



ORAU TEAM Dose Reconstruction Project for NIOSH

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Subject Expert(s): Paul J. Demopoulos, Milton Gorden, and Donald Palmrose Site Expert(s): N/A			
Approval:	<u>Signature on File</u> Susan L. Winslow, Document Owner	Approval Date:	<u>08/13/2009</u>
Approval:	<u>Richard E. Merrill Signature on File for</u> John M. Byrne, Objective 1 Manager	Approval Date:	<u>08/14/2009</u>
Concurrence:	<u>Keith A. McCartney Signature on File for</u> Edward F. Maher, Objective 3 Manager	Concurrence Date:	<u>08/14/2009</u>
Concurrence:	<u>Signature on File</u> Kate Kimpan, Project Director	Concurrence Date:	<u>08/21/2009</u>
Approval:	<u>Signature on File</u> James W. Neton, Associate Director for Science	Approval Date:	<u>08/24/2009</u>

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
03/17/2004	00	New Technical Basis Document for the Portsmouth Gaseous Diffusion Plant - Occupational Environmental Dose. First approved issue. Initiated by Mark D. Notich.
09/08/2006	01	Updates document for biennial review. Adds a Purpose and Scope subsection to the Introduction (Section 4.1). Changes the ambient maximum value to 44.8 mrem in Table 4-6. Adds Table 4-7 Perimeter road ambient radiological conditions from GM measurements and citations. Adds locations 9 and 15 of GM monitoring to Figure 4-1. Approved issue of Revision 01. This revision results in an increase in assigned dose and a PER is required. Training required: As determined by the Task Manger. Initiated by Paul J. Demopoulos.
08/24/2009	02	Changes were made to the document as per OCAS comments. The Uranium daughter intake values were corrected in Table 4-2. Footnote f was added: "Uranium progeny intakes calculated from recorded or estimated equilibrium fractions with the Uranium parent radionuclides." Changed the term, "claimant favorable" to "favorable to claimant(s)" as appropriate throughout the document. Incorporates formal internal and NIOSH review comments, such as revising wording of footnote "e" in Table 4-2. Equation 4-1 for the geometric standard deviation (GSD) has been deleted along with citations to the GSD in the text and in Table 4-2. This follows ORAUT-PROC-0031 guidance. Deleted Table 4-7 due to the data being limited and not adding value. Revised Section 4.2.3 to provide a better description of the calculations. Training required: As determined by the Objective Manger. Initiated by Susan L. Winslow.

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ACRONYMS AND ABBREVIATIONS

Bq	Becquerel
CAF ₂ :Dy	calcium fluoride:dysprosium
Ci	curie
cm	centimeter
DOE	U.S. Department of Energy
EEOICPA	<i>Energy Employees Occupational Illness Compensation Program Act</i>
EPA	U.S. Environmental Protection Agency
ft	foot
GAT	Goodyear Atomic Corporation
g	grams
GM	Geiger-Muller (tube assembly)
hr	hour
LiF	lithium fluoride
m ³	cubic meters
mo	month
mR	milliRoentgen
mrem	millirem
MTU	metric tons of uranium
NIOSH	National Institute for Occupational Safety and Health
NRC	U.S. Nuclear Regulatory Commission
ORAU	Oak Ridge Associated Universities
PORTS	Portsmouth Gaseous Diffusion Plant
POC	probability of causation
REMS	Radiation Exposure Monitoring System
TBD	technical basis document
TLD	thermoluminescent dosimetry
UF ₆	uranium hexafluoride
USEC	United States Enrichment Corporation
yr	year

4.1 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word “facility” is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an “atomic weapons employer facility” or a “Department of Energy facility” as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [(42 U.S.C. Sections 7384l (5) and (12))]. EEOICPA defines a DOE facility as “any building, structure, or premise, including the grounds upon which such building, structure, or premise is located ... in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations ... pertaining to the Naval Nuclear Propulsion Program)” [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled “Exposure in the Performance of Duty.” That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer “shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer ... was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation¹] guidelines established under subsection (c) ...” [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) define “performance of duty” for DOE employees with a covered cancer or restrict the “duty” to nuclear weapons work (NIOSH 2007).

The statute also includes a definition of a DOE facility that excludes “buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program” [42 U.S.C. § 7384l(12)]. While this definition excludes Naval Nuclear Propulsion Facilities from being covered under the Act, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled “Exposure in the Performance of Duty”] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally-derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external occupational radiation exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (NIOSH 2007):

- Background radiation, including radiation from naturally occurring radon present in conventional structures

¹ The U.S. Department of Labor (DOL) is ultimately responsible under the EEOICPA for determining the POC.

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

4.1.1 Purpose

The purpose of this TBD is to describe the environmental radiation released or emanating from fixed sources in the environment for the Portsmouth Gaseous Diffusion Plant (PORTS). This document discusses historical and current practices in relation to the evaluation of environmental external and internal exposure data for PORTS workers.

This PORTS technical basis document (TBD) describes the potential for internal dose from the breathing of airborne concentrations of radionuclides released on the PORTS site (Section 4.2), the potential for external dose from sources of radiation outside and inside the process buildings (Section 4.3), and possible sources of uncertainty associated with both these sources of environmental dose (Section 4.4).

4.1.2 Scope

This TBD contains supporting documentation to assist in the evaluation of ambient external and internal doses from environmental releases or fixed source terms for workers at PORTS. An objective of this document is to provide supporting technical environmental data or survey information to evaluate, with assumptions favorable to the claimant for worker external and internal dose assessments.

The receptors of concern whom this TBD addresses are unmonitored workers; that is, employees at PORTS who did not wear personnel dosimetry and who were not monitored for internal dose. At PORTS, there were several periods when all workers, even those with administrative duties, wore film badges or thermoluminescent dosimeters (TLDs) at all times. However, not all film badges were analyzed. For these periods, representative samples for various groups of workers were analyzed (ATL 2003a). To provide the basis for estimating the environmental dose for years when monitoring did not occur or was not sufficient to apply to coworkers, this TBD provides actual and estimated annual intakes and ambient environmental doses for every year from 1955 to 2001.

4.2 INTERNAL DOSE FROM ONSITE ATMOSPHERIC RADIONUCLIDE CONCENTRATION

4.2.1 Ambient Air Sample Collection Network

In 1964, PORTS established a network of permanent on- and offsite stations to collect continuous ambient air samples (DOE 1994). Sampling data are available for five offsite locations (one several miles from PORTS to provide background measurements) beginning in 1964 and for four onsite locations beginning in 1974 (Goslow 1986).

The principal purpose of the ambient air monitoring network is to assess whether air emissions from PORTS affected air quality in the surrounding area. This would demonstrate compliance with DOE Derived Concentration Guidelines, the U.S. Environmental Protection Agency (EPA), the State of Ohio Environmental Protection Agency, or (as of 1997) U.S. Nuclear Regulatory Commission (NRC) regulations for airborne releases to the general public around PORTS. Thus, most of the monitoring stations are off the site, along the site boundary, or next to the Perimeter Road. There have been a limited number of onsite monitoring stations. Therefore, this document considers only those ambient air monitoring locations at or within the PORTS site boundary for worker internal dose. Table 4-1 lists these air monitors and their locations.

Table 4-1. Ambient air sampling station locations.

Designation	Location	Direction from center of site
Within PORTS boundary (fence line)		
A3	South Access Rd., south of DOE property line	SSW
A12	McCorkle Rd., north of East Access Rd.	ENE
A24	North Access Rd., north of Shyville Rd.	N
A29	U.S. Rt. 23 on near leg of old GAT (Goodyear Atomic Corporation) sign	W
Onsite air sampling locations (near Perimeter Road)		
A10	X-230-J3 west (ditch) environmental monitoring station	W
A35	X-230-J2 south (holding pond) environmental monitoring station	S
A36	X-611 water treatment plant, southeast corner of facility parking lot	ENE
A38	X-230-J environmental storage building	ESE
A39	X-760 chemical engineering facility	Near mid-point
A40	X-100 administration building penthouse	Near mid-point

Source: Table 2.1.8 on page 135 of DOE (1988).

As would be expected, several changes to the sampling program were associated principally with sampling technique and equipment; there were at least two major changes of monitoring locations. From 1964 to 1993, low-volume samplers were the principal type of sampler used, employing several filter types and flow rates. In general, filters were changed after sampling approximately 200 to 210 m³ of air. Depending on the set flow rate (1.2 or 0.3 m³/hr), filter exchanges were performed weekly or monthly. Major upgrades of the monitoring network occurred in 1987 (number of locations and sampling technique) and from 1993 to 1995 [addition of high-volume samplers and segregation of monitoring responsibilities between DOE and United States Enrichment Corporation (USEC)].

The general practice for air samples was to perform gross alpha and beta-gamma counts. Gross alpha activity was associated with the release of uranium, and beta-gamma activity was associated with the release of ⁹⁹Tc and daughter products of uranium (Goslow 1986). If the gross counts exceeded established limits of 100 dpm alpha or 200 dpm beta-gamma, the filters would be analyzed for specific radionuclides (DOE 1994). Only in the last several years have filters been analyzed for specific radionuclides. However, no air samples exceeded established limits while they were in effect.

There have been releases of radionuclides to the atmosphere since the beginning of operations. PORTS release data have been estimated or recorded since 1954 for uranium, since 1967 for uranium daughter products, and since 1976 for ⁹⁹Tc (Goslow 1986). Dose reconstructors must consider several issues, such as the accuracy of the amounts released and the fact that there was no ambient air monitoring network in operation for the first 10 yr of operations and not all radionuclides of concern were originally measured in the air effluent release streams. Therefore, this TBD discusses a methodology favorable to the claimant for estimating potential radionuclide air concentrations, not only for the period from when operations began to 1964 but also to account for potential uncertainty in the release data. The assumptions developed to address the missing data will be overly conservative to help ensure that the methodology is favorable to the claimant.

4.2.2 Methodology

Estimating airborne concentrations at locations around the PORTS site using traditional transport modeling approaches is limited by the following factors:

- The numerous release points, which include stacks, vents, and other emission sources
- The characteristics of the release points

- The limited number of air sampling locations
- The relatively short distances between release points and onsite receptor locations
- The density and configurations of buildings at PORTS

Therefore, it is unnecessary to develop a complex dispersal model and perform transport calculations for the PORTS site because such modeling is not likely to yield accurate results.

The methodology for determining internal dose from onsite atmospheric radionuclide concentrations applies directly to the available air sampling data. To be favorable to the claimant for each year for which data are available, the maximum site measurement for gross alpha (uranium) and gross beta-gamma (uranium daughter products and ^{99}Tc) will be applied for the entire site.

The annual intake associated with each radionuclide of concern is based on the fraction given in the annual release as appropriately contributing to either gross alpha or gross beta-gamma sampling results. Since the gross alpha is only from uranium radionuclides, the highest air monitoring concentration is directly applied to the fraction of a uranium radionuclide to the total uranium release at that time, multiplied by the assumed individual ventilation rate to yield the annual intake for each uranium radionuclide. The gross beta/gamma is segregated in a similar manner between ^{99}Tc and the uranium daughters, where the uranium daughters are further fractioned by 6 percent of the uranium daughter fraction for ^{231}Th and the remainder equally split between ^{234}Th and $^{234\text{m}}\text{Pa}$ (Goslow 1986).

4.2.3 Estimation of Ambient Airborne Radionuclide Concentrations Prior to 1964

Because there are no ambient airborne monitoring data prior to 1964, an alternative empirical approach was developed for estimating airborne radionuclide concentrations prior to 1964. Based on other dose reconstruction developments (ATL 2003b), an empirical relationship of maximum annual air concentration for the entire site with respect to uranium release estimates provides a direct relationship of air concentration to material release. The empirical relationship is described by Equation 4-1. The maximum uranium/alpha air concentration measured at the air monitoring station is divided by the release estimates for a given year to estimate an annual, site-specific, Chi/Q value.

$$\text{Chi/Q (m}^{-3}\text{)} = \frac{\text{Maximum Radionuclide Air Concentration (Ci m}^{-3}\text{)}}{\text{Annual Radionuclide Activity Release (Ci)}} \quad (4-1)$$

The empirical Chi/Q value can be determined for each year for which air sampling data are available. However, due to the significant decrease in annual releases beginning in 1994 (from placing the enrichment cascade in cold shutdown), the empirical Chi/Q values will be determined only for 1964 to 1993 (i.e., the beginning of air monitoring data to the last operational year). The available annual environmental reports were reviewed and the highest air concentration (alpha or uranium) was used to determine the Chi/Q value. The average Chi/Q value and annual radionuclide emissions (Goslow 1986) were used to calculate the radionuclide concentration for the years where ambient air monitoring data was not available. For example following Equation 4-1, the highest alpha air concentration for 1974 is $2.56 \times 10^{-13} \text{ Ci m}^{-3}$ (DOE 1975) divided by the annual radionuclide activity release for 1974 of 0.023 Ci (Goslow 1986) resulting in $1.11 \times 10^{-11} \text{ m}^{-3}$. This method was used for each year where environmental data is available. An average Chi/Q value was then calculated for 1964 through 1993. This average Chi/Q value was applied to the annual uranium emissions for each year prior to 1964 factoring in an assumed individual ventilation rate of $2,400 \text{ m}^3$ per year to estimate the maximum annual uranium intakes provided in Table 4-2.

4.2.4 Data for Ambient Airborne Radionuclide Concentrations and Annual Airborne Releases

This document relied on several data sources for estimating ambient airborne radionuclide concentrations and for the annual airborne releases by radionuclide. The two principal sources were the annual environmental reports from 1972 and 2001 (the Reference List at the end of this TBD includes all DOE site environmental reports from 1973 through 2002) and a special study of historic radiological releases (Goslow 1986). Measurements from the air monitoring locations listed in Table 4-1 were collected from these documents and applied to the methodology described above. When data were not provided or additional information was required, these core documents were supplemented by air monitoring information provided by USEC (ATL 2003c) or by estimating the release quantity for specific situations using historical trends or physical processes (such as secular equilibrium).

The data provided by Goslow (1986) include accidental releases in addition to routine emissions. The largest of such releases occurred in March 1978, when a 14-ton feed cylinder fell from its carrier and cracked open, releasing an estimated 4,820 kg of uranium to the atmosphere and an additional 680 kg of uranium through the plant sewers, for a total activity of less than 3 Ci. Other major accidental releases included two valve failures on a tails cylinder in July 1969 and October 1978 and a process malfunction in the Side Purge Cascade in December 1983. In addition, a string of accidental releases of mostly depleted uranium during the first 5 yr of plant operation accounted for essentially all the uranium lost to the atmosphere from 1955 through 1958 and 20% of the losses in 1959. Thus, the variations seen in the uranium radionuclide fractions and, ultimately, in the calculated uranium radionuclide intake values are due to the quantity of depleted or enriched material released during a given year.

The uranium daughters identified as a potential environmental concern were ^{231}Th , ^{234}Th , and $^{234\text{m}}\text{Pa}$ (Goslow 1986). PORTS estimated the fraction of ^{231}Th to be 2.5 percent to 6 percent of all uranium daughter radiation measurements; the remaining uranium daughter radiation is evenly split between ^{234}Th and $^{234\text{m}}\text{Pa}$. For the purposes of estimating the intake of specific uranium daughter radionuclides, 6 percent should be from ^{231}Th and 47 percent for ^{234}Th and $^{234\text{m}}\text{Pa}$ (Goslow 1986). Also, since the enrichment cascade was shutdown in 1993, if the quantity of uranium daughters released were not specifically given in the DOE annual environmental reports after 1993, they will be assumed to be in secular equilibrium (i.e., at the same activity as the parent radionuclide).

It is important to note that the release data has values and relationships that one might believe to be atypical. For example, there are years where the quantity of uranium daughters released exceeds the quantity of total uranium released (i.e., 1979, 1981, and 1984). The expected situation is that the uranium and its daughters would exist together and, in accordance with their respective decay half-lives, in secular equilibrium, where the activity of uranium daughter would be the same as the uranium parent. The only time that the uranium daughters can be considered in secular equilibrium with the uranium parent is after 1993, when the cascade was shutdown. Another example is isotopic quantity of uranium released. The first two years of releases (1955 and 1956) were zero for ^{234}U , while the same years had the total uranium released as approximately 0.55 and 0.24 Curies. Such atypical data is probably due to the nature of the physics of gaseous diffusion, initial enrichment of feed at Paducah prior to enrichment at PORTS, and how and where in the enrichment cascade the releases were performed.

4.2.4.1 Airborne Release Estimation for Neptunium, Plutonium, Uranium Daughters, and ^{99}Tc

A review of the airborne environmental release data for the PORTS site shows a lack of information during the first 20 years of operation for radionuclides that later became a source of concern with subsequent inclusion in the environmental monitoring program. The principal radionuclides added to

the environmental monitoring program were the uranium daughters in 1967 and ^{99}Tc in 1976 (ATL 2003d). However, there could be a concern for releases of transuranics from the processing of recycled uranium and for the releases of uranium daughters prior to 1967 and for ^{99}Tc prior to 1976 (BJC 2000). This section investigates the potential for these unknown releases and how to include their contribution for the environmental occupational dose.

Based on the information given in the Recycled Uranium Mass Balance Project (BJC 2000), the principal transuranics that were fed into the cascade were Np and Pu radionuclides. Both were determined to have annual inventory levels of less than 100 g over the entire history of PORTS (see Table 5.1-1 and Figure 5.1-1 of BJC 2000). In addition, the Np and Pu that entered the cascade soon plates out on cascade components (BJC 2000, pg 67). The Np and Pu radionuclides would be removed with the uranium deposits when the process equipment was removed and decontaminated. The uranium deposits containing the Np and Pu radionuclides went into the uranium recovery process, so a small fraction of the transuranics stayed in the recovered uranium as impurities or were removed into the liquid or solid wastes stream. Therefore, due to the low levels of Np and Pu radionuclides that entered the cascade, their plating out, and the material staying in liquid and solid product or waste streams, airborne releases of Np and Pu are considered to be in trace amounts only and not contributors to the environmental occupational doses.

To estimate the potential releases of uranium daughters prior to the beginning of release measurements in 1967, a key item to note is the tremendous difference in the half-lives of the parent radionuclides (over millions of years) and of the daughters (minutes to days). Such differences in half-lives results in the daughters being in what is defined as secular equilibrium with the parent radionuclide (i.e., daughter's activity is at the same activity as the parent radionuclide). Therefore, by assuming secular equilibrium, ^{231}Th would have the same activity as its parent, ^{235}U , and $^{234\text{m}}\text{Pa}$ and ^{234}Th would each have the same activity as its parent, ^{238}U . For most years, this assumption would be favorable to the claimant since the average uranium daughter released activity was approximately 0.3 of the uranium released activity, where this value would be closer to 1.0 if both were in secular equilibrium.

With the discovery of ^{99}Tc in the east drainage ditch during the first quarter of FY1975, this radionuclide was added to those already being monitored (uranium and uranium daughters). What is known of the physical migration process for ^{99}Tc is that it plates out on surfaces within the cascades and slowly migrates through the enriched cascade, and would result in relatively higher counts for the gross beta monitoring of the release vents once reaching the purge cascade (ATL 2003d). Thus, with the pre-enrichment of the recycled uranium at Paducah first removing the ^{99}Tc from the PORTS feed material and the slow migration time to reach any release point such as the purge cascade, release of ^{99}Tc is considered negligible prior to 1975.

4.2.5 Estimation of Annual Intake from Airborne Radionuclides

Using the maximum airborne radionuclide concentration in a year (either from a direct reading or a calculated value), this document used an assumed individual ventilation rate of 2,400 m^3/yr to derive annual intakes that are favorable to the claimant for the radionuclides of concern. Table 4-2 lists annual intakes for each radionuclide of concern for each year.

4.2.6 Contribution of Airborne Radionuclides to External Dose

From the data shown in Table 4-2, the levels of annual intakes during the early years of operations at PORTS are two to three orders of magnitude higher than the years after 1966. High airborne concentrations can have a significant contribution to the direct radiation exposure through the pathway of submersion within a cloud of radioactive material. With such variations in the air

concentrations used to determine the estimated annual intakes, a demonstration of the potential occupational impacts would show the potential contribution to the external site dose from submersion. Since the highest airborne intake is due to uranium daughters based on the 1955 intake, these radionuclides and concentration levels would demonstrate the conditions most favorable to the claimant. The submersion dose was calculated using the air submergence dose factors in Federal Guidance Report No. 12 for the uranium daughter radionuclides of ²³¹Th, ²³⁴Th, and ^{234m}Pa. As previously stated, the contribution of each radionuclide is 6 percent of the uranium daughter fraction for ²³¹Th and the remainder equally split between ²³⁴Th and ^{234m}Pa. The potential contribution to the annual external exposure from these uranium daughters at the highest airborne concentrations only yields 1.2 µrem (Goslow 1986). Therefore, airborne radioactivity at the PORTS site over all years of concern would have a negligible impact to the annual occupational external exposure.

Table 4-2. Maximum annual intakes (Bq per year).

Year	⁹⁹ Tc	Uranium progeny ^(f)	²³⁴ U	²³⁵ U	²³⁶ U	²³⁸ U	Total U
1953	—	—	—	—	—	—	—
1954	—	—	—	—	—	—	—
1955 ^(a) (e)	0.000E+00	6.553E+01	6.011E+01	2.706E+00	1.422E-01	1.174E+02	1.803E+02
1956 ^(a) (e)	0.000E+00	2.832E+01	2.598E+01	8.139E-01	6.137E-02	5.108E+01	7.793E+01
1957 ^(a)	0.000E+00	1.745E+00	1.100E+00	1.320E-01	5.721E-03	3.563E+00	4.801E+00
1958 ^(a)	0.000E+00	1.461E+01	3.497E+01	1.540E+00	4.732E-02	3.629E+00	4.019E+01
1959 ^(a)	0.000E+00	3.609E+01	4.289E+01	2.794E+00	1.175E-01	5.349E+01	9.930E+01
1960 ^(a)	0.000E+00	1.389E+01	1.540E+01	1.078E+00	4.498E-02	2.171E+01	3.823E+01
1961 ^(a)	0.000E+00	2.769E+01	3.277E+01	2.222E+00	9.023E-02	4.111E+01	7.620E+01
1962 ^(a)	0.000E+00	1.067E+01	1.628E+01	9.018E-01	2.938E-02	1.214E+01	2.935E+01
1963 ^(a)	0.000E+00	1.233E+00	3.079E+00	2.860E-01	4.160E-03	2.200E-02	3.392E+00
1964	0.000E+00	6.454E+00	1.579E+01	1.283E+00	2.099E-02	9.867E-02	1.776E+01
1965	0.000E+00	2.582E+01	5.751E+01	3.890E+00	8.398E-02	8.288E+00	7.104E+01
1966	0.000E+00	3.227E+00	7.804E+00	5.651E-01	1.050E-02	2.153E-01	8.880E+00
1967	0.000E+00	3.108E-01	7.992E+00	3.552E-01	1.050E-02	4.884E-01	8.880E+00
1968	0.000E+00	1.480E-01	7.400E+00	2.960E-01	1.050E-02	1.184E+00	8.880E+00
1969	0.000E+00	1.696E-01	1.830E+00	2.410E-01	1.050E-02	6.809E+00	8.880E+00
1970	0.000E+00	2.029E-01	3.102E+00	1.432E-01	4.514E-03	5.966E-01	3.818E+00
1971	0.000E+00	1.614E+00	2.992E+00	1.834E-01	5.249E-03	1.207E+00	4.440E+00
1972	0.000E+00	5.486E-01	8.626E-01	6.470E-02	1.785E-03	5.823E-01	1.510E+00
1973	0.000E+00	4.980E-02	2.037E+00	9.960E-02	2.729E-03	9.960E-02	2.309E+00
1974	0.000E+00	1.977E-01	1.779E+01	9.884E-01	2.687E-02	4.448E+00	2.273E+01
1975	0.000E+00	4.098E+00	1.009E+01	3.759E-01	1.333E-02	7.170E-01	1.128E+01
1976	3.609E+01	8.216E-05	8.052E+00	3.779E-01	1.039E-02	3.862E-01	8.791E+00
1977	2.559E+01	7.057E-01	2.001E+00	7.773E-02	2.729E-03	2.293E-01	2.309E+00
1978	2.429E+01	3.535E-02	4.778E-01	3.341E-02	1.480E-03	7.396E-01	1.252E+00
1979	5.479E+00	1.133E+00	7.536E-01	2.270E-02	9.553E-04	2.724E-02	8.081E-01
1980	6.864E+00	2.898E-01	7.758E-01	2.442E-02	9.553E-04	5.746E-03	8.081E-01
1981	6.965E+00	4.757E+00	3.472E+00	1.078E-01	4.293E-03	6.386E-02	3.632E+00
1982	3.181E+01	3.090E+00	1.079E+01	5.449E-01	1.365E-02	2.008E-01	1.154E+01
1983	6.020E+00	1.654E-01	6.073E+00	2.943E-01	7.642E-03	9.036E-02	6.465E+00
1984	5.021E+00	2.927E+00	1.666E+00	4.760E-02	2.110E-03	1.190E-01	1.785E+00

Year	⁹⁹ Tc	Uranium progeny ^(f)	²³⁴ U	²³⁵ U	²³⁶ U	²³⁸ U	Total U
1985	5.445E+00	6.007E-01	8.426E-01	4.837E-02	1.291E-03	2.177E-01	1.092E+00
1986	6.895E+00	1.409E+00	1.154E+00	6.145E-02	1.719E-03	7.044E-01	2.098E+00
1987	1.333E+01	1.288E-01	2.575E+00	8.454E-02	1.214E-04	2.226E-02	2.664E+00
1988	2.113E+01	2.811E-01	5.328E+00	1.998E-01	1.998E-03	1.079E-01	5.594E+00
1989	1.603E+01	3.079E-01	1.089E+00	4.156E-02	1.056E-03	2.284E-02	4.085E+00
1990	2.356E+01	1.811E-01	3.113E-01	8.963E-03	4.881E-05	1.248E-02	1.776E+00
1991	6.022E+01	6.749E-01	4.724E+00	1.384E-01	4.724E-04	2.092E-01	5.062E+00
1992	1.332E+01	7.745E-01	1.228E+00	3.589E-01	1.133E-03	2.078E-01	1.322E+01
1993	1.434E+02	2.756E-01	2.123E+00	5.586E-02	2.383E-04	1.080E-01	2.309E+00
1994	5.329E+00	4.305E-02	5.231E-01	1.655E-02	1.606E-04	9.989E-03	7.104E-01
1995	1.411E+01	8.431E-02	1.313E+00	3.847E-02	3.889E-04	3.459E-02	1.386E+00
1996 ^(b)	1.045E+01	1.161E+00	2.999E+00	1.077E-01	2.154E-03	2.468E-01	3.356E+00
1997 ^(b)	1.607E+01	1.785E+00	2.121E+00	9.193E-02	1.051E-03	6.963E-01	2.910E+00
1998 ^(b)	1.576E+02	1.751E+01	8.890E+00	3.186E-01	1.058E-02	6.138E-01	9.833E+00
1999 ^(c)	3.692E+01	4.103E+00	1.966E+01	7.011E-01	1.336E-02	2.266E+00	2.264E+01
2000 ^(c)	1.120E+01	1.245E+00	4.167E+00	1.486E-01	2.831E-03	4.801E-01	4.798E+00
2001 ^(d)	3.552E-01	3.552E-02	2.042E-01	8.702E-03	1.954E-03	7.637E-02	2.913E-01

- a. Average empirical Chi/Q value from 1964 through 1993 used to estimate the annual intake.
- b. Applied release amounts as given in annual NESHAP reports 1995-1998 (ATL 2003e).
- c. Applied average fractions for isotopic releases as given in annual NESHAP reports 1995-1996 (ATL 2003e).
- d. Air sample measurements by radionuclide, not gross alpha or gross beta-gamma.
- e. For the years 1955 and 1956, the potential intake of ²³⁴U is based on a calculated fraction of 0.5 of ²³⁴U compared to the Total Uranium activity between 1957 through 1962. The Total U was then increased by 50% in order to maintain the concentrations of ²³⁵U and ²³⁸U.
- f. Uranium progeny intakes calculated from recorded or estimated equilibrium fractions with the Uranium parent radionuclides.

4.3 EXTERNAL DOSE

Workers are subjected to external doses from ambient radiation levels. Until September 1981, external gamma radiation levels were measured with a calibrated open-shield Geiger-Muller (GM) tube 3 ft above ground level. Beginning in September 1981, TLD readings of gamma radiation were taken. The minimum detection limit for the GM tube assembly is not known; however, in the period of 1972 through 1981, the minimum dose rate detected was 0.0048 mrem/hr (DOE 1974). Information is not available on the TLD detection limit.

Between 1981 and 1992, TLDs used to measure onsite environmental gamma radiation levels contained calcium fluoride: dysprosium (CaF₂:Dy) chips. Commercially available CaF₂-based environmental dosimeters have a detection limit of 10 mR/mo, however, no particular reference for Portsmouth CaF₂ TLDs identifying the detection level have been identified. These TLDs were used because of their sensitivity (ICN 2003).

Beginning in late 1992, PORTS began using TLDs containing lithium fluoride (LiF) chips to monitor ambient conditions. These TLDs had the same technology used to monitor worker doses (DOE 1996). TLDs used from 1981 through the mid-to-late 1990s were not calibrated to measure neutrons.

TLDs were upgraded in the mid-to-late 1990s to be able to measure beta, gamma, and neutron radiation. These TLDs can differentiate dose between the different forms of radiation and between shallow and deep dose. Neutron dose is included in the deep dose (DOE 1999a). The minimum limit of detection is 10 mrem for beta-gamma and 10 mrem for neutrons (ICN 2003).

Table 4-3 summarizes the history of the type of instruments used for ambient environmental monitoring.

Table 4-3. Instruments used for ambient environmental monitoring.

Instrument	Period of use	Minimum detection level
GM tube	1955-1981	4.8×10^{-3} mR/hr
TLD (CAF ₂ :Dy chip)	1981-1992	10 mR (based on current TLDs with CAF ₂ :Dy chip)
TLD (LiF chip)	1992 – mid to late 1990s	Unknown
ICN 760 TLD (LiF chip)	Mid to late 1990s – present	10 mrem for beta-gamma 10 mrem for neutrons

Throughout the history of the site, environmental radiological measurements were taken at outdoor locations around Perimeter Road and at offsite locations to monitor public dose (locations 3, 12, 24, 29, A36, A39, A40, and 874). Since 1998, ambient radiological conditions at six major facilities (X-7725, X-326, X-345, X-744G, X-745C, and X-745E) at the interior of the site have been recorded, in addition to those at the Perimeter Road locations, to assist in monitoring worker dose. Figure 4-1 shows the locations of the public and worker monitoring points. Table 4-4 includes a description of each location. The TLDs used to monitor facilities at the interior of the site are outside the buildings.

Data collected by TLDs used to monitor public dose were used to establish ambient environmental doses for most areas and most years because these data are all that is available to establish ambient environmental conditions inside the site boundary. Ambient environmental doses for workers were not monitored consistently until 1998 (see Table 4-5) because of the emphasis on monitoring public dose and because throughout much of PORTS history, most workers were monitored with personal dosimetry. The ambient environmental data for workers, listed in Table 4-5, do not provide enough information and are too specific to the buildings listed in the table for application over all years and all outdoor areas.

The Perimeter Road TLD locations changed over the years. For some of these locations (described in the previous paragraph), TLD readings might have been taken off the site during certain years, but are attributed to the particular location as the nearest point to the industrial area. For example, in the early years, location 29 on the west side of the site was at the U.S. Highway 23 exit ramp of the main access road to the site; this location was later moved to the Perimeter Road/main access road intersection. This TBD assumes that all public dose readings were at the Perimeter Road.

4.3.1 Ambient Radiation

The environmental radiological profile has been developed for PORTS for use by dose reconstructors when personal dosimetry or bioassay program participation was not required. Annual site environmental reports, health physics surveys, and other reports were reviewed for data that would be useful in reconstructing ambient radiation levels. Data in these documents (see reference section for citations) include TLD radiation measurements. Tables 4-5 and 4-6 list the GM and TLD results. The following sections discuss these tables further.

Table 4-4. Environmental measurement locations^a.

Designation (Other designations used over the years for measurements taken in this vicinity)	Location
3 (39, X-230-J2, A35)	Generally, south side of site, near south holding pond.
12 (PP933)	Power pole 933 opposite East Access Road.
24 (PP906)	Power pole 906 opposite North Access Road.
29 (10, PP862)	Power pole 862 opposite main access road.
A36 (X-611)	Vicinity of water treatment plant.
A39 (PP722)	Power pole 722 at south end of Pike Ave. between X-231 oil biodegradation plots.
A40 (35, X-100)	Vicinity of Guard headquarters.
PP518	Power pole 518 near X-104.
PP1406 (PP1404A)	Near X-7725 and warehouses on west side of site.
874	On power pole 874 at northwest corner of X-745C Depleted Uranium Storage Yard.
X-7725	Waste Storage Facility.
X-326	Process Building.
X-330	Process Building.
X-333	Process Building.
X-344	Containment Building.
X-345	Special Nuclear Material (SNM) Storage Building.
X-705	Decontamination Building.
X-720	Maintenance and Stores Building.
X-744G	Bulk Storage Building.
X-745C, X-745E	Depleted Uranium Cylinder Storage Yards.

a. Source: ATL (2003f).

Table 4-5. Site interior ambient radiological conditions^a.

Mean annual dose by location ^{(b), (c)} (mrem/year)												
Year	X-7725		X-326		X-345		X-744G		X-745C		X-745E	
	Avg. deep dose	Avg. shallow dose	Avg. deep dose	Avg. shallow dose	Avg. deep dose	Avg. shallow dose	Avg. deep dose	Avg. shallow dose	Avg. deep dose	Avg. shallow dose	Avg. deep dose	Avg. shallow dose
1998	21	36	2	4	19	26	—	—	35	39	20	21
1999	5	10	1	4	1	3	23	19	37	30	56	47
2000	14	—	0	—	0	—	285	—	122	—	178	—
2001	23	—	0	—	0	—	1,056	—	142	—	175	—

a. Sources: DOE (1999a), DOE (2001a), DOE (2001b), and DOE (2002).

b. 2,000-hour work-year, prorated from an 8,736-hour year.

c. Includes beta, gamma, and neutron. Neutrons included in deep dose.

— No data.

Table 4-6. Perimeter road ambient radiological conditions from GM and TLD measurements.

Mean annual dose by location ^{(a), (b)} (mrem/year)										
Year	874	PP518	29 (10, PP862)	24 (PP906)	12 (PP933)	PP1406	3 (39, X-230- J2, A35)	A40 (35, X-104)	A36 (X- 611)	A39 (PP722)
1954	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
1972	—	—	23.6	23.8	22.4	—	24.0	—	—	—
1973	—	—	27.8	26.4	25.6	—	27.2	—	—	—
1974	—	—	28.2	27.0	26.0	—	26.8	—	—	—
1975	—	—	19.2	18.8	18.4	—	18.8	—	—	—
1976	—	—	20.6	20.4	20.0	—	20.0	—	—	—
1977	—	—	23.8	24.0	24.2	—	24.4	—	—	—
1978	—	—	21.8	21.4	20.6	—	21.2	—	—	—
1979	—	—	21.8	21.2	22.0	—	20.2	—	—	—
1980	—	—	21.4	20.8	20.8	—	21.6	—	—	—
1981	—	—	21.0	22.6	20.2	—	19.8	—	—	—
1982	—	—	14.4	15.6	14.6	—	16.2	17.4	—	—
1983	—	—	15.6	12.8	13.4	—	15.2	15.8	—	—
1984	—	—	12.4	6.4	12.8	—	20.4	11.4	—	—
1985	—	—	13.8	13.8	13.8	—	13.8	13.8	—	—
1986	239.3	—	20.3	16.4	19.1	—	16.9	16.4	20.6	19.1
1987	267.5	—	21.6	20.0	21.4	—	18.9	19.4	24.5	22.8
1988	260.6	—	19.6	17.4	19.4	—	20.8	16.6	23.2	21.6
1989	257.2	—	22.7	20.8	20.7	—	20.7	17.4	22.5	22.7
1990	250.7	—	23.7	17.9	24.7	—	20.0	19.6	21.0	—
1991	261.0	16.7	21.5	17.0	21.7	21.7	20.1	NR	20.9	—
1992	246.5	29.1	36.6	17.4	19.9	44.8	33.7	NR	25.6	—
1993	150.4	24.8	25.4	24.0	23.6	12.2	35.9	26.0	26.9	—
1994	27.8	22.9	24.6	30.3	24.6	22.1	29.8	19.9	32.3	—
1995	90.0	20.0	16.3	16.8	17.4	17.3	18.1	15.5	19.4	—
1996	112.0	14.0	22.1	26.9	28.4	13.4	15.7	10.5	29.7	—
1997	131.4	13.8	21.5	25.9	27.5	13.9	15.2	10.4	28.5	—
1998	135.0	22.0	23.3	23.3	24.3	23.1	24.7	20.4	24.3	—
1999	131.4	18.5	19.2	16.9	20.6	20.8	20.4	15.8	20.1	—
2000	149.2	24.5	22.0	20.6	29.5	22.0	24.0	19.7	23.8	—
2001	150.4	19.1	23.2	16.8	27.2	19.2	20.8	15.7	19.5	—
2002	142.4	18.4	23.3	15.7	27.1	18.8	20.4	14.8	18.4	—

a. 2,000-hour work-year, prorated from an 8,736-hour year.

b. Data for all years are from PORTS annual environmental reports with the exception of 1993 – 2002 for locations PP518, PP862, PP906, PP933, PP1406, A35, A40, A36 and 874, which were obtained from USEC by separate communication (ATL 2003f).

— No data.

4.3.1.1 Background Radiation

The ambient radiation measured by TLDs near Perimeter Road included natural background radiation, nuclear weapons testing fallout, and cosmic radiation (DOE 1994). These TLDs provided an indication of worker dose levels in the general proximity of Perimeter Road (with the exception of the cylinder storage yards), but not inside buildings. Table 4-6 lists annual dose levels for locations near Perimeter Road. These data, available for 1954 and 1972-2002, are representative of dose for a 2000-hr work-year.

Because of a lack of environmental dosimetry data prior to the year 1972, an extrapolation will be assumed based on the available data. To support the assumptions, it is necessary to determine if there is a correlation between the production levels (in metric tons uranium (MTU)) and/or the accumulation of material (i.e., tails in the cylinder yards) at the PORTS site and the available environmental dosimetry. The annual production levels are available in Appendix IV of the *Recycled Uranium Mass Balance Project, Portsmouth, Ohio Site Report* (BJC 2000). However, annual data on the accumulation of tails material in the cylinder yards does not appear to be publicly available. Instead, an assumption is made that a significant majority of the feed material processed at PORTS would eventually leave the enrichment cascade as tails material and placed into long-term storage in one of the site's cylinder yards. Therefore, the cumulative quantity of feed material by year based on the data given in Appendix IV of the *Recycled Uranium Mass Balance Project Report* would be proportional to the accumulation of the tails material.

Figure 4-2 shows the cumulative quantity of feed material by year at PORTS versus the available environmental dosimetry data previously presented in Tables 4-5 and 4-6. This figure demonstrates that no direct relationship exists between the quantity of material accumulated at the PORTS site and the environmental dosimetry readings for the years available (after 1972). Figure 4-3 compares the same environmental dosimetry data to the annual MTU processed by PORTS from 1955 to 1997. This result would show if there is a potential for "building shine" as a contributor to external environmental radiation levels within the central area of PORTS. It is also important to compare the site readings to distant reading locations (i.e., background radiation levels). If there is an effect caused by the quantity of material processed, it should be an additive value to the site's background radiation levels. As shown in Figure 4-3, the environmental dosimetry data fluctuates more with the background radiation levels than the quantity of material processed. Therefore, the amount of feed stock processed per year (i.e., building shine or general radiation levels) does not significantly contribute to the environmental dose that all site workers would be expected to receive. It can therefore be assumed that the data presented in Tables 4-5 and 4-6 are representative of ambient radiological conditions for the entire period of 1954 to 2002.

In the past, personal dosimetry devices worn by site workers were stored in racks at the guard gates. Based on a 1989 study to review the practice of using storage racks, some employees were allowed to leave PORTS with their personal dosimetry. Beginning in 1999, all workers were allowed to leave PORTS with their personal dosimetry. Procedures require an exchange of dosimetry if the worker believes the dosimetry might have been inadvertently exposed away from PORTS due to dose from a medical exam, airport security system, or other sources (ATL 2003g).

Exposure to neutrons is not a factor in PORTS outdoor areas except in the uranium hexafluoride (UF₆) cylinder storage yards (see Section 4.3.1.2). Other areas where neutron dose might be of concern are indoors (Cardarelli 1997).

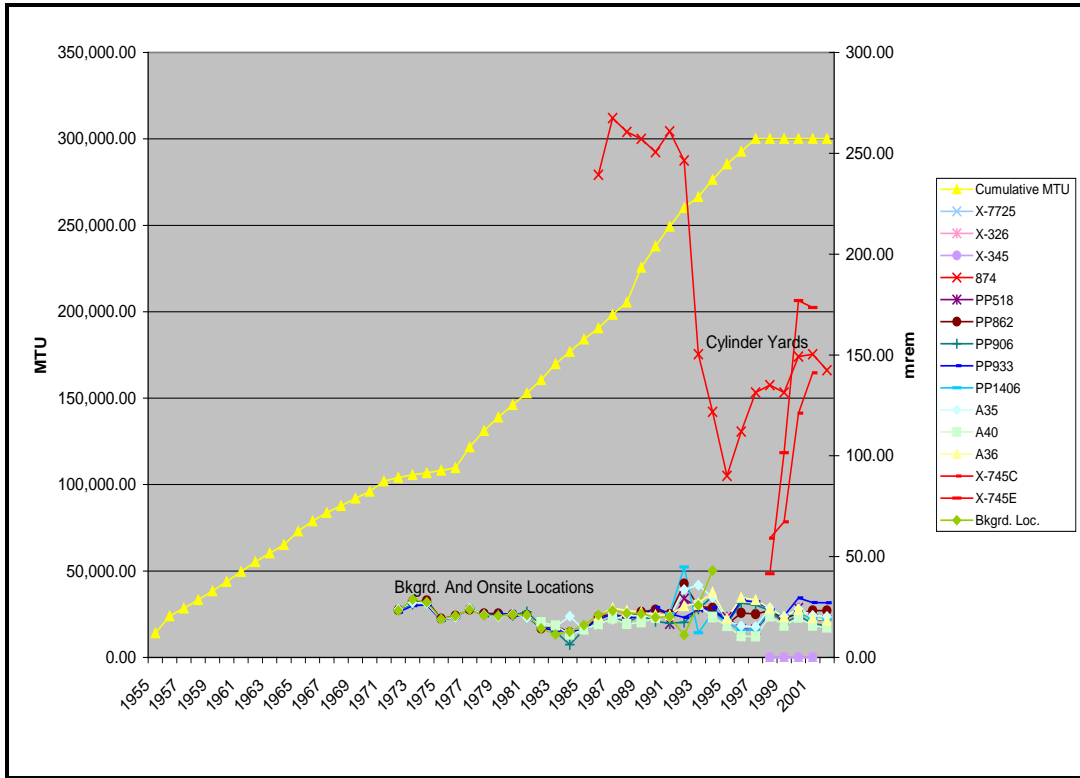


Figure 4-2. Cumulative quantity of material by year

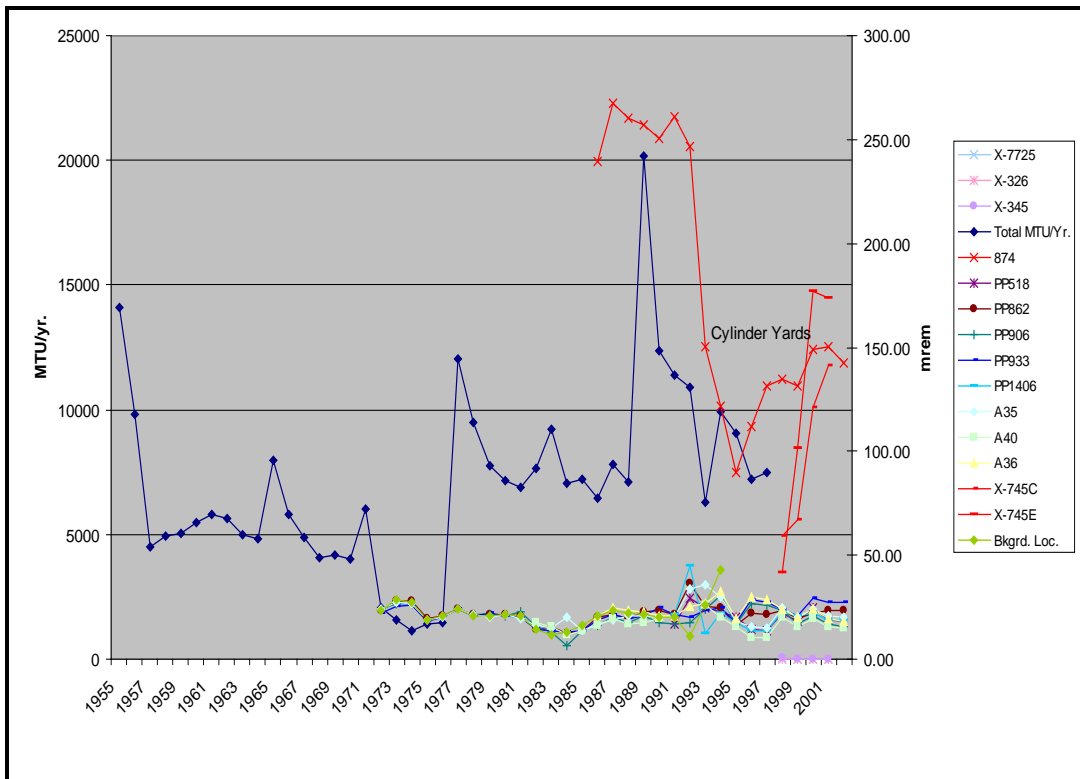


Figure 4-3. Annual MTU vs. work year doses (2000 hrs/yr)

If background is not to be subtracted, the maximum value of 44.8 mrem from Table 4-6 can be used to assign annual ambient environmental dose to workers in areas near Perimeter Road, such as the

general employee parking lots; the guard gates on the outer perimeter of the security area; the switchyards; warehouses X-744S, T, and U; process buildings, and wastewater facility X-611. (The values in Table 4-6 for location 874 are much higher, but are specific to the UF₆ cylinder storage yards and not to the rest of the facility.) If background is to be subtracted, the ambient radiation for these areas should be assigned a value of 0 mrem because of the argument presented above.

The data in Table 4-5 are representative of ambient radiological conditions for the areas immediately surrounding X-7725, X-326, X-345, and 744G. These data are applicable only to 1998 through 2001 as specified in the table. It is difficult to apply the data in Table 4-5 for other years because of its variability and limited amount. The value of 44.8 mrem per year should be used for 1954 to 1997 outside these four buildings. For 744G, an outdoor ambient dose of more than 1,000 mrem for 2001 (2,000-hr work-year) is expected because of the increasing inventory of nuclear material stored in this facility (ATL 2003h). The data in Table 4-5 associated with X-745C and X-745E cylinder storage yards are discussed in Section 4.3.1.2.

4.3.1.2 Ambient Radiological Conditions in Cylinder Storage Yards

Several TLDs were near the UF₆ cylinder storage yards, so elevated ambient radiation levels are likely near the storage yards in comparison to other outdoor areas of the site. TLD 874, on a power pole on Perimeter Road at the X-745C cylinder storage yard, monitors public dose. The average dose from 1986 to 2002 was 1,116 mrem/yr with a maximum of 1,172 mrem over 24 hr and 365 d/yr. This is equivalent to an average of 255 mrem and a maximum of 267 mrem for a 2,000-hr work-year as indicated in Table 4-6 for TLD 874. An approximate 40% drop in dose readings at this location in 1993 was probably due to a change in the type of TLD monitor in late 1992 (this cannot be confirmed but it corresponds to a period in which TLDs were upgraded). The TLDs used to monitor this dose were not calibrated to detect neutrons until 1998. Because the TLD on the power pole was probably not within several feet of a UF₆ cylinder but was used to monitor public dose, neutrons are not an exposure factor; the 10-ton cylinders produced radiation levels of 0.5 mrem/hr neutron dose equivalent rate at the surface and would quickly decrease to background radiation levels due to distance (i.e., 1/r² rule) (Cardarelli 1997).

In comparison, Table 4-5 lists results for a different set of TLDs in cylinder yards X-745C and X-745E from 1998 to 2001. These TLDs are in the cylinder yards, not on the perimeter of the yards, to focus on worker dose. They were calibrated to measure neutrons, which are included in the values for deep dose equivalent. The average dose for the two cylinder yards over 4 yr was 130 mrem (deep plus shallow dose), with a maximum of 178 mrem. These values are less than those measured on the power pole.

In another document, the average radiation dose to cylinder yard workers from 1990 to 1995 ranged from 55 to 196 mrem/yr based on personal dosimetry (DOE 1999b). These workers conducted activities in other site facilities wearing the same TLDs and probably did not work in the cylinder yards 2,000 hr each year.

Given the above information, an ambient radiation dose of 267 mrem (2,000 hr work-year), which is favorable to the claimant, should be applied to cylinder yard workers. The portion of this dose attributable to neutrons can be assumed to be 178 mrem per year. This value for the annual neutron dose is obtained from Table 4-5 as the maximum annual deep dose equivalent reported in the period 1998 to 2001 for the cylinder storage yards X-745C and X-745E. This assumes that the neutron dose is the only contributor to the deep dose equivalent. All of these assumptions are favorable to the claimant.

4.3.1.3 Ambient Radiological Conditions Inside Buildings

Because all workers were badged and monitored throughout much of the PORTS operating history, coworker dose data can be used to assign dose to unmonitored workers for the periods during which all workers were not badged or were badged, but not analyzed. Other sources of information that describe potential radiation doses can be used as backup to coworker data.

In 1983, a survey by the Centers for Disease Control and Prevention recorded area beta and gamma measurements for buildings X-326, X-330, X-333, X-344, X-705, and X-720. The highest gamma measurement was 4,000 mrem/yr. The highest median gamma measurement was 160 mrem/yr. Both of these measurements occurred in X-344 (CDC 1987). The 160-mrem median gamma measurement can be used to indicate conservative ambient conditions inside all buildings that contain radiological materials or contamination. The highest gamma measurement of 4,000 mrem is not an external dose reading that could be considered reflective of overall operations and should not be assumed over an exposure period because personal dosimetry results do not indicate this type of exposure level at PORTS according to the information from the Radiation Exposure Monitoring System (REMS) (Section 4.3.1.2).

4.4 UNCERTAINTY

As discussed in the previous sections, estimates of annual intakes employed conservative assumptions (i.e., favorable to the claimant). For example, applying maximum annual dose to all years is an assumption favorable to the claimant.

The locations of the monitoring points from which data are summarized in this TBD add uncertainty to the results. These points, as stated above, were around the site perimeter and off the site to monitor public dose. Until 1998, external environmental exposures were not monitored in relation to workers; that is, monitoring locations were not normally at the interior of the site among the process buildings. Because of data availability, however, public dose information had to be used for worker environmental doses. The maximum value of environmental dose is recommended for years for which data are unavailable to compensate for lack of worker-specific environmental dose information.

All external environmental dose data are adjusted to reflect a 2,000-hr work-year. The data were originally reported in site environmental reports as representative of an employee who works at the site 24 hr/d, 365 d/yr. Using a permanently located employee at the site, however, is an unrealistic assumption that might overstate onsite environmental doses.

4.5 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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GLOSSARY

alpha radiation

Radiation consisting of charged particles of the isotope helium-4, consisting of two protons and two neutrons. Alpha radiation is common for heavier nuclei.

background radiation

Radiation received that is not associated with a worker's occupation. This includes cosmic, terrestrial, and man-made sources.

Becquerel

The derived SI unit of radioactivity equal to one disintegration per second.

beta radiation

Radiation consisting of charged particles of very small mass (i.e., the electron) emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the direct fission products emit beta radiation. Physically, the beta particle is identical to an electron moving at high velocity.

deep dose equivalent

The dose equivalent at the respective depth of 1.0 cm in tissue.

Derived Concentration Guidelines

A calculated concentration that would result in an annual dose of 100 mrem.

dosimetry

The science of assessing absorbed dose, dose equivalent, effective dose equivalent, etc., from external and/or internal sources of radiation.

exposure

As used in the technical sense, exposure refers to a measure expressed in roentgens (R) of the ionization produced by photon radiation (i.e., gamma and X-rays) in air.

film badge

In general, a "film packet" that contains one or more pieces of film in a light-tight wrapping. The film, when developed, has an image caused by radiation that can be measured using an optical densitometer.

gamma rays

Electromagnetic radiation (photons) originating in atomic nuclei and accompanying many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Physically, gamma rays are identical to X-rays of high energy, the only essential difference being that X-rays do not originate in the nucleus.

neutron

A basic particle that is electrically neutral, having nearly the same mass as the hydrogen atom.

radiation

Alpha, beta, neutron, and photon radiation.

Radiation Exposure Monitoring System (REMS)

An online DOE database that contains records of personal dosimetry information.

radioactivity

The spontaneous emission of radiation, generally, alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

rem

A unit of dose equivalent, which is equal to the product of the number of rad absorbed and the "quality factor."

shallow dose equivalent

The dose equivalent at the respective depth of 0.07 mm of the skin or an extremity.

thermoluminescent dosimeter (TLD)

A holder containing solid chips of material that, when heated, release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

uranium hexafluoride (UF₆) cylinder storage yard

Storage yards at the Paducah and Portsmouth Gaseous Diffusion Plants and Oak Ridge K-25 site. These yards maintain cylinders containing depleted UF₆. The cylinders, which typically weigh 10 and 14 tons, contain depleted UF₆ primarily in a solid form.