the corresponding health-based guidelines, are presented in Table 11 (below). None of the estimated exposure doses exceed health-based guidelines for ingestion; therefore, *ATSDR did not evaluate metal exposure further for this pathway.*

Table 11. Estimated current exposure doses and health-based guidelines for chemical (metal) contaminants in soil pathways

Contaminant	Estimated Ingestion Dose for a Child (mg/kg/day)*	Health-based Guidelines*
Arsenic	8×10^{-6}	3×10^{-3} mg/kg/day (ATSDR chronic oral MRL) 1.5 $(mg/kg/day)^{-1}$ (EPA oral CSF)
Barium	5×10^{-4}	0.07 mg/kg/day (EPA oral RfD)
Manganese	7×10^{-3}	0.07 mg/kg/day (ATSDR interim oral guideline)

Key:
mg/kg/day = milligrams of substance per kilogram of body weight per day
MRL = Minimal Risk Level
RfD = Reference Dose
CSF = EPA's Cancer Slope Factor
EPA = US Environmental Protection Agency
* Equations used to calculate exposure doses and Health-based Guidelines are described in Appendix B.

Radiation

Two *radiation* doses for exposure from the soil pathway were calculated: a committed effective dose (whole body) and a committed equivalent dose (bone surface). The doses were estimated by using the International Commission on Radiological Protection's models and methodology (ICRP 1995a).

Past Exposure

The maximum past uranium concentration (92 pCi/g) was detected in a soil sample from the eastern site boundary in 1973. Using this concentration, ATSDR scientists estimated doses for the *hypothetical* scenario previously described. The committed effective dose is 0.2 mrem (0.002 mSv) per year of ingestion, and the committed equivalent dose to the bone surface is 2.9 mrem (0.029 mSv) per year of ingestion.

Current Exposure

ATSDR scientists used the maximum concentrations for all radioactive contaminants detected in off-site soils (Table 9) to estimate *current radiation* doses. The concentrations were detected in similar directions from the site (east and northeast). ATSDR also used the *hypothetical* scenario previously described. The doses to a child are presented in Table 12.

It is interesting to note that the dose contribution from only uranium in current years (both before and after 1992) is approximately the same as the past exposure dose which was based solely on uranium. Although these doses are low and would not be expected to cause adverse health effects, they are included in the discussion for uranium exposure in the Health Implication section of this report.

Table 12. Estimated current doses for a child from one year exposure to radioactive contaminants in soil east of the site

Contaminant	Estimated Committed Effective Doses (Whole body) in mrem (mSv) per year[1]		Estimated Committed Equivalent Doses (Bone surface) in mrem (mSv) per year[2]	
	Pre-1992 Excavation	Post-1992 Excavation	Pre-1992 Excavation	Post-1992 Excavation
Uranium 234	0.10 (0.0010)	0.10 (0.0010)	2.05 (0.0205)	2.05 (0.0205)
Uranium 238	0.08 (0.0008)	0.08 (0.0008)	1.24 (0.0124)	1.24 (0.0124)
Radium 226	0.22 (0.0022)	0.03 (0.0003)	8.23 (0.0823)	1.13 (0.0113)
Radium 228	0.12 (0.0012)	0.12 (0.0012)	5.04 (0.0504)	5.04 (0.0504)
Thorium 228	0.01 (0.0001)	0.01 (0.0001)	0.34 (0.0034)	0.31 (0.0031)
Thorium 230	0.19 (0.0019)	0.03 (0.0003)	7.46 (0.0746)	1.09 (0.0109)
Thorium 232	0.02 (0.0002)	0.01 (0.0001)	0.91 (0.0091)	0.51 (0.0051)
TOTAL	0.74 (0.0074)	0.38 (0.0038)	25.27 (0.2527)	11.37 (0.1137)

Key: mrem = millirem
mSv = millisievert (1 mSv = 100 mrem)
Sources: [1] (ICRP 1996), [2] (ICRP 1994; ICRP 1995)

Potential Future Exposure

ATSDR scientists evaluated the likelihood that off-site areas will become a source of human exposure to contaminants from the Fernald site in the *future*. To do so, ATSDR used current measurements of contaminants in on-site and off-site soils and information about current and proposed remediation strategies for the site. Remedial activities at the Fernald site are expected to continue through 2006. During that time, contaminated soils and other materials will be removed and transported to an off-site disposal site or disposed in the on-site disposal cells. *On the basis of available information, there is no indication that future activities will result in adverse health effects from off-site exposure to contaminated soils from the Fernald facility.* However, if additional information becomes available indicating that contaminants have been released or migrated to soil off site, the soil exposure pathway should be re-evaluated.