DOE Review Release 08/31/2012

Document Title: **Paducah Gaseous Diffusion Plant – Occupational Environmental Dose**	Document Number: ORAUT-TKBS-0019-4 Revision: 03 Effective Date: 08/24/2012 Type of Document: TBD Supersedes: Revision 02

Subject Expert(s): Jodie L. Phillips

Approval:	Signature on File Jodie L. Phillips, Document Owner	Approval Date:	08/21/2012
Concurrence:	Signature on File John M. Byrne, Objective 1 Manager	Concurrence Date:	08/21/2012
Concurrence:	Signature on File Edward F. Maher, Objective 3 Manager	Concurrence Date:	08/21/2012
Concurrence:	Vickie S. Short Signature on File for Kate Kimpan, Project Director	Concurrence Date:	08/21/2012
Approval:	Signature on File James W. Neton, Associate Director for Science	Approval Date:	08/24/2012

☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
08/24/2004	00	Technical Basis Document for the Paducah Gaseous Diffusion Plant – Occupational Environmental Dose. First approved issue. Initiated by Jay J. Maisler.
11/07/2006	01	Approved Revision 01 initiated to address comments from earlier unresolved comments received on TBD. Constitutes a total rewrite of document. Incorporates additional information obtained through additional data capture for the Paducah Gaseous Diffusion Plant. This revision to addresses the Worker Outreach comment: "The use of the Site Profile is redundant and does not help claimants in any way. The Site Profile only represents incorrect, inaccurate, and incomplete information provided by DOE" This revision involved researching documents to provide a revision which ensured that the most correct, accurate, and complete information available was used. Text was added or modified in sections 4.1, 4.2, 4.3, 4.4, and in the Acronyms and Abbreviations, References, and Glossary. No sections were deleted. Incorporates internal, NIOSH and DOL formal review comments. This revision results in an increase in assigned dose and a PER is required. The increase in assigned dose is based on the revision to Table 4-2 that adds transuranic exposures in the environment. Training required: As determined by the Task Manager. Initiated by Paul A. Szalinski.
04/23/2007	02	Approved Revision 02 initiated to incorporate Attributions and Annotations section. Rearranged tables and corrected the List of Tables. Constitutes a total rewrite of the document. Incorporates formal internal review comments. This revision results in no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Daniel S. Mantooth.
08/24/2012	03	This site profile was predominantly revised to address SC&A concerns about the document as identified in SC&A-TR-TASK1-0016, *Review of the NIOSH Site Profile for the Paducah Gaseous Diffusion Plant.* Wording was revised throughout the document to add clarity. Figure 4-5 was added to show onsite air monitoring locations. The external dose equivalent rates in Table 4-6 have been revised based on available historical data. Guidance provided in ORAUT-PROC-0060 has been added. Acronyms and Abbreviations, References, and Glossary Sections have been updated. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Jodie L. Phillips.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

Bq	becquerel
cfm	cubic feet per minute
CIP	Cascade Improvement Program
cm	centimeter
cpm	counts per minute
CUP	Cascade Upgrade Program
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
FP	fission product
ft	foot
g	gram
GM	Geiger-Müller
hr	hour
kdpm	kilodisintegrations per minute
km	kilometer
m	meter
mg	milligram
mR	milliroentgen
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
PGDP	Paducah Gaseous Diffusion Plant
RU	recycled uranium
s	second
TBD	technical basis document
TLD	thermoluminescent dosimeter
TRU	transuranic
UF_4	uranium tetrafluoride
UF_6	uranium hexafluoride
UO_2	uranium oxide
UO_2F_2	uranyl fluoride
UO_3	uranium trioxide
U.S.C.	United States Code
yr	year
§	section

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 [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 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 causation[1]] 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) restrict the "performance of duty" referred to in 42 U S. C. § 7384n(b) to nuclear weapons work (NIOSH 2010).

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 2010):

- Background radiation, including radiation from naturally occurring radon present in conventional structures
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

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

4.1.1 Purpose

This TBD provides technical data and other key information that serve as the technical basis for evaluating environmental radiation dose for EEOICPA claimants who were employed at the Paducah Gaseous Diffusion Plant (PGDP).

4.1.2 Scope

This TBD discusses the radionuclides potentially encountered by PGDP employees and released to the environment during the Plant's operational history. The PGDP mission was to enrich uranium in the form of uranium hexafluoride (UF_6) from roughly 0.7% ^{235}U (natural enrichment) to around 3% ^{235}U for use in domestic and foreign power reactors (BJC 2000). Enrichment operations began in 1952 in the first two process buildings C-331 and C-333. From 1953 until 1977, UF_6 feed material was produced from uranium trioxide (UO_3) at the Plant. From 1953 to 1964, and again from 1968 to 1977, UF_6 was produced from the recycled uranium (RU) produced from spent reactor fuel. In May 1977, the feed plant ceased operation and all feed to the enrichment process was in the form of UF_6 from outside sources. Other chemical compounds of uranium were present throughout the Plant's history, including uranyl fluoride (UO_2F_2), uranium tetrafluoride (UF_4), and uranium oxide (UO_2).

ORAUT (2012c) contains detailed information on the history of PGDP and the feed conversion and enrichment process.

Sections 4.2 and 4.3 discuss internal and external environmental dose, respectively. Section 4.4 discusses uncertainty. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 4.5.

This document provides supporting technical data in the evaluation of ambient external and internal doses from environmental releases or fixed source terms for workers at the PGDP. PGDP is one of the original sites that was designated by Congress as part of the Special Exposure Cohort (SEC) under EEOICPA [42 U.S.C. § 7384l(14)]. This designation is as follows:

> *(A) The employee was so employed for a number of work days aggregating at least 250 work days before February 1, 1992, at a gaseous diffusion plant located in Paducah, Kentucky, Portsmouth, Ohio, or Oak Ridge, Tennessee, and, during such employment—*
>
> *(i) was monitored through the use of dosimetry badges for exposure at the plant of the external parts of employee's body to radiation; or*
>
> *(ii) worked in a job that had exposures comparable to a job that is or was monitored through the use of dosimetry badges.*

Dose reconstruction guidance in this document is presented to provide a technical basis for dose reconstructions for nonpresumptive cancers that are not covered in the SEC class through January 31, 1992. Dose reconstructions for individuals employed at PGDP before February 1, 1992, but who do not qualify for inclusion in the SEC, can be performed using this guidance as appropriate.

4.2 INTERNAL DOSE FROM ONSITE ATMOSPHERIC RADIONUCLIDE CONCENTRATIONS

4.2.1 Preoperational Background Survey

Carbide and Carbon Chemicals Company analyzed samples for airborne uranium in August 1952 to document preoperational conditions at PGDP (Whiteaker and Farrar 1953). Ten chemically processed samples showed 0.00 mg/m^3 of uranium in the air. Two samples analyzed for alpha activity had results of 0.00 and 0.018 cpm/ft^3 (approximately 0.01 Bq/m^3). However, what is known about the collection process and analysis of samples indicates that these results are not sufficient to conclude that there was no preexisting airborne radioactivity in the area. As sampling and analysis techniques improved over the years, the presence of measurable radioactivity from sources other than PGDP became evident (such as fallout from atomic weapons testing and fly ash from nearby fossil-fuel power plants) [1].

4.2.2 Ambient Air Sample Collection Network

By 1958, PGDP had established a network of permanent stations on and off the site to collect continuous ambient air samples (Baker and Brown 1959). Sampling data are available in annual environmental reports published since 1958 for four perimeter locations (inside the fence) and varying numbers of offsite locations. The 1959 environmental monitoring report describes outdoor air sampling:

> *The outdoor air samples for alpha and beta active particulates were collected approximately every eight days at the same locations as the fluoride samples. They were 24-hour samples and were collected on Whatman number 40 filter paper at a flow rate of 0.5 cubic feet per minute. These samples were counted for alpha activity on parallel plate counters equipped with amplifiers and scalers and were counted for beta activity with Geiger-Muller tubes equipped with scalers* (Brown and Mitchell 1960).

The environmental report for 1960 indicates that the change in monitoring techniques occurred about mid-1960 (Brown and Baker 1961). A paper from PGDP describes the air sampling equipment used during this period (Mitchell undated). A 115 volt electric-powered air sampler continuously collects particulate samples on membrane filters, having a pore size of 0.8 micron, at a flow rate of 0.3 cubic feet per minute.

The principal purpose of the ambient air monitoring network was to assess if air emissions from PGDP affected the air quality in the surrounding area. This would demonstrate compliance with DOE Derived Concentration Guidelines or U.S. Environmental Protection Agency, Commonwealth of Kentucky, and (as of 1997) U.S. Nuclear Regulatory Commission regulations for airborne releases to the public around PGDP. Therefore, the majority of the monitoring stations are off the site or just inside the security fence. There have been a limited number of onsite monitoring stations, but reports from these stations are not available. Therefore, in the calculation of worker intake, this TBD considers only those results from ambient air monitoring locations adjacent to or outside the PGDP security fence. Table 4-1 lists these monitors and their locations. Brown and Mitchell (1960), Rogers and Jett (1989), and Lockheed Martin Energy Systems (LMES 1996) contain maps showing the old and new naming conventions.

Table 4-1. Ambient air sampling stations.

Designation	Location	Direction from center of Plant
PN-6	At security fence between Buildings C-535 and C-537	North
PE-8	At security fence near McCaw Road	East
PS-2	At security fence about 300 m south of Building C-100	South
PW-5	At security fence near C-749	West
IN	Off site about 2 km north of PN	North
IE	Off site about 1 km east-northeast of PE	East
ISE	Off site about 2 km southeast of PS	Southeast
IS	Off site approx 1.5 km south-southwest of PS	South
IW	Off site approx 1.2 km west-northwest of PW	West
BN	At the north boundary of property, 0.3 km north of PN	North

See figure 4-5 for air sampling station locations.

Several changes to the sampling program occurred over time, primarily involving sample technique and equipment. From 1958 to 1993, low-volume samplers were the principal samplers, with multiple filter types and flow rates.

The general practice for air samples was to perform gross alpha and beta-gamma counts. The activity of gross alpha was associated with the release of uranium, while beta-gamma activity was associated with the release of ^{99}Tc. Overall, the alpha activity was about 7% of the beta activity in air samples [2].

There have been releases of radionuclides to the atmosphere since the beginning of operations, including accidental releases. PGDP release data have been estimated or recorded since operations began in 1953. The uncertainty in the amounts released and lack of a complete ambient air monitoring network for the first 6 years of operation are technical issues that the occupational dose reconstruction must address. Therefore, Section 4.2.3 discusses a method to estimate potential radionuclide air concentrations for 1953 to 1958 and to account for potential uncertainty in the release data.

There are several points of airborne release. These include the stacks for Buildings C-310, C-340, C-400, and C-410. The first two stacks are on the east side of the Plant, while the remaining release points are near the center of the Plant. General Plant ventilation exhausts released lesser concentrations over large areas of the building roofs. The many sources of airborne releases, use of stacks, and the nearly constant wind contribute to a very effective diffusion of contaminants over the small site with no significant terrain features to channel or moderate the wind. Figure 4-1 shows a wind rose from the 1993 annual environmental report for PGDP, which shows winds blowing predominantly from the south-southwest (MMES 1994). When the wind rose is laid over the Plant layout, the predominant winds line up with the cascade buildings.

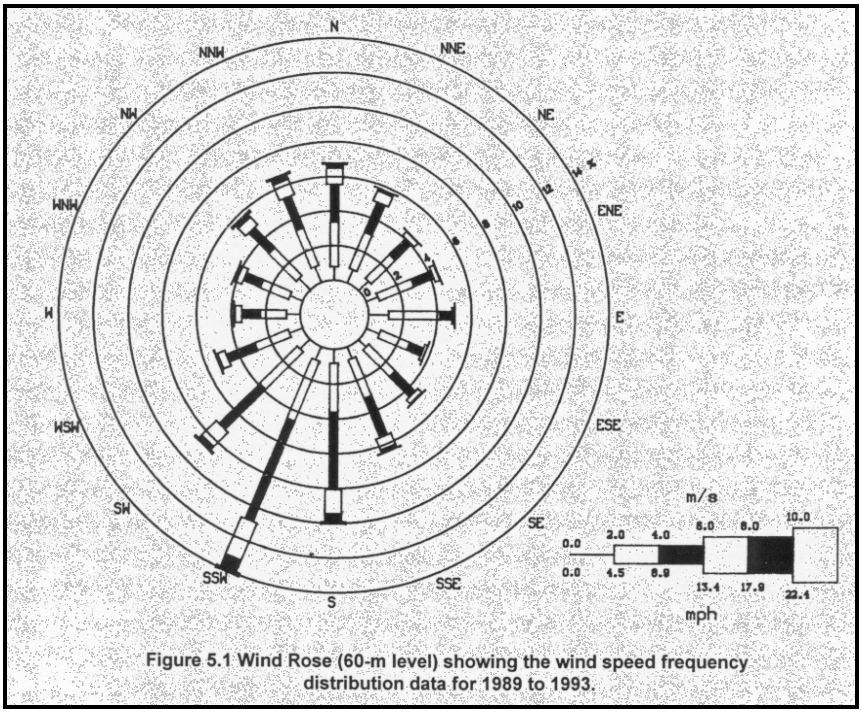

Figure 5.1 Wind Rose (60-m level) showing the wind speed frequency distribution data for 1989 to 1993.

Figure 4-1. Wind rose from MMES (1994).

4.2.3 Methodology

The estimation of airborne concentrations at specific locations around the PGDP site using traditional transport modeling approaches is limited by several 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 the release points and the onsite receptor locations
- The density and configurations of buildings at the site

Past estimates of doses to members of the public off the site indicate that the potential internal dose from airborne releases to PGDP workers should be relatively low, about 10 mrem committed effective dose equivalent or less [3]. Air data from nearby locations and at the security fence are consistent from location to location, but fallout levels from weapons testing dominated the results through the early 1960s. This collection of data provides reasonable approximations of general airborne radioactivity and establishment of trends as a function of time [4].

Factors other than transport and release rates influence the gradual reduction in the air concentration over the 50-year history of PGDP. The records show that releases fell by 5 orders of magnitude while concentrations decreased by less than 3 orders of magnitude [5]. These factors include:

- Improved monitoring methods reduced the minimum detectable concentrations.

- Concentrations of naturally occurring radioactive material released from a nearby fossil fuel power plant fell over the years because of improved environmental controls. (Figure 4-5 in Section 4.3.1 shows the proximity of the power plant.)

- The effect of atmospheric weapons testing and the radioactive decay of fallout (air monitoring results correspond more with fallout than with Plant releases).

The methodology for the intake from onsite atmospheric radionuclide concentrations applies directly to available air sampling data. The maximum site measurement for gross alpha and gross beta-gamma should be applied for all workers throughout the site [6]. Air sampling measurement error and uncertainty should be accounted for by use of the maximum value reported for the year at any location. Available data are limited to annual averages for each location; the limited amount of data does not support statistical analysis.

4.2.4 Estimation of Ambient Airborne Radionuclide Concentrations

In years for which air concentration data are unavailable, release data and maximum air concentration data for adjacent years were evaluated to generate estimates of the air concentration. The alpha concentrations chosen were based on the higher value indicated by releases (1952 to 1956) or by air monitoring trends (1990 and 1994). Similarly, the beta concentrations were chosen to be proportional to releases (1952 to 1958 and 1989) and for the later years (1993 and 1995 to 2001) as an approximate average of the preceding 10 measurements, which results in higher estimates than the downward trend [7].

Figures 4-2 and 4-3 show these data and demonstrate that chosen values are reasonable and will not underestimate dose. These graphs, one for alpha and one for beta, show release values for each year available, measured airborne concentrations, and estimates of assigned values for airborne concentrations if actual measurements were not available.

4.2.5 Data for Ambient Airborne Radionuclide Concentrations and Annual Airborne Releases

This TBD relied on several data sources for estimating ambient airborne radionuclide concentrations and for annual airborne releases by radionuclide. The principal sources were the annual environmental reports for PGDP from 1958 to 2001 (the TBD text cites some of these reports; the References section lists all of them). Measurements from the air monitoring locations were collected from these documents and applied using the method described. Attachment A provides an expanded version of these data, including additional background monitoring points. If data were not provided or additional information was required, these documents were supplemented by information provided by DOE, Bechtel Jacobs Company, or the United States Enrichment Corporation.

4.2.6 Estimation of Annual Intake from Airborne Radionuclides

Using the maximum airborne radionuclide concentration in a year (either from actual data or an estimated value), annual intakes for the radionuclides were derived with an assumed annual respiration rate of 2,400 m^3/yr.

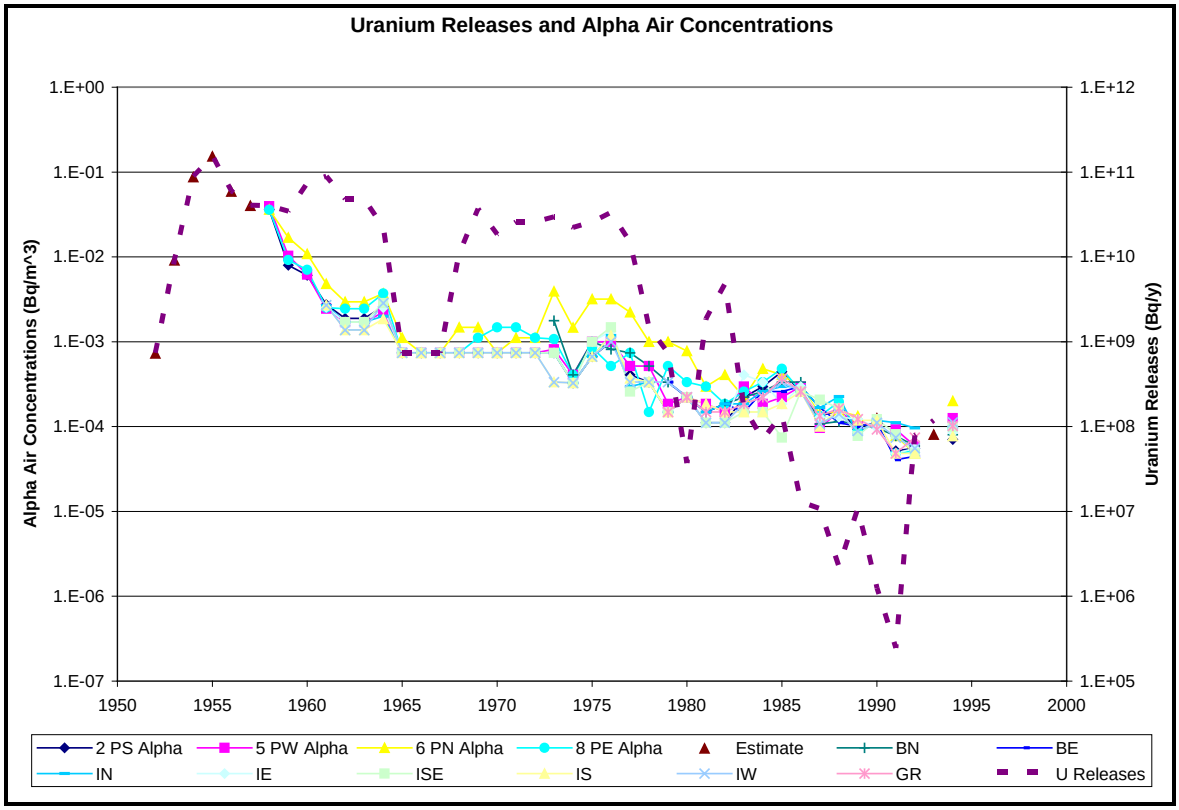

Figure 4-2. Alpha air concentrations.

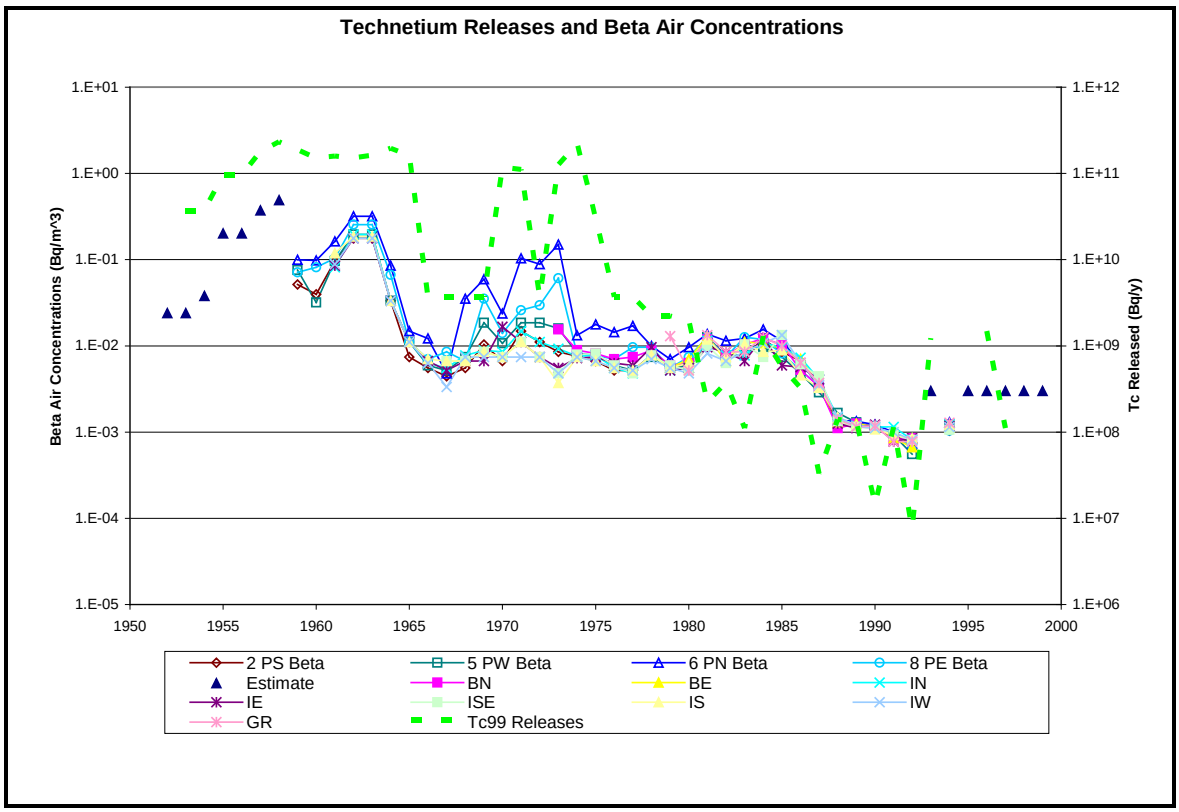

Figure 4-3. Beta air concentrations.

Transuranic (TRU) radionuclides were introduced to the facility with RU feed material beginning in 1953 and continuing to 1977 (for 5 of the years during this period RU was not included in the feed material) (Ritter, Trowbridge, and Meiners 1990). There were areas in the buildings that contributed to intake, mainly around the ash from the fluorination process and the cylinder heels.

The facility operators soon became aware of the rising TRU presence in the feed plant ash, cylinder heels and, to some extent, the cascade (PACE and University of Utah 2000; DOE 2000). There was a period when ^{237}Np was recovered from feed plant ash and shipped to Oak Ridge National Laboratory (BJC 2000).

Workers and safety personnel were used to being able to see contamination. This was due to the low specific activity of natural and low-enriched uranium and because enough material had to be present to be visible as a stain before the meters of the time would indicate contamination [8]. Management became concerned in 1959 when contamination was discovered on a piece of equipment without a stain, and soon concluded that the source of the contamination was 50% neptunium by chemical and pulse height analysis at 25 kdpm/m^2. The 25 kdpm/m^2 was loose contamination determined by swipe, and the 50% neptunium was determined by scraping the metal surface of the spool piece. Due to the known plating characteristics of neptunium, it is likely that the isotopic distribution from the scraping sample might not be representative of the swipe's isotopic distribution (CCCC undated).

A paper prepared for the 1964 Bioassay Conference reports these findings (Baker 1962). The paper includes a discussion of the dust characteristics, established neptunium controls, and monitoring for exposure. The nature of the contamination was studied to characterize particle size and solubility as well as retention and distribution of neptunium in laboratory animals. Retention was reported at 2% while more than 90% was excreted in feces and 2% in urine. These factors reduce the dose impact of an uptake of neptunium.

There were also bioassays performed on the highest exposed individuals. Urinalysis and whole-body counting came back negative on these workers. Later studies showed that widespread distribution in the cascade was not likely. The surface area consisted of 90% barrier material, and that is where the neptunium would have been found. In addition, it would have been removed from the cascade during the Cascade Improvement Program (CIP) and Cascade Upgrade Program (CUP) that replaced barrier material.

Baker (1987) stated:

> *From old records and interviews, estimates were made of 20-year average air concentrations and the particle size of the radioactive aerosols in the various operations areas and of the number of hours operators spent in each job. The fraction of the airborne radioactivity due to the various radionuclides was estimated for each area. Deposition factors were taken from Figure 5.1 of ICRP* [International Commission on Radiological Protection] *Part 1 to provide a correction for particle size. External radiation exposure was determined by film badge dosimetry. From this the average annual 50-year committed dose equivalent was calculated to be 1.54 rem/yr. Of this, TRU and FP's* [fission products] *contributed 12 percent.*

Further:

> *In 1962, 14 employees considered to be among those with the highest potential exposure to neptunium and uranium in each of three plant groups (^{237}Np recovery, converter disassembly, feed plant operations) were sent to Y-12* [in Oak Ridge, Tennessee] *to be counted. None of the employees had detectable ^{237}Np* (Baker 1962).

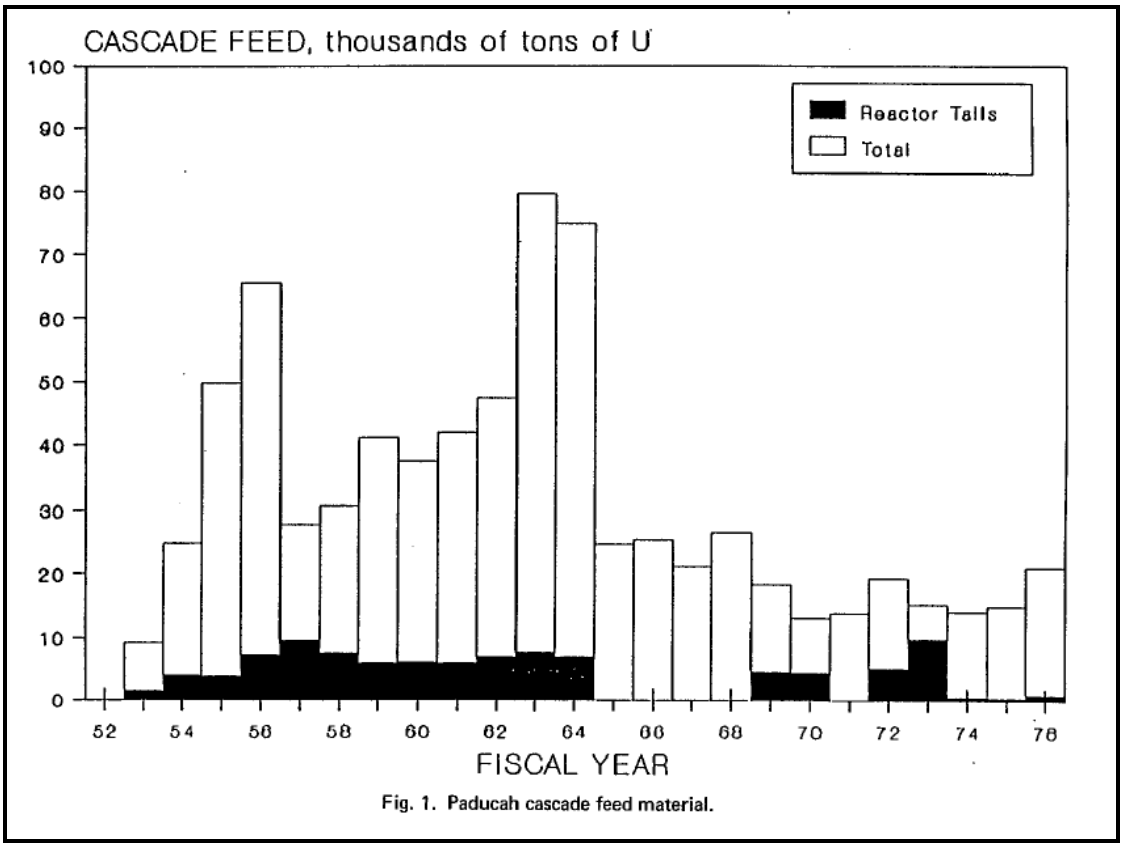

Figure 4-4. Cascade feed in thousands of tons of uranium, 1952 to 1978 (Ritter, Trowbridge, and Meiners 1990).

The Y-12 counter had been calibrated specifically for ^{237}Np. In addition,

> *Deposition of ^{237}Np in the lung from exposure to dust from cascade equipment disassembly and modification was lower than predicted by air sampling because of the large size of the dispersed particulates* (Baker 1987).

There were comments about some very high neptunium alpha fractions, especially during the maintenance on converters during the CIP/CUP years. Some fractions were as high as 90%. Little is known about how these fractions were determined in the early years. As assay techniques improved, such high alpha fractions have not been found.

From Ritter, Trowbridge, and Meiners (1990):

> *Neptunium, as discussed in the chemistry section of this report, is relatively immobile. A survey of equipment removed from the cascade during the more recent upgrade program showed Np concentrated in the vicinity of the historical feed points for RU, several years after it had been fed to those locations in quantities sufficient to account for the material found. On the other hand, a small proportion of product cylinders in the late 1970s showed ppb levels of Np. Thus, there may be a very slight tendency to mobility on a time scale of decades. Most likely, the Np fed to the cascade is still in the equipment to which it was fed. Some of the converters, however, were physically relocated within the cascade, and a large number had their barrier and other cascade components removed during upgrade programs*.

In addition:

> *The 1974 study examined, among other things, soil contamination levels in drainage ditches that had been used during early years of the plant for discharge of liquid streams potentially containing radionuclides. From these analyses it was estimated that less than 4 grams of Np were present in the soil of these drainage ditches* (Ritter, Trowbridge, and Meiners 1990).

Table 4-2 lists uranium releases, alpha airborne concentrations, and intakes. Table 4-3 lists ^{99}Tc releases, beta airborne concentrations, and intakes.

Table 4-2. Uranium releases, alpha airborne concentrations, and intakes.

Year	Uranium release (Bq/yr)	Outdoor alpha concentrations (Bq/m^3) at certain monitoring locations							Annual uranium intake (Bq/yr)
		2 PS alpha	5 PW alpha	6 PN alpha	8 PE alpha	Estimate for missing years	Maximum reported	Applied concentration	
1952	7.4E+08					7.3E-04		7.3E-04	1.7E+00
1953	9.3E+09					9.1E-03		9.1E-03	2.2E+01
1954	8.9E+10					8.7E-02		8.7E-02	2.1E+02
1955	1.6E+11					1.5E-01		1.5E-01	3.7E+02
1956	6.0E+10					5.9E-02		5.9E-02	1.4E+02
1957	4.1E+10					4.0E-02		4.0E-02	9.6E+01
1958	4.0E+10	3.6E-02	4.0E-02	3.6E-02	3.6E-02		4.0E-02	4.0E-02	9.5E+01
1959	3.4E+10	8.0E-03	1.0E-02	1.7E-02	9.2E-03		1.7E-02	1.7E-02	4.0E+01
1960	7.4E+10	6.1E-03	6.2E-03	1.1E-02	7.0E-03		1.1E-02	1.1E-02	2.6E+01
1961	8.9E+10	2.7E-03	2.4E-03	4.8E-03	2.5E-03		4.8E-03	4.8E-03	1.2E+01
1962	4.8E+10	1.9E-03	1.7E-03	3.0E-03	2.4E-03		3.0E-03	3.0E-03	7.1E+00
1963	4.8E+10	1.9E-03	1.7E-03	3.0E-03	2.4E-03		3.0E-03	3.0E-03	7.1E+00
1964	2.2E+10	2.6E-03	2.2E-03	3.7E-03	3.7E-03		3.7E-03	3.7E-03	8.9E+00
1965	7.4E+08	7.4E-04	7.4E-04	1.1E-03	7.4E-04		1.1E-03	1.1E-03	2.7E+00
1966	7.4E+08	7.4E-04	7.4E-04	7.4E-04	7.4E-04		7.4E-04	7.4E-04	1.8E+00
1967	7.4E+08	7.4E-04	7.4E-04	7.4E-04	7.4E-04		7.4E-04	7.4E-04	1.8E+00
1968	1.1E+10	7.4E-04	7.4E-04	1.5E-03	7.4E-04		1.5E-03	1.5E-03	3.6E+00
1969	3.7E+10	7.4E-04	7.4E-04	1.5E-03	1.1E-03		1.5E-03	1.5E-03	3.6E+00
1970	1.9E+10	7.4E-04	7.4E-04	7.4E-04	1.5E-03		1.5E-03	1.5E-03	3.6E+00
1971	2.6E+10	7.4E-04	7.4E-04	1.1E-03	1.5E-03		1.5E-03	1.5E-03	3.6E+00
1972	2.6E+10	7.4E-04	7.4E-04	1.1E-03	1.1E-03		1.1E-03	1.1E-03	2.7E+00
1973	3.0E+10	7.4E-04	8.1E-04	3.9E-03	1.1E-03		3.9E-03	3.9E-03	9.4E+00
1974	2.2E+10	3.3E-04	4.1E-04	1.5E-03	4.1E-04		1.5E-03	1.5E-03	3.5E+00
1975	2.6E+10	6.7E-04	1.0E-03	3.2E-03	8.5E-04		3.2E-03	3.2E-03	7.6E+00
1976	3.3E+10	1.0E-03	1.0E-03	3.2E-03	5.2E-04		3.2E-03	3.2E-03	7.6E+00
1977	1.5E+10	4.1E-04	5.2E-04	2.2E-03	7.4E-04		2.2E-03	2.2E-03	5.3E+00
1978	1.5E+09	3.3E-04	5.2E-04	1.0E-03	1.5E-04		1.0E-03	1.0E-03	2.4E+00
1979	7.4E+08	1.5E-04	1.9E-04	1.0E-03	5.2E-04		1.0E-03	1.0E-03	2.4E+00
1980	3.7E+07	2.2E-04	2.2E-04	7.8E-04	3.3E-04		7.8E-04	7.8E-04	1.9E+00
1981	1.9E+09	1.1E-04	1.9E-04	3.0E-04	3.0E-04		3.0E-04	3.0E-04	7.1E-01
1982	4.8E+09	1.1E-04	1.5E-04	4.1E-04	1.9E-04		4.1E-04	4.1E-04	9.8E-01
1983	1.7E+08	2.2E-04	3.0E-04	2.2E-04	2.6E-04		3.0E-04	3.0E-04	7.1E-01
1984	7.0E+07	3.0E-04	1.9E-04	4.8E-04	3.3E-04		4.8E-04	4.8E-04	1.2E+00
1985	1.4E+08	4.4E-04	2.2E-04	4.1E-04	4.8E-04		4.8E-04	4.8E-04	1.2E+00
1986	1.3E+07	2.6E-04	3.0E-04	3.0E-04	2.6E-04		3.0E-04	3.0E-04	7.1E-01
1987	1.1E+07	1.3E-04	1.3E-04	1.4E-04	1.3E-04		1.4E-04	1.4E-04	3.4E-01
1988	2.2E+06	1.6E-04	1.5E-04	1.5E-04	2.0E-04		2.0E-04	2.0E-04	4.7E-01
1989	1.1E+07	9.3E-05	1.1E-04	1.3E-04	8.9E-05		1.3E-04	1.3E-04	3.2E-01
1990	1.2E+06					1.2E-04		1.2E-04	3.0E-01
1991	2.5E+05	5.2E-05	9.3E-05	7.8E-05	4.8E-05		9.3E-05	9.3E-05	2.2E-01
1992	7.8E+07	5.6E-05	5.9E-05	4.8E-05	5.2E-05		5.9E-05	5.9E-05	1.4E-01
1993	1.2E+08					8.0E-05		8.0E-05	1.9E-01

Year	Uranium release (Bq/yr)	Outdoor alpha concentrations (Bq/m^3) at certain monitoring locations							Annual uranium intake (Bq/yr)
		2 PS alpha	5 PW alpha	6 PN alpha	8 PE alpha	Estimate for missing years	Maximum reported	Applied concentration	
1994		7.0E-05	1.3E-04	2.0E-04	9.3E-05		2.0E-04	2.0E-04	4.8E-01
1996	1.1E+08								

Table 4-3. Technetium-99 releases, beta airborne concentrations, and intakes.

Year	Tc-99 release (Bq/yr)	Outdoor beta concentrations (Bq/m^3) at certain monitoring stations							Tc-99 intake (Bq/yr)
		2 PS beta	5 PW beta	6 PN beta	8 PE beta	Estimate	Maximum	Applied	
1954						2.4E-02		2.4E-02	5.7E+01
1955	3.7E+10					2.4E-02		2.4E-02	5.7E+01
1956	3.7E+10					3.8E-02		3.8E-02	9.1E+01
1957	9.6E+10					2.0E-01		2.0E-01	4.8E+02
1958	9.6E+10					2.0E-01		2.0E-01	4.8E+02
1959	1.8E+11					3.7E-01		3.7E-01	8.9E+02
1960	2.3E+11					4.9E-01		4.9E-01	1.2E+03
1961	1.9E+11	5.1E-02	7.6E-02	1.0E-01	7.1E-02		1.0E-01	1.0E-01	2.4E+02
1962	1.5E+11	4.0E-02	3.2E-02	9.8E-02	8.1E-02		9.8E-02	9.8E-02	2.4E+02
1963	1.6E+11	9.6E-02	9.6E-02	1.6E-01	1.0E-01		1.6E-01	1.6E-01	3.9E+02
1964	1.5E+11	1.8E-01	2.0E-01	3.2E-01	2.6E-01		3.2E-01	3.2E-01	7.6E+02
1965	1.6E+11	1.8E-01	2.0E-01	3.2E-01	2.6E-01		3.2E-01	3.2E-01	7.6E+02
1966	2.0E+11	3.3E-02	3.3E-02	8.5E-02	6.7E-02		8.5E-02	8.5E-02	2.0E+02
1967	1.6E+11	7.4E-03	1.1E-02	1.5E-02	1.1E-02		1.5E-02	1.5E-02	3.6E+01
1968	3.7E+09	5.6E-03	5.9E-03	1.2E-02	7.0E-03		1.2E-02	1.2E-02	2.9E+01
1969	3.7E+09	4.4E-03	5.2E-03	4.8E-03	8.5E-03		8.5E-03	8.5E-03	2.0E+01
1970	3.7E+09	5.6E-03	7.4E-03	3.5E-02	6.7E-03		3.5E-02	3.5E-02	8.4E+01
1971	3.7E+09	1.0E-02	1.9E-02	5.9E-02	3.5E-02		5.9E-02	5.9E-02	1.4E+02
1972	1.2E+11	6.7E-03	1.1E-02	2.4E-02	1.4E-02		2.4E-02	2.4E-02	5.7E+01
1973	1.1E+11	1.5E-02	1.9E-02	1.0E-01	2.6E-02		1.0E-01	1.0E-01	2.5E+02
1974	3.7E+09	1.1E-02	1.9E-02	8.9E-02	3.0E-02		8.9E-02	8.9E-02	2.1E+02
1975	1.3E+11	8.5E-03	1.6E-02	1.5E-01	6.1E-02		1.5E-01	1.5E-01	3.6E+02
1976	2.2E+11	7.6E-03	8.3E-03	1.3E-02	8.1E-03		1.3E-02	1.3E-02	3.2E+01
1977	3.0E+10	6.7E-03	7.8E-03	1.8E-02	7.8E-03		1.8E-02	1.8E-02	4.3E+01
1978	3.7E+09	5.2E-03	5.9E-03	1.4E-02	7.0E-03		1.4E-02	1.4E-02	3.5E+01
1979	3.7E+09	5.2E-03	5.2E-03	1.7E-02	9.6E-03		1.7E-02	1.7E-02	4.1E+01
1980	2.2E+09	7.8E-03	7.4E-03	1.0E-02	9.6E-03		1.0E-02	1.0E-02	2.4E+01
1981	2.2E+09	5.6E-03	5.6E-03	7.0E-03	5.6E-03		1.3E-02	1.3E-02	3.1E+01
1982	2.0E+09	5.9E-03	5.9E-03	9.6E-03	7.4E-03		9.6E-03	9.6E-03	2.3E+01
1983	2.2E+08	1.1E-02	1.3E-02	1.4E-02	1.3E-02		1.4E-02	1.4E-02	3.3E+01
1984	3.7E+08	7.8E-03	7.8E-03	1.1E-02	7.4E-03		1.1E-02	1.1E-02	2.8E+01
1985	1.1E+08	7.8E-03	1.0E-02	1.2E-02	1.3E-02		1.3E-02	1.3E-02	3.0E+01
1986	1.3E+09	1.2E-02	9.6E-03	1.6E-02	1.2E-02		1.6E-02	1.6E-02	3.7E+01
1987	5.7E+08	8.5E-03	7.4E-03	1.1E-02	8.1E-03		1.3E-02	1.3E-02	3.2E+01
1988	3.3E+08	6.7E-03	4.8E-03	6.3E-03	5.2E-03		7.3E-03	7.3E-03	1.7E+01
1989	3.3E+07	3.3E-03	2.9E-03	3.7E-03	3.4E-03		4.4E-03	4.4E-03	1.1E+01
1990	1.4E+08	1.2E-03	1.7E-03	1.4E-03	1.4E-03		1.7E-03	1.7E-03	4.0E+00
1991	1.3E+08	1.2E-03	1.3E-03	1.3E-03	1.1E-03		1.3E-03	1.3E-03	3.2E+00
1992	1.4E+07	1.1E-03	1.1E-03	1.2E-03	1.2E-03		1.2E-03	1.2E-03	2.9E+00
1993	1.1E+08	9.3E-04	9.3E-04	1.0E-03	8.5E-04		1.1E-03	1.1E-03	2.8E+00
1994	7.6E+06	7.4E-04	5.6E-04	7.4E-04	7.0E-04		8.5E-04	8.5E-04	2.0E+00
1995	1.2E+09					3.0E-03		3.0E-03	7.2E+00
1996		1.0E-03	1.2E-03	1.3E-03	1.0E-03		1.3E-03	1.3E-03	3.1E+00
1997						3.0E-03		3.0E-03	7.2E+00
1998	1.5E+09					3.0E-03		3.0E-03	7.2E+00
1999	1.1E+08					3.0E-03		3.0E-03	7.2E+00
2000						3.0E-03		3.0E-03	7.2E+00
2001						3.0E-03		3.0E-03	7.2E+00

4.2.7 Summary of Transuranic and Fission Product Exposure

To determine the general risk from TRU and FP exposures, an analysis was performed to determine the relative intake of TRU materials and ^{99}Tc to uranium. PACE and University of Utah (2000) reports ^{99}Tc as the fission product of concern. Tables 4-4 and 4-5 are derived from Barton (2006) and ORAUT (2012a), respectively. In this case, natural uranium is used because its lower specific activity gives a more favorable-to-claimant ratio and because reports describe releases of UF_6 from Building C-410 during the fluorination process prior to enrichment (BJC 2000; PACE and University of Utah 2000).

Table 4-4. Barton (2006) bounding isotopic contributions in PGDP operations (pCi/g U).

Radionuclide	1 Pulverizer, ash handling, green salt C-410 pre-1983[a]	2 Converter salvage line pre-1983[a]	3 Converter salvage line post-1983[b]	4 Tc/Np recovery operations, C-400[c]	5 Balance of plant pre-1983[c]	6 Balance of plant post-1983[b]
Np-237	3.55E+04	1.61E+06	3.81E+04	1.76E+07	1.67E+03	3.67E+00
Pu-239/240	9.00E+05	3.24E+04	7.09E+04	4.42E+06	4.11E+01	1.95E+00
Pu-238	1.94E+05	7.01E+03	1.53E+04	9.54E+05	8.89E+00	4.21E-01
Pu-242	4.46E+01	1.61E+00	3.52E+00	2.19E+02	2.04E-03	9.67E-05
Pu-241	3.51E+07	1.27E+06	2.76E+06	1.72E+08	1.61E+03	3.38E-01
Am-241	1.56E+05	5.62E+03	1.85E+03	7.65E+05	7.13E+00	4.21E+00
Th-230	1.18E+06	1.67E+05	3.64E+05	2.27E+07	2.11E+02	1.00E+01
Tc-99	1.20E+05	1.20E+05	1.20E+05	3.81E+07	1.20E+05	1.20E+05
U-234	6.81E+05	6.81E+05	6.81E+05	6.81E+05	6.81E+05	6.81E+05
U-235	4.27E+04	4.27E+04	4.27E+04	4.27E+04	4.27E+04	4.27E+04
U-238	3.27E+05	3.27E+05	3.27E+05	3.27E+05	3.27E+05	3.27E+05
U-236	9.00E+02	9.00E+02	9.00E+02	9.00E+02	9.00E+02	9.00E+02

a. PACE and University of Utah (2000).
b. Hightower et al. (2000).
c. BJC (2000).

Table 4-5. ORAUT (2012a) bounding isotopic contributions in PGDP operations (pCi/pCi U)[a].

Radionuclide	1 Pulverizer, ash handling, green salt C-410 pre-1983[a]	2 Converter salvage line pre-1983[a]	3 Converter salvage line post-1983[b]	4 Tc/Np recovery operations, C-400[c]	5 Balance of plant pre-1983[c]	6 Balance of plant post-1983[b]
Np-237	3.38E-02	1.53E+00	3.63E-02	1.67E+01	1.59E-03	3.49E-06
Pu-239/240	8.56E-01	3.08E-02	6.75E-02	4.21E+00	3.91E-05	1.86E-06
Pu-238	1.85E-01	6.67E-03	1.46E-02	9.08E-01	8.46E-06	4.01E-07
Pu-242	4.24E-05	1.53E-06	3.35E-06	2.08E-04	1.94E-09	9.20E-11
Pu-241	3.34E+01	1.21E+00	2.63E+00	1.64E+02	1.53E-03	3.22E-07
Am-241	1.48E-01	5.35E-03	1.76E-03	7.28E-01	6.79E-06	4.01E-06
Th-230	1.12E+00	1.59E-01	3.46E-01	2.16E+01	2.01E-04	9.52E-06
Tc-99	1.14E-01	1.14E-01	1.14E-01	3.63E+01	1.14E-01	1.14E-01
U-234	4.88E-01	4.88E-01	4.88E-01	4.88E-01	4.88E-01	4.88E-01
U-235	2.17E-02	2.17E-02	2.17E-02	2.17E-02	2.17E-02	2.17E-02
U-238	4.88E-01	4.88E-01	4.88E-01	4.88E-01	4.88E-01	4.88E-01
U-236	1.31E-03	1.31E-03	1.31E-03	1.31E-03	1.31E-03	1.31E-03

a. Table 4-5 converted from picocuries per gram of uranium (2% enriched) to pCi/pCi of uranium (natural). Conservative assumption when uranium basis by weight is 2% enriched because the activity is higher, however when uranium activity basis is used, the lower specific activity of natural uranium should be used.

4.3 EXTERNAL DOSE

Workers received external dose from ambient radiation levels. Until September 1981, external gamma radiation levels were measured with a calibrated Geiger- Müller (GM) counter 3 ft above the ground. The limit of sensitivity for the GM tube was 1.0×10^{-4} mR/hr (the basis for energy calibration is not known). The frequency of the GM exposure rate surveys varied; sometimes they were weekly and sometimes they were monthly [9].

From 1981 to the present, thermoluminescent dosimeters (TLDs) have been used to determine ambient radiation levels. TLD readings are more accurate than GM measurements because the GM counter takes more discrete readings and could miss fluctuations in gamma levels. TLD locations include those previously monitored by GM counters. TLDs offer greater sensitivity and represent an integration of data rather than the discrete results associated with a GM counter. Information is not available on the environmental TLD detection limit [10].

Over the years, various combinations of TLD chip configurations and monitoring locations were used. It is clear from security fence data that external exposure rates increased over the life of the site. Two factors contributed to this trend: (1) the improved monitoring of the newer TLDs and, more significantly, (2) the increasing inventory of depleted uranium cylinders [11]. The highest security fence observation was 224 mrem deep dose equivalent for 2,000 hours (BJC 1999). This occurred in 1998 near the UF_6 cylinder storage yards. During the early period of PGDP operations, significant quantities of depleted uranium cylinders would not have been stored at the site. As production continued, the inventory of depleted uranium and associated direct radiation levels increased [12].

Unmonitored workers in the early years did not have significant inventories of depleted uranium to contribute to external dose. Later, unmonitored workers would not spend their entire work year at the depleted cylinder storage yards and would, therefore, not reach the maximum dose recorded by fenceline monitoring. No other significant sources of external exposure are associated with PGDP operations. An assumed deep dose equivalent rate of 224 mrem/yr for all years would be reasonable, and deficiencies in earlier measurement techniques thereby become immaterial.

4.3.1 Ambient Radiation

The environmental radiological profile has been developed for PGDP for use by dose reconstructors when personal dosimetry or bioassay program participation was not performed or required. Site annual environmental reports, health physics surveys, and other reports were reviewed for data that would be useful in reconstructing ambient radiation levels (the TBD text cites some of these reports; the References section lists all of them). Ambient radiation includes natural background and that from the facility. Data in these documents (see the References section) include GM counter and TLD radiation measurements. Table 4-6 lists the GM counter and TLD results.

Figure 4-5 shows the locations of air sample stations where the GM counter readings were taken and Figure 4-6 shows the locations of the TLDs.

Table 4-6. External dose equivalent rates, PGDP external gamma exposure rate of mrem/2,000 hr.

Location	PN	PE	PS	PW	IN	IE	IS	IW	ISE	Reported background
1962	40	60	40	40	40	40	40	40		
1963	40	60	40	40	40	40	40	40	40	
1965	40	40	40	40	40	40	40	40	40	
1966	40	40	40	40	40	40	40	40	40	
1967	40	40	40	40	40	40	40	40	40	
1968	40	40	40	40	40	40	40	40	40	
1969	40	100	40	40	40	40	40	40	40	
1970	40	80	40	40	40	40	40	40	40	
1971	40	80	40	40	40	40	40	40	40	
1982	15	17	33	35	15	15	17	14	17	
1984	16	29	45	38	15	16	16	15	21	
1986	11	22	24	24	11	0	11	12	12	
1987	12	78	38	26	66	122	196	162	156	
1988	12	187	139	37	8	11	11	14	14	
1989	9	109	108	27	6	5	9	9	9	
1991	12	18	88	38	10	10	13	14	16	
1992	12	55	81	38	10	10	14	13	13	
1993	10	10	97	28	8	10	10	12	12	
Location	**T1**	**T2**	**T3**	**T47**	**T48**	**T50**	**T51**	**T52**	**T53**	
1998	114	102	224							26
1999	97	167	173	25						23
2000	97	171	107	28	42					24
2001	115	186	99	53	33	39	37	30	68	26

The ambient radiation measured by GM counter and TLDs near the security fence included natural background radiation, fallout, and cosmic radiation. The GM counter readings and the TLD results provided an indication of worker exposure levels in the general proximity of the security fence, but not inside the buildings. Table 4-6 lists annual exposure levels for locations near the security fence. These data have been adjusted to be representative of exposure for a 2,000-hour work year.

Observations reported in the early environmental reports (before 1982), based on surveys with portable instruments, reported 0.02 mrem/hr at all locations, with the exception of air sampling station PE, which is near the UF_6 cylinder storage yards. For a 2,000-hour work year, this indicates a dose of 40 mrem. The instrumentation was less advanced by today's standards and did not provide continuous monitoring, so the results produced are overshadowed by recent, more reliable observations [13].

PGDP personnel have annually compared these data with TLD data from offsite locations and literature values for State of Kentucky and regional exposure levels. The determination has always been that onsite ambient radiological conditions as measured at the security fence are not significantly different from offsite, State, and regional annual exposure levels. This is attributed to the geology of the region around PGDP [14]. Exceptions to this observation have been monitoring locations near depleted uranium cylinder storage yards in recent years. These locations show an increase in external exposure as the inventory of depleted uranium increased. External exposure in this TBD has not had background environmental radiation subtracted.

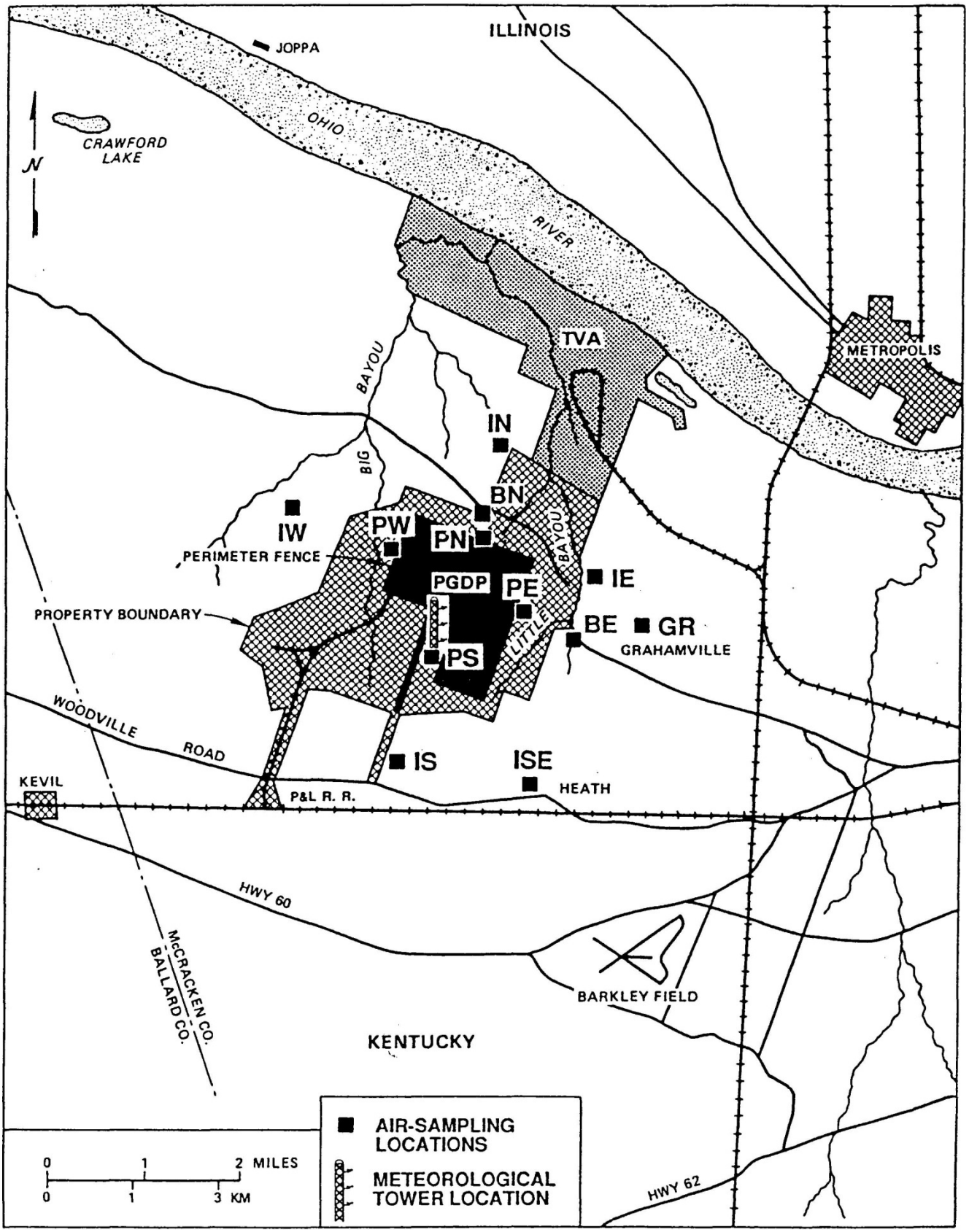

Figure 4-5. Air sampling stations at PGDP (MMES 1990).

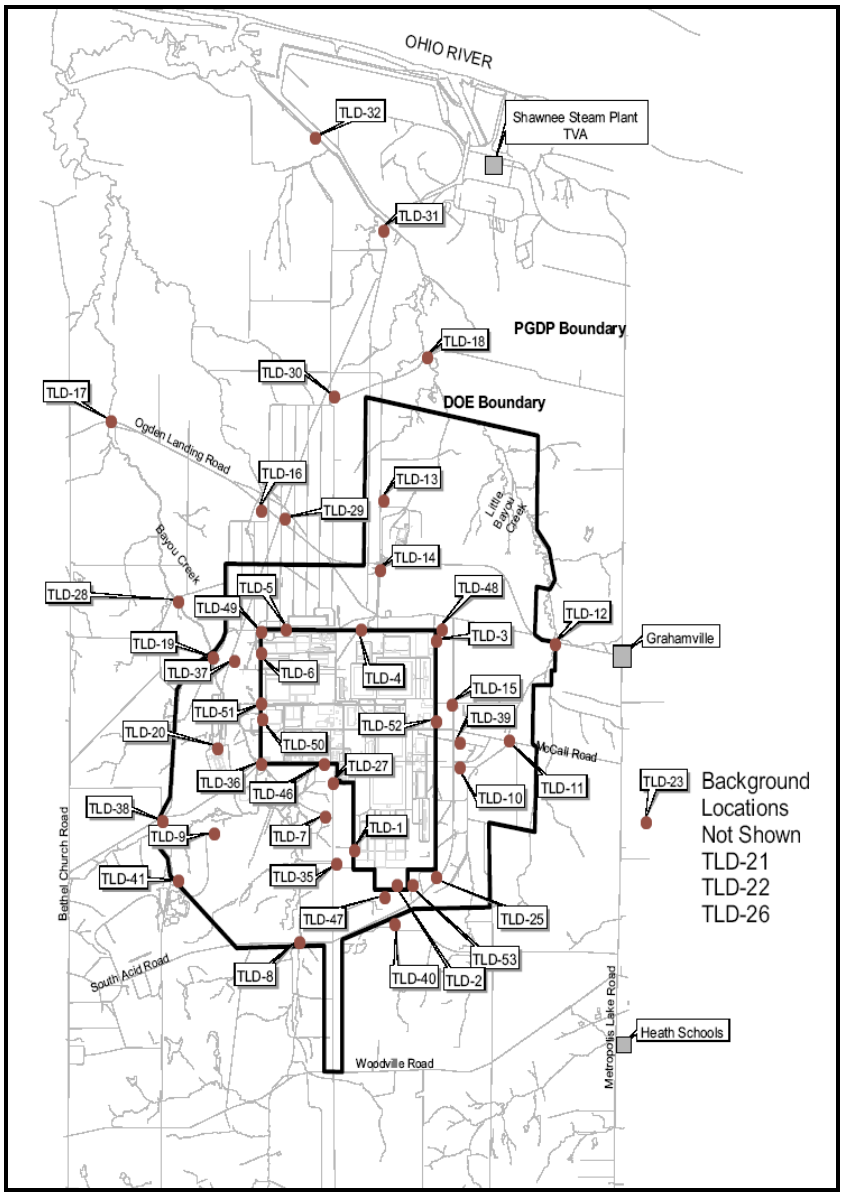

Figure 4-6. TLD locations.

4.3.2 Radiological Conditions in Cylinder Storage Yards

Observations reported in the early environmental reports (before 1982), based on surveys with portable instruments, reported increased dose rates at air sampling station, PE which is near the UF_6 cylinder storage yards. Several fenceline TLDs were adjacent to the storage yards and, due to their proximity (less than 100 m), represent within a certain amount of confidence the dose rate ranges near the storage yards [15]. Workers performed activities in other facilities and probably did not work in the cylinder yards 2,000 hr/yr without dosimetry. During recent years, this area has been posted as a radiological area, which has reduced the number of unmonitored workers spending significant time in the area to zero [16].

Missed and unmonitored neutron dose is discussed in the External Dosimetry Section for this site (ORAUT 2012b.)

Given this information, an ambient annual radiation dose equivalent of 224 mrem should be applied to unmonitored workers working near the cylinder yards [17]. Coworker dose is recommended for an unmonitored worker who worked primarily in the cylinder yards and should have been monitored.

4.3.3 Radiological Conditions Inside Buildings

Because all workers were badged and monitored throughout much of the PGDP operating history, coworker exposure data can be used to assign dose to unmonitored workers for those periods in which all workers were not badged or were badged but not analyzed. Other sources of information that describe potential radiation exposures can be used as backup to the coworker data [18].

4.4 UNCERTAINTY

The locations of the monitoring points add uncertainty to the results. The monitoring points, as stated above, have been located around the PGDP perimeter and off the site to monitor public exposures. Before 1998, external environmental exposures were not monitored in relation to workers; that is, monitoring stations were not normally placed at the interior of the site among the process buildings. Because of data availability, this analysis used public exposure information for worker environmental exposures. The maximum value of environmental exposure is recommended for years when data are unavailable to compensate for lack of worker-specific environmental dose information.

All external environmental dose data listed in Table 4-6 were adjusted to reflect a 2,000-hour work year. The early data were originally reported in site environmental reports as GM counter dose rates in millirem per hour. The TLD data were originally reported as representative of an employee who worked at the site 24 hr/d, 365 d/yr. Using an employee permanently on the site, however, is an unrealistic assumption that would clearly overstate onsite environmental exposures [19]. Therefore, a 2,600-hour work year (multiplication factor of 1.3) should be applied as a maximizing assumption, while a 2,500-hour work year (multiplication factor of 1.25) should be assumed for best estimates. An uncertainty of 30% should also be applied to the assigned doses (ORAUT 2006).

Uncertainty related to internal exposures presents similar concerns. The highest internal exposures occurred during the early years and lessened over time with increased controls and better equipment. Assumption of the maximum uptake for all years reduces the need to include an uncertainty factor (other than default values) for intakes [20].

4.5 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in the preceding text, bracketed callouts have been inserted to indicate information, conclusions, and recommendations to assist in the process of worker dose reconstruction. These callouts are listed in this section with information that identifies the source and justification for each item. Conventional references are provided in the next section that link data, quotations, and other information to documents available for review on the Oak Ridge Associated Universities (ORAU) Team servers.

[1] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
This wording demonstrates the emerging science of environmental monitoring; as instrumentation improved, more was learned about the environment. State-of-the-art instrumentation was crude by today's standards and procedures were not clearly defined.

[2] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
Summary statement of sampling methods, and general results.

[3] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
Summary statement based on environmental monitoring report data represented in Figures 4-2 and 4-3 that cover the life span of the facility.

[4] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
These data are presented in this way to demonstrate that the sampling program was recording changes in the airborne activity that were primarily from sources other than the facility. These data provide the basis for airborne intake for the unmonitored worker. The primary source term in this case originates from offsite sources.

[5] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
This is a summary statement that is based on environmental reports and represented in Figures 4-2 and 4-3 (see the description of reference sources in Section 4.2.5). In addition, the purpose is to establish basis for estimates of airborne concentrations in years for which applicable data are not a part of the record.

[6] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
There are a limited number of observations and not of wide distribution. It is clear that determination of the location of the unmonitored worker is difficult. Using the maximum observed concentration is favorable to claimants.

[7] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
Estimates were required for missing years. The method of selection is presented.

[8] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
The referenced document (CCCC undated) states that high alpha activity was found on metal without a visible uranium stain (low specific activity). As is often the case with uranium, the visible stain indicates its presence. Minor activity can be found without a stain (especially with modern instruments), but activity to the extent observed was outside the experience of the survey technicians and Health Physics staff.

[9] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
This summary statement is based on environmental operating reports. The surveys conducted by GM are “snapshots.” The continuous monitoring by TLDs provides a more complete picture. No documents have been found to distinguish the environmental TLD chip set from the chips used in personnel monitoring.

[10] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
This summary statement is based on environmental operating reports. The surveys conducted by GM are “snapshots.” The continuous monitoring by TLDs provides a more complete picture. No documents have been found to distinguish environmental TLD chips as different than the chips used in personnel monitoring.

[11] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
Two factors contribute to the buildup of external doses around the cylinders. It is well understood that the buildup of progeny increases the gamma field around stored uranium. Because depleted uranium is a byproduct of the enrichment process, the storage of depleted uranium increased proportionally to production. Some depleted uranium was removed from onsite storage yards, but is not seen as a significant factor in this case.

[12] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
Two factors contribute to the buildup of external doses around the cylinders. It is well understood that the buildup of progeny increases the gamma field around stored uranium.

Because depleted uranium is a byproduct of the enrichment process, the storage of depleted uranium increased proportionally to production. Some depleted uranium was removed from onsite storage yards, but is not seen as a significant factor in this case.

[13] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
This is a summary to form support for the numbers chosen. Later instrumentation provides better data, and the stability and knowledge of the source term add to confidence.

[14] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
Environmental photon surveys were consistent across the lower Ohio Valley, including most monitoring points around PGDP, with the exception of areas within a few meters of the depleted uranium storage cylinders.

[15] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
The depleted cylinders are arranged such that unmonitored workers would not spend a lot of time in the area. Some maintenance of fence, lighting, and grounds is to be expected. The assumption of 2,000 hours of exposure within 100 m of the cylinders is judged to not underestimate the dose to unmonitored workers.

[16] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
There are two reasons for this statement: (1) During the earlier years, the depleted uranium was young, and it takes decades of storage for the gamma-emitting progeny to ingrow, and (2) a series of changes in directives, rules, and regulations elevated the importance and compliance of radiological postings.

[17] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
This summary statement provides a simple method of accounting for ambient radiation.

[18] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
Specific studies of area dose rates and incident investigations could be used to refine dose estimates. However, based on available documentation, such studies are unlikely to yield dose estimates to an unmonitored worker that are greater than the external doses proposed in this section.

[19] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
To be consistent with Project guidance, only expected work-hours onsite are included.

[20] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
There are a limited number of data points for each year. The assignment of the maximum uptake is favorable to the claimant.

REFERENCES

Baker, R. C., 1962, "Neptunium-237 Contamination Controls in a Gaseous Diffusion Plant," draft, Union Carbide Nuclear Company, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, March. [SRDB Ref ID: 30509]

Baker, R. C. 1987, "Exposure Assessment-Uranium Recycle Materials in the Paducah Feed Plant," attachment to letter to J. W. Parks (U.S. Department of Energy, Oak Ridge Operations), Martin Marietta Energy Systems, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, October 9. [SRDB Ref ID: 30642, pp. 5-19]

Baker, R. C., and E. G. Brown, 1959, *Environmental Monitoring Summary for the Paducah Plant for 1958*, KY-273, Union Carbide Nuclear Company, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, May 22. [SRDB Ref ID: 27035]

Barton, C. B., 2006, "Verifying and Expanding Paducah Occupational Internal Dose Document Tables," memorandum to D. S. Mantooth, Dade Moeller & Associates, Inc., Richland, Washington, May. [SRDB Ref ID: 24017]

BJC (Bechtel Jacobs Company), 1999, *Paducah Site 1998 Annual Environmental Report*, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12638]

BJC (Bechtel Jacobs Company), 2000, *Recycled Uranium Mass Balance Project Paducah Gaseous Diffusion Plant Site Report*, Draft for Review, BJC/PGDP-167, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, March 5. [SRDB Ref ID: 16498]

Brown, E. G., and R. C. Baker, 1961, *Environmental Monitoring Summary for the Paducah Plant for 1960*, KY-371, Union Carbide Nuclear Company, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, May 31. [SRDB Ref ID: 26388]

Brown E. G., and K. K. Mitchell, 1960, *Environmental Monitoring Summary for the Paducah Plant for 1959*, KY-332, Union Carbide Nuclear Company, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12635]

CCCC (Carbide and Carbon Chemicals Company), undated, "The Neptunium Problem at the Paducah Plant," Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 30636]

DOE (U. S. Department of Energy), 2000, *Phase II, Independent Investigation of the Paducah Gaseous Diffusion Plant, Environment, Safety and Health Practices, 1952-1990*, Office of Oversight, Environment, Safety and Health, Washington, D.C., February. [SRDB Ref ID: 12040]

Hightower, J. R., L. R. Dole, D. W. Lee, G. E. Michaels, M. I. Morris, D. G. O'Conner, S. J. Pawel, R. A. Schmoyer, L. D. Trowbridge, and V. S. White, 2000, *Strategy for Characterizing Transuranics and Technetium Contamination in Depleted UF_6 Cylinders*, ORNL/TM-2000/242, UT-Battelle, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October. [SRDB Ref ID: 23571]

LMES (Lockheed Martin Energy Systems), 1996, *Paducah Site Annual Environmental Report for 1994*, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12622]

Mitchell, K. K., undated, *Continuous Outdoor Air Sampler*, Union Carbide Corporation, Nuclear Division, Paducah, Kentucky. [SRDB Ref ID: 18485]

MMES (Martin Marietta Energy Systems), 1994, *Paducah Gaseous Diffusion Plant Annual Site Environmental Report for 1993*, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12619]

NIOSH (National Institute for Occupational Safety and Health), 2010, *Radiation Exposures Covered for Dose Reconstructions Under Part B of the Energy Employees Occupational Illness Compensation Program Act*, DCAS-IG-003, Rev. 1, Division of Compensation Analysis and Support, Cincinnati, Ohio, October.

ORAUT (Oak Ridge Associated Universities Team), 2006, *Occupational Onsite Ambient Dose Reconstruction for DOE Sites,* ORAUT-PROC-0060, Rev. 01, Oak Ridge, Tennessee, June 28.

ORAUT (Oak Ridge Associated Universities Team), 2012a, *Paducah Gaseous Diffusion Plant – Occupational Internal Dose*, ORAUT-TKBS-0019-5, Rev. 03, Oak Ridge, Tennessee, August 24.

ORAUT (Oak Ridge Associated Universities Team), 2012b, *Paducah Gaseous Diffusion Plant – Occupational External Dose*, ORAUT-TKBS-0019-6, Rev. 04, Oak Ridge, Tennessee, August 24.

ORAUT (Oak Ridge Associated Universities Team), 2012c, *Paducah Gaseous Diffusion Plant – Site Description*, ORAUT-TKBS-0019-2, Rev. 03, Oak Ridge, Tennessee, August 22.

PACE (Paper, Allied Industrial, Chemical and Energy Workers International Union) and University of Utah, 2000, *Exposure Assessment Project at the Paducah Gaseous Diffusion Plant*, SRDB Ref ID: 10870, December. [SRDB Ref ID: 10870]

Ritter, R. L., L. D. Trowbridge, and S.E. Meiners, 1990, *Neptunium Experience at PGDP*, K/ETO-30, Martin Marietta Energy Systems, Uranium Enrichment Organization, Oak Ridge, Tennessee, September. [SRDB Ref ID: 30497]

Rogers, J. G., and T. G. Jett, 1989, *Paducah Gaseous Diffusion Plant Site Environmental Report for 1988*, ES/ESH-8/V3, Martin Marietta Energy Systems, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 39298]

Whiteaker, B. H., and R. B. Farrar, 1953, *Water, Mud & Air Survey at the Paducah Plant*, KYL-11, Carbide and Carbon Chemicals Company, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 27034]

Environmental Reports and Related Documents

Baker, R. C., 1964, *Environmental Monitoring Summary for the Paducah Plant for 1962 and 1963*, KY-458, Union Carbide Corporation, Nuclear Division, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, July 1. [SRDB Ref ID: 12648]

Baker, R. C., and A. W. Russell, 1965, *Environmental Monitoring Summary for the Paducah Plant for 1964*, KY-484, Union Carbide Corporation, Nuclear Division, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12650]

Baker, R. C., and K. A. Davis, 1967, *Environmental Monitoring Summary for the Paducah Plant for 1965 & 1966*, KY-543, Union Carbide Corporation, Nuclear Division, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, September 1. [SRDB Ref ID: 12652]

BJC (Bechtel Jacobs Company), 1998, *Paducah Site 1997 Annual Environmental Report*, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12637]

BJC (Bechtel Jacobs Company), 2001, *Paducah Site Annual Site Environmental Report for 1999*, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12646]

Brown, E. G., and R. C. Baker, 1962, *Environmental Monitoring Summary for the Paducah Plant for 1961*, KY-419, Union Carbide Nuclear Company, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, July 20. [SRDB Ref ID: 12642]

CDM Federal Services, 2001, *Paducah Site Annual Site Environmental Report for Calendar Year 2000*, BJC/PAD-237, Kevil, Kentucky, October. [SRDB Ref ID: 12649]

CDM Federal Services, 2002, *Paducah Site Annual Site Environmental Report for Calendar Year 2001*, BJC/PAD-219, Kevil, Kentucky, September. [SRDB Ref ID: 12647]

Davis, K. A., 1970, *Environmental Monitoring Summary for the Paducah Plant for 1969*, KY-624, Union Carbide Corporation, Nuclear Division, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, November 2. [SRDB Ref ID: 12656]

Davis, K. A., 1971, *Environmental Monitoring Summary for the Paducah Plant for 1970*, KY-629, Union Carbide Corporation, Nuclear Division, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, April 1. [SRDB Ref ID: 12657]

Davis, K. A., and E. G. Brown, 1969, *Environmental Monitoring Summary for the Paducah Plant for 1967 and 1968*, KY-582, Union Carbide Corporation, Nuclear Division, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, May 9. [SRDB Ref ID: 12655]

LMES (Lockheed Martin Energy Systems), 1997a, *Paducah Site Annual Report for 1995*, KY/EM-176, Environmental Management Division, Kevil, Kentucky, January. [SRDB Ref ID: 12314]

LMES (Lockheed Martin Energy Systems), 1997b, *Paducah Site Annual Environmental Report for 1996*, KY/EM-206, Environmental Management Division, Kevil, Kentucky, December. [SRDB Ref ID: 12316]

MMES (Martin Marietta Energy Systems), 1984, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant*, Calendar Year 1983, KY-742, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12594]

MMES (Martin Marietta Energy Systems), 1985, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant, Calendar Year 1984*, KY-747, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12595]

MMES (Martin Marietta Energy Systems), 1986, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant, Calendar Year 1985*, KY-755, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12596]

MMES (Martin Marietta Energy Systems), 1990, *Paducah Gaseous Diffusion Plant Environmental Report for 1989*, ES/ESH-13/V3, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12615]

MMES (Martin Marietta Energy Systems), 1991, *Paducah Environmental Report for 1990*, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12616]

MMES (Martin Marietta Energy Systems), 1992, *Paducah Gaseous Diffusion Plant Environmental Report for 1991*, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12617]

MMES (Martin Marietta Energy Systems), 1993, *Paducah Gaseous Diffusion Plant Environmental Report for 1992*, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12618]

Oakes, T. W., 1983, "PGDP TLD Results," memorandum to R. C. Baker, Union Carbide Corporation, Nuclear Division, February 23. [SRDB Ref ID: 37840]

Oakes, T. W., 1985, "PGDP TLD Results," memorandum to R. C. Baker, Martin Marietta Energy Systems, Paducah, Kentucky, March 7. [SRDB Ref ID: 37842]

Oakes, T. W., 1985, "PGDP TLD Results," memorandum to R. C. Baker, Martin Marietta Energy Systems, Paducah, Kentucky, February 27. [SRDB Ref ID: 37843]

Oakes, T. W., D. L. Ashburn, and F. M. O'Hara, 1987, *Environmental Surveillance of the U.S. Department of Energy Paducah Reservation and Surrounding Environs During 1986*, ES/ESH-1/V3, Martin Marietta Energy Systems, Oak Ridge, Tennessee, and Paducah, Kentucky, April. [SRDB Ref ID: 4084, pp. 6-267]

Rogers, J. G., and D. L. Ashburn, 1988, *Environmental Surveillance of the U.S. Department of Energy Paducah Reservation and Surrounding Environs During 1987*, ES/ESH-4/V3, Martin Marietta Energy Systems, Oak Ridge, Tennessee, and Paducah, Kentucky, April. [SRDB Ref ID: 4084, pp. 269-683]

UCC (Union Carbide Company), undated, *Environmental Concentrations of Radioactive Materials near the Paducah Plant, Report for the First Half of 1971,* Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 18510]

UCC (Union Carbide Company), 1980, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant, Calendar Year 1979*, Y/UB-14, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12677]

UCC (Union Carbide Company), 1981, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant, Calendar Year 1980*, KY-717, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12568]

UCC (Union Carbide Company), 1982, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant, Calendar Year 1981*, KY-724, Nuclear Division, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12570]

UCC (Union Carbide Company), 1983, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant for Calendar Year 1982*, KY-731, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12592]

UCC (Union Carbide Corporation), 1972, *Environmental Monitoring Report, United States Atomic Energy Commission, Paducah Gaseous Diffusion Plant, Calendar Year 1971*, UCC-ND-222, Nuclear Division, Paducah Gaseous Diffusion Plant, Paducah, Kentucky. [SRDB Ref ID: 12658]

UCC (Union Carbide Corporation), 1973, *Environmental Monitoring Report, United States Atomic Energy Commission, Paducah Gaseous Diffusion Plant, Calendar Year 1972*, UCC-ND-245, Nuclear Division, Oak Ridge, Tennessee. [SRDB Ref ID: 12660]

UCC (Union Carbide Corporation), 1974, *Environmental Monitoring Report, United States Atomic Energy Commission, Paducah Gaseous Diffusion Plant, Calendar Year 1973*, UCC-ND-279, Nuclear Division, Oak Ridge, Tennessee. [SRDB Ref ID: 12663]

UCC (Union Carbide Corporation), 1975, *Environmental Monitoring Report, United States Energy Research and Development Administration, Paducah Gaseous Diffusion Plant, Calendar Year 1974*, UCC-ND-303, Nuclear Division, Oak Ridge, Tennessee. [SRDB Ref ID: 12665]

UCC (Union Carbide Corporation), 1976, *Environmental Monitoring Report, United States Energy Research and Development Administration, Paducah Gaseous Diffusion Plant, Calendar Year 1975*, Y/UB-5, Nuclear Division, Oak Ridge, Tennessee. [SRDB Ref ID: 12672]

UCC (Union Carbide Corporation), 1977, *Environmental Monitoring Report, United States Energy Research and Development Administration, Paducah Gaseous Diffusion Plant, Calendar Year 1976*, Y/UB-7, Nuclear Division, Oak Ridge, Tennessee. [SRDB Ref ID: 12674]

UCC (Union Carbide Corporation), 1978, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant, Calendar Year 1977*, Y/UB-9, Nuclear Division, Oak Ridge, Tennessee. [SRDB Ref ID: 12675]

UCC (Union Carbide Corporation), 1979, *Environmental Monitoring Report, United States Department of Energy, Paducah Gaseous Diffusion Plant, Calendar Year 1978*, Y/UB-11, Nuclear Division, Oak Ridge, Tennessee. [SRDB Ref ID: 12676]

GLOSSARY

air sampling
Collection of samples of the ambient atmosphere to detect or measure the presence of radioactive material in the air.

alpha radiation
Positively charged particle emitted from the nuclei of some radioactive elements. An alpha particle consists of two neutrons and two protons (a helium nucleus) and has an electrostatic charge of +2.

background radiation
Radiation from cosmic sources, naturally occurring radioactive materials including naturally occurring radon, and global fallout from the testing of nuclear explosives. Background radiation does not include radiation from source, byproduct, or Special Nuclear Materials regulated by the U.S. Nuclear Regulatory Commission. The average individual exposure from background radiation is about 360 millirem per year.

becquerel (Bq)
International System unit of radioactivity equal to 1 disintegration per second; 1 curie equals 37 billion (3.7×10^{10}) Bq.

beta radiation
Charged particle emitted from some radioactive elements with a mass equal to 1/1,837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is a positron.

byproduct
Material left over from a nuclear, physical, or chemical process designed to produce a particular substance. Examples include the tailings or wastes from the extraction or concentration of uranium or thorium from ore.

committed effective dose equivalent (CEDE)
Sum of the effective dose equivalents to various tissues or organs in the body each multiplied by the appropriate tissue weighting factor and committed for a 50-year period following an acute intake or the onset of chronic intake. It does not include contributions from external dose. See *dose*.

contamination
Radioactive material in an undesired location including air, soil, buildings, animals, and persons.

counter
Radiation detection meters that detect and measure radiation in which one count indicates a detected ionization event.

deep dose equivalent
Dose equivalent in units of rem or sievert for a 1-centimeter depth in tissue (1,000 milligrams per square centimeter). See *dose*.

depleted uranium (DU)
Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium.

depleted uranium
Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium.

dose
In general, the specific amount of energy from ionizing radiation that is absorbed per unit of mass. Effective and equivalent doses are in units of rem or sievert; other types of dose are in units of roentgens, rads, reps, or grays.

dose equivalent
In units of rem or sievert, product of absorbed dose in tissue multiplied by a weighting factor and sometimes by other modifying factors to account for the potential for a biological effect from the absorbed dose. See *dose*.

dosimeter
Device that measures the quantity of received radiation, usually a holder with radiation-absorbing filters and radiation-sensitive inserts packaged to provide a record of absorbed dose received by an individual. See *film dosimeter* and *thermoluminescent dosimeter*.

dosimetry
Measurement and calculation of internal and external radiation doses.

effective dose
Sum of the equivalent doses in the principal tissues and organs of the body, each weighted by a tissue weighting factor that represents the relative contributions of that tissue or organ to the total detriment from uniform irradiation of the body.

effective dose equivalent
Average of the dose equivalents weighted for the susceptibility of harm to different tissues or organs in units of rem or sievert. See *dose*.

enriched uranium (EU)
Uranium in which processing has increased the proportion of ^{235}U to ^{238}U to above the natural level of 0.7% by mass. Reactor-grade uranium is usually about 3.5% ^{235}U; weapons-grade uranium contains greater than 90% ^{235}U.

enrichment
Isotopic separation process that increases the percentage of a radionuclide in a given amount of material above natural levels. For uranium, enrichment increases the amount of ^{235}U in relation to ^{238}U. Along with the enriched uranium, this process results in uranium depleted in ^{235}U. At PGDP this involves a process that occurs as UF_6 passes through barriers in converters allowing isotopes of lower molecular weight to pass through.

environmental occupational dose
Dose received from radiation site-related activities (i.e., above normal background levels) while on a site, which is often recorded by monitoring stations in specific areas or along the boundaries of facilities (e.g., plant stack emissions).

exposure
In general, the act of being exposed to ionizing radiation.

film dosimeter
Package of film for measurement of ionizing radiation exposure for personnel monitoring purposes. A film dosimeter can contain two or three films of different sensitivities, and it can

contain one or more filters that shield parts of the film from certain types of radiation. When developed, the film has an image caused by radiation measurable with an optical densitometer. Also called film badge.

fission product (FP)

(1) Radionuclides produced by fission or by the subsequent radioactive decay of radionuclides. (2) Fragments other than neutrons that result from the splitting of an atomic nucleus.

gaseous diffusion enrichment

Process by which uranium hexafluoride (UF_6) is filtered through a series of semipermeable molecular barriers to separate the lighter ^{235}U from the heavier, more naturally abundant ^{238}U.

gaseous diffusion plant

Facility where uranium hexafluoride (UF_6) gas is filtered to enrich the ^{235}U and separate it from ^{238}U. The process requires enormous amounts of electric power and results in an increase in ^{235}U enrichment from 1% to about 3%.

Geiger-Müller (G-M, GM) counter

Most common radiation detection and measuring instrument, usually known simply as a Geiger counter, it is a gas-filled tube containing electrodes between which there is a voltage potential but no current flow. When ionizing radiation passes through, a short, intense pulse of current passes from one electrode to the other. The number of pulses per second (or counts per minute) indicates the rate of ionizing events in the tube.

monitoring

Periodic or continuous determination of the presence or amount of ionizing radiation or radioactive contamination in air, surface water, groundwater, soil, sediment, equipment surfaces, or personnel (for example, bioassay or alpha scans). In relation to personnel, monitoring includes internal and external dosimetry including interpretation of the measurements.

natural uranium

Uranium as found in nature, approximately 99.27% ^{238}U, 0.72% ^{235}U, and 0.0054% ^{234}U by mass. The specific activity of this mixture is 2.6×10^7 becquerel per kilogram (0.7 microcuries per gram).

radioactivity

Property possessed by some elements (e.g., uranium) or isotopes (e.g., ^{14}C) of spontaneously emitting energetic particles (electrons or alpha particles) by the disintegration of their atomic nuclei.

rem

Traditional unit of radiation dose equivalent that indicates the biological damage caused by radiation equivalent to that caused by 1 rad of high-penetration X-rays multiplied by a quality factor. The average American receives 360 millirem a year from background radiation. The sievert is the International System unit; 1 rem equals 0.01 sievert. The word derives from roentgen equivalent in man; rem is also the plural.

roentgen (R)

Unit of photon (gamma or X-ray) exposure for which the resultant ionization liberates a positive or negative charge equal to 2.58×10^{-4} coulombs per kilogram (or 1 electrostatic unit of electricity per cubic centimeter) of dry air at 0°C and standard atmospheric pressure. An

exposure of 1 R is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher energy photons (generally greater than 100 kiloelectron-volts).

Special Nuclear Material (SNM)

Plutonium or uranium enriched to a higher-than-natural assay including ^{239}Pu, ^{233}U, uranium containing more than the natural abundance of ^{235}U, or any material artificially enriched in one of these isotopes.

spent nuclear fuel

Fuel that has been in a reactor long enough to become ineffective because the proportion of fissile material has dropped below a certain level. Spent nuclear fuel contains fission and activation products.

tails

Unwanted remains of a process such as mining, milling, chemical separation, or another refinement method.

thermoluminescent dosimeter (TLD)

Device for measuring radiation dose that consists of a holder containing solid chips of material that, when heated by radiation, release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

transuranic (TRU) elements

Elements with atomic numbers above 92 (uranium). Other examples include plutonium and americium.

uranium hexafluoride (UF_6) cylinder storage yard

Site for maintenance of cylinders containing depleted UF_6. The cylinders typically weigh 10 and 14 tons. The depleted UF_6 is primarily in a solid form. There are storage yards at Paducah Gaseous Diffusion Plant and the Oak Ridge K-25 site.

ATTACHMENT A
OUTDOOR BETA AND ALPHA CONCENTRATIONS
Page 1 of 3

Table A-1 lists outdoor beta concentrations, and Table A-2 lists outdoor alpha concentrations.

ATTACHMENT A
OUTDOOR BETA AND ALPHA CONCENTRATIONS

Table A-1. Outdoor beta concentrations.

Year	Release (Bq/yr) Tc-99	Outdoor beta concentrations (Bq/m^3) at each monitoring location															Bq/yr uptake
		2 PS beta	5 PW beta	6 PN beta	8 PE beta	BN	BE	IN	IE	ISE	IS	IW	GR	Estimate	Maximum	Applied	
1954														2.4E-02		2.4E-02	5.7E+01
1955	3.7E+10													2.4E-02		2.4E-02	5.7E+01
1956	3.7E+10													3.8E-02		3.8E-02	9.1E+01
1957	9.6E+10													2.0E-01		2.0E-01	4.8E+02
1958	9.6E+10													2.0E-01		2.0E-01	4.8E+02
1959	1.8E+11													3.7E-01		3.7E-01	8.9E+02
1960	2.3E+11													4.9E-01		4.9E-01	1.2E+03
1961	1.9E+11	5.1E-02	7.6E-02	1.0E-01	7.1E-02										1.0E-01	1.0E-01	2.4E+02
1962	1.5E+11	4.0E-02	3.2E-02	9.8E-02	8.1E-02										9.8E-02	9.8E-02	2.4E+02
1963	1.6E+11	9.6E-02	9.6E-02	1.6E-01	1.0E-01			8.1E-02	8.5E-02		1.2E-01	8.9E-02			1.6E-01	1.6E-01	3.9E+02
1964	1.5E+11	1.8E-01	2.0E-01	3.2E-01	2.6E-01			2.0E-01	1.8E-01		1.9E-01	1.8E-01			3.2E-01	3.2E-01	7.6E+02
1965	1.6E+11	1.8E-01	2.0E-01	3.2E-01	2.6E-01			2.0E-01	1.8E-01		1.9E-01	1.8E-01			3.2E-01	3.2E-01	7.6E+02
1966	2.0E+11	3.3E-02	3.3E-02	8.5E-02	6.7E-02			3.3E-02	3.3E-02		3.3E-02	3.3E-02			8.5E-02	8.5E-02	2.0E+02
1967	1.6E+11	7.4E-03	1.1E-02	1.5E-02	1.1E-02			1.1E-02	1.1E-02		1.1E-02	1.1E-02			1.5E-02	1.5E-02	3.6E+01
1968	3.7E+09	5.6E-03	5.9E-03	1.2E-02	7.0E-03			6.3E-03	6.7E-03		7.0E-03	6.3E-03			1.2E-02	1.2E-02	2.9E+01
1969	3.7E+09	4.4E-03	5.2E-03	4.8E-03	8.5E-03			5.6E-03	5.2E-03	6.7E-03	6.7E-03	3.3E-03			8.5E-03	8.5E-03	2.0E+01
1970	3.7E+09	5.6E-03	7.4E-03	3.5E-02	6.7E-03			7.8E-03	6.7E-03	6.7E-03	6.7E-03	7.4E-03			3.5E-02	3.5E-02	8.4E+01
1971	3.7E+09	1.0E-02	1.9E-02	5.9E-02	3.5E-02			8.9E-03	6.7E-03	8.5E-03	8.5E-03	7.4E-03			5.9E-02	5.9E-02	1.4E+02
1972	1.2E+11	6.7E-03	1.1E-02	2.4E-02	1.4E-02			8.5E-03	1.7E-02	7.4E-03	7.4E-03	7.4E-03			2.4E-02	2.4E-02	5.7E+01
1973	1.1E+11	1.5E-02	1.9E-02	1.0E-01	2.6E-02			1.5E-02	1.1E-02	1.1E-02	1.1E-02	7.4E-03			1.0E-01	1.0E-01	2.5E+02
1974	3.7E+09	1.1E-02	1.9E-02	8.9E-02	3.0E-02			1.1E-02	7.4E-03	7.4E-03	7.4E-03	7.4E-03			8.9E-02	8.9E-02	2.1E+02
1975	1.3E+11	8.5E-03	1.6E-02	1.5E-01	6.1E-02	1.6E-02		9.3E-03	5.6E-03	4.8E-03	3.7E-03	4.8E-03			1.5E-01	1.5E-01	3.6E+02
1976	2.2E+11	7.6E-03	8.3E-03	1.3E-02	8.1E-03	8.9E-03		7.6E-03	7.2E-03	7.9E-03	7.4E-03	7.4E-03			1.3E-02	1.3E-02	3.2E+01
1977	3.0E+10	6.7E-03	7.8E-03	1.8E-02	7.8E-03	8.1E-03		7.8E-03	7.4E-03	8.1E-03	6.7E-03	6.7E-03			1.8E-02	1.8E-02	4.3E+01
1978	3.7E+09	5.2E-03	5.9E-03	1.4E-02	7.0E-03	7.0E-03		5.6E-03	6.3E-03	5.9E-03	5.6E-03	5.6E-03			1.4E-02	1.4E-02	3.5E+01
1979	3.7E+09	5.2E-03	5.2E-03	1.7E-02	9.6E-03	7.4E-03		4.8E-03	5.9E-03	4.8E-03	5.2E-03	5.2E-03			1.7E-02	1.7E-02	4.1E+01
1980	2.2E+09	7.8E-03	7.4E-03	1.0E-02	9.6E-03	8.9E-03		8.1E-03	9.6E-03	7.8E-03	7.8E-03	7.0E-03			1.0E-02	1.0E-02	2.4E+01
1981	2.2E+09	5.6E-03	5.6E-03	7.0E-03	5.6E-03	5.9E-03	5.6E-03	5.2E-03	5.2E-03	5.9E-03	5.6E-03	5.6E-03	1.3E-02		1.3E-02	1.3E-02	3.1E+01
1982	2.0E+09	5.9E-03	5.9E-03	9.6E-03	7.4E-03	6.3E-03	7.0E-03	5.6E-03	5.6E-03	5.2E-03	6.3E-03	4.8E-03	5.2E-03		9.6E-03	9.6E-03	2.3E+01
1983	2.2E+08	1.1E-02	1.3E-02	1.4E-02	1.3E-02	1.2E-02	1.3E-02	1.1E-02	9.6E-03	1.0E-02	1.2E-02	8.1E-03	1.3E-02		1.4E-02	1.4E-02	3.3E+01
1984	3.7E+08	7.8E-03	7.8E-03	1.1E-02	7.4E-03	7.8E-03	6.7E-03	7.8E-03	8.5E-03	6.3E-03	7.4E-03	6.7E-03	8.5E-03		1.1E-02	1.1E-02	2.8E+01
1985	1.1E+08	7.8E-03	1.0E-02	1.2E-02	1.3E-02	1.0E-02	1.1E-02	7.8E-03	6.7E-03	1.0E-02	1.0E-02	8.5E-03	8.5E-03		1.3E-02	1.3E-02	3.0E+01
1986	1.3E+09	1.2E-02	9.6E-03	1.6E-02	1.2E-02	1.2E-02	1.1E-02	1.1E-02	1.3E-02	7.4E-03	8.5E-03	1.1E-02	1.3E-02		1.6E-02	1.6E-02	3.7E+01
1987	5.7E+08	8.5E-03	7.4E-03	1.1E-02	8.1E-03	1.0E-02	9.3E-03	9.6E-03	5.9E-03	1.3E-02	8.9E-03	1.3E-02	1.0E-02		1.3E-02	1.3E-02	3.2E+01
1988	3.3E+08	6.7E-03	4.8E-03	6.3E-03	5.2E-03	5.3E-03	7.1E-03	7.3E-03	5.7E-03	6.1E-03	4.6E-03	6.4E-03	6.4E-03		7.3E-03	7.3E-03	1.7E+01
1989	3.3E+07	3.3E-03	2.9E-03	3.7E-03	3.4E-03	3.4E-03	3.6E-03	4.1E-03	4.1E-03	4.4E-03	3.3E-03	3.5E-03	3.7E-03		4.4E-03	4.4E-03	1.1E+01
1990	1.4E+08	1.2E-03	1.7E-03	1.4E-03	1.4E-03	1.1E-03	1.3E-03	1.5E-03	1.3E-03	1.3E-03	1.5E-03	1.5E-03	1.4E-03		1.7E-03	1.7E-03	4.0E+00
1991	1.3E+08	1.2E-03	1.3E-03	1.3E-03	1.1E-03	1.3E-03	1.3E-03	1.2E-03	1.1E-03	1.1E-03	1.2E-03	1.1E-03	1.1E-03		1.3E-03	1.3E-03	3.2E+00
1992	1.4E+07	1.1E-03	1.1E-03	1.2E-03	1.2E-03	1.1E-03	1.1E-03	1.1E-03	1.2E-03	1.1E-03	1.1E-03	1.1E-03	1.2E-03		1.2E-03	1.2E-03	2.9E+00
1993	1.1E+08	9.3E-04	9.3E-04	1.0E-03	8.5E-04	8.1E-04	8.5E-04	1.1E-03	7.8E-04	9.3E-04	9.3E-04	1.0E-03	7.8E-04		1.1E-03	1.1E-03	2.8E+00
1994	7.6E+06	7.4E-04	5.6E-04	7.4E-04	7.0E-04	8.5E-04	6.7E-04	8.1E-04	8.5E-04	8.1E-04	8.5E-04	8.1E-04	7.8E-04		8.5E-04	8.5E-04	2.0E+00
1995	1.2E+09													3.0E-03		3.0E-03	7.2E+00
1996		1.0E-03	1.2E-03	1.3E-03	1.0E-03		1.1E-03	1.2E-03	1.2E-03	1.1E-03	1.2E-03	1.1E-03	1.3E-03		1.3E-03	1.3E-03	3.1E+00
1997														3.0E-03		3.0E-03	7.2E+00
1998	1.5E+09													3.0E-03		3.0E-03	7.2E+00
1999	1.1E+08													3.0E-03		3.0E-03	7.2E+00
2000														3.0E-03		3.0E-03	7.2E+00
2001														3.0E-03		3.0E-03	7.2E+00

ATTACHMENT A
OUTDOOR BETA AND ALPHA CONCENTRATIONS

Table A-2. Outdoor alpha concentrations.

Year	Release (Bq/yr) U	Outdoor alpha concentrations (Bq/m^3) at each monitoring location															(Bq/yr) annual uranium intake
		2 PS alpha	5 PW alpha	6 PN alpha	8 PE alpha	BN	BE	IN	IE	ISE	IS	IW	GR	Estimate for missing years	Maximum reported	Applied concentration	
1952	7.4E+08													7.3E-04		7.3E-04	1.7E+00
1953	9.3E+09													9.1E-03		9.1E-03	2.2E+01
1954	8.9E+10													8.7E-02		8.7E-02	2.1E+02
1955	1.6E+11													1.5E-01		1.5E-01	3.7E+02
1956	6.0E+10													5.9E-02		5.9E-02	1.4E+02
1957	4.1E+10													4.0E-02		4.0E-02	9.6E+01
1958	4.0E+10	3.6E-02	4.0E-02	3.6E-02	3.6E-02										4.0E-02	4.0E-02	9.5E+01
1959	3.4E+10	8.0E-03	1.0E-02	1.7E-02	9.2E-03										1.7E-02	1.7E-02	4.0E+01
1960	7.4E+10	6.1E-03	6.2E-03	1.1E-02	7.0E-03										1.1E-02	1.1E-02	2.6E+01
1961	8.9E+10	2.7E-03	2.4E-03	4.8E-03	2.5E-03										4.8E-03	4.8E-03	1.2E+01
1962	4.8E+10	1.9E-03	1.7E-03	3.0E-03	2.4E-03										3.0E-03	3.0E-03	7.1E+00
1963	4.8E+10	1.9E-03	1.7E-03	3.0E-03	2.4E-03			2.7E-03	2.6E-03		2.7E-03	2.7E-03			3.0E-03	3.0E-03	7.1E+00
1964	2.2E+10	2.6E-03	2.2E-03	3.7E-03	3.7E-03			1.7E-03	1.7E-03	1.7E-03	1.4E-03	1.4E-03			3.7E-03	3.7E-03	8.9E+00
1965	7.4E+08	7.4E-04	7.4E-04	1.1E-03	7.4E-04			1.7E-03	1.7E-03	1.7E-03	1.4E-03	1.4E-03			1.1E-03	1.1E-03	2.7E+00
1966	7.4E+08	7.4E-04	7.4E-04	7.4E-04	7.4E-04			2.0E-03	2.5E-03	2.8E-03	1.9E-03	2.8E-03			7.4E-04	7.4E-04	1.8E+00
1967	7.4E+08	7.4E-04	7.4E-04	7.4E-04	7.4E-04			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			7.4E-04	7.4E-04	1.8E+00
1968	1.1E+10	7.4E-04	7.4E-04	1.5E-03	7.4E-04			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.6E+00
1969	3.7E+10	7.4E-04	7.4E-04	1.5E-03	1.1E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.6E+00
1970	1.9E+10	7.4E-04	7.4E-04	7.4E-04	1.5E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.6E+00
1971	2.6E+10	7.4E-04	7.4E-04	1.1E-03	1.5E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.6E+00
1972	2.6E+10	7.4E-04	7.4E-04	1.1E-03	1.1E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.1E-03	1.1E-03	2.7E+00
1973	3.0E+10	7.4E-04	8.1E-04	3.9E-03	1.1E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			3.9E-03	3.9E-03	9.4E+00
1974	2.2E+10	3.3E-04	4.1E-04	1.5E-03	4.1E-04			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.5E+00
1975	2.6E+10	6.7E-04	1.0E-03	3.2E-03	8.5E-04	1.8E-03		7.4E-04	7.4E-04	7.4E-04	3.3E-04	3.3E-04			3.2E-03	3.2E-03	7.6E+00
1976	3.3E+10	1.0E-03	1.0E-03	3.2E-03	5.2E-04	4.1E-04		3.3E-04	3.3E-04	3.3E-04	3.3E-04	3.3E-04			3.2E-03	3.2E-03	7.6E+00
1977	1.5E+10	4.1E-04	5.2E-04	2.2E-03	7.4E-04	1.0E-03		6.7E-04	1.0E-03	1.0E-03	6.7E-04	6.7E-04			2.2E-03	2.2E-03	5.3E+00
1978	1.5E+09	3.3E-04	5.2E-04	1.0E-03	1.5E-04	8.1E-04		1.2E-03	1.3E-03	1.5E-03	1.2E-03	1.0E-03			1.0E-03	1.0E-03	2.4E+00
1979	7.4E+08	1.5E-04	1.9E-04	1.0E-03	5.2E-04	7.4E-04		3.0E-04	3.7E-04	2.6E-04	3.7E-04	3.3E-04			1.0E-03	1.0E-03	2.4E+00
1980	3.7E+07	2.2E-04	2.2E-04	7.8E-04	3.3E-04	5.2E-04		3.3E-04	3.3E-04	3.3E-04	3.3E-04	3.3E-04			7.8E-04	7.8E-04	1.9E+00
1981	1.9E+09	1.1E-04	1.9E-04	3.0E-04	3.0E-04	3.3E-04	3.3E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	3.3E-04	1.5E-04		3.0E-04	3.0E-04	7.1E-01
1982	4.8E+09	1.1E-04	1.5E-04	4.1E-04	1.9E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04		4.1E-04	4.1E-04	9.8E-01
1983	1.7E+08	2.2E-04	3.0E-04	2.2E-04	2.6E-04	1.5E-04	1.5E-04	1.5E-04	1.1E-04	1.1E-04	1.9E-04	1.1E-04	1.5E-04		3.0E-04	3.0E-04	7.1E-01
1984	7.0E+07	3.0E-04	1.9E-04	4.8E-04	3.3E-04	1.9E-04	1.9E-04	1.9E-04	1.1E-04	1.1E-04	1.5E-04	1.1E-04	1.5E-04		4.8E-04	4.8E-04	1.2E+00
1985	1.4E+08	4.4E-04	2.2E-04	4.1E-04	4.8E-04	2.2E-04	1.5E-04	1.9E-04	4.1E-04	1.5E-04	1.5E-04	1.9E-04	1.9E-04		4.8E-04	4.8E-04	1.2E+00
1986	1.3E+07	2.6E-04	3.0E-04	3.0E-04	2.6E-04	2.6E-04	2.6E-04	2.6E-04	3.3E-04	1.5E-04	1.5E-04	2.2E-04	2.2E-04		3.0E-04	3.0E-04	7.1E-01
1987	1.1E+07	1.3E-04	1.3E-04	1.4E-04	1.3E-04	3.3E-04	2.6E-04	3.0E-04	1.9E-04	7.4E-05	1.9E-04	3.3E-04	3.7E-04		1.4E-04	1.4E-04	3.4E-01
1988	2.2E+06	1.6E-04	1.5E-04	1.5E-04	2.0E-04	3.3E-04	3.0E-04	3.0E-04	3.0E-04	2.6E-04	2.6E-04	2.6E-04	2.6E-04		2.0E-04	2.0E-04	4.7E-01
1989	1.1E+07	9.3E-05	1.1E-04	1.3E-04	8.9E-05	1.1E-04	1.7E-04	1.7E-04	1.3E-04	2.1E-04	1.0E-04	1.1E-04	1.3E-04		1.3E-04	1.3E-04	3.2E-01
1990	1.2E+06					1.1E-04	1.1E-04	2.3E-04	1.3E-04	1.6E-04	1.6E-04	1.4E-04	1.6E-04	1.2E-04		1.2E-04	3.0E-01
1991	2.5E+05	5.2E-05	9.3E-05	7.8E-05	4.8E-05	1.1E-04	1.0E-04	8.1E-05	1.2E-04	7.8E-05	1.2E-04	8.9E-05	1.2E-04		9.3E-05	9.3E-05	2.2E-01
1992	7.8E+07	5.6E-05	5.9E-05	4.8E-05	5.2E-05	9.6E-05	1.1E-04	1.2E-04	9.6E-05	1.2E-04	1.2E-04	1.1E-04	9.3E-05		5.9E-05	5.9E-05	1.4E-01
1993	1.2E+08					7.8E-05	4.1E-05	1.1E-04	4.8E-05	8.1E-05	4.8E-05	7.4E-05	4.8E-05	8.0E-05		8.0E-05	1.9E-01
1994		7.0E-05	1.3E-04	2.0E-04	9.3E-05	5.9E-05	4.4E-05	9.6E-05	5.6E-05	4.8E-05	4.8E-05	5.6E-05	7.4E-05		2.0E-04	2.0E-04	4.8E-01
1996	1.1E+08					8.0E-05	9.6E-05	9.9E-05	8.5E-05	1.0E-04	7.7E-05	1.1E-04	1.0E-04				