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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.

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ACRONYMS AND ABBREVIATIONS

Bq	becquerel
CEDE	committed effective dose equivalent
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
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
FP	fission product
ft	foot
g	gram
GM	Geiger-Muller
hr	hour
kdpm	kilodisintegrations per minute
LMES	Lockheed Martin Energy Systems
m	meter
mg	milligram
MMES	Martin Marietta Energy Systems
mR	milliroentgen
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
PGDP	Paducah Gaseous Diffusion Plant
RU	recycled uranium
s	second
TBD	technical basis document
TLD	thermoluminescent dosimeter
TRU	transuranic
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) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute 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 contains an exclusion with respect to the Naval Nuclear Propulsion Program, 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 dosimetry monitoring results are considered valid for use in 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:

- Radiation from naturally occurring radon present in conventional structures
- Radiation from diagnostic X-rays received in the treatment of work-related injuries

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

4.1.1 Purpose

This TBD provides technical data and other key information, which will 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 document 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% uranium-235 (^{235}U) (natural enrichment) to around 3% ^{235}U for use in domestic and foreign power reactors (DOE 2000a). Enrichment operations began in 1952 in the first four process buildings, C-331, C-333, C-310, and C-315. 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 plants ceased operation and all feed to the enrichment process was in the form of UF_6 obtained from outside sources. Other chemical compounds of uranium were present throughout the Plant's history including uranyl fluoride (UO_2F_2), uranium fluoride (UF_4), and uranium oxide (UO_3).

ORAUT (2004) contains detailed information on the history of PGDP and the feed conversion and enrichment process.

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.

4.2 INTERNAL DOSE FROM ONSITE ATMOSPHERIC RADIONUCLIDE CONCENTRATIONS

4.2.1 Preoperational Background Survey

The Carbide and Carbon Chemicals Company analyzed samples for airborne uranium in August 1952 to document the preoperational conditions at PGDP (CCCC 1953). Ten chemically processed samples showed 0.00 mg/m^3 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 (UCNC 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).

An air sampling procedure from September 1962 describes environmental air sampling: "The samples are collected by a 110 volt Gast pump using membrane filter type AM-4 2 in. at a flow rate of 0.3 cfm (11 cm/s). Samples are continuous and of week-long duration" (UCNC 1962a). The environmental report for 1960 indicates that the change in monitoring techniques occurred about mid-1960 (UCNC 1961). A paper from PGDP describes the air sampling equipment used during this period (UCNC 1962b).

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 the U.S. Environmental Protection Agency, the State of Kentucky, and (as of 1997) the 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. Publications from Brown and Mitchell (1960), Martin Marietta Energy Systems (MMES 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 C-535 and C-537	North
PE-8	At security fence near McCaw Road	East
PS-2	At security fence approximately 300 meters south of C-100	South
PW-5	At security fence near C-749	West
IN	Offsite about 2 km north of PN	North
IE	Offsite about 1 km east-northeast of PE	East
ISE	Offsite about 2 km southeast of PS	Southeast
IS	Offsite approx 1.5 km south-southwest of PS	South
IW	Offsite approx 1.2 km west-northwest of PW	West
BN	At the north boundary of property, 0.3 km north of PN	North

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 technetium-99 (^{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 three cascade buildings.

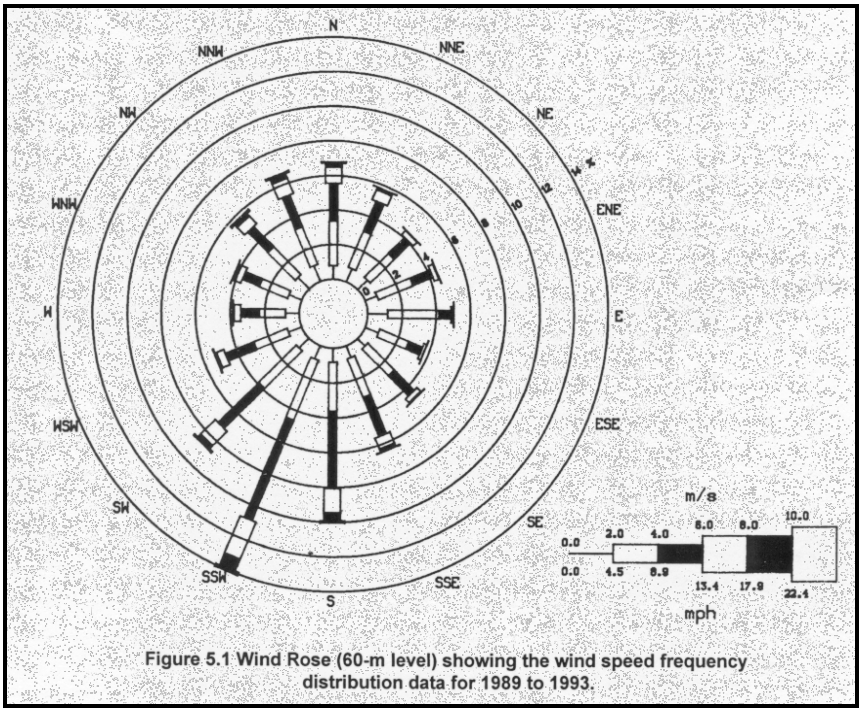

Figure 4-1. Wind rose from MMES (1994).

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 (CEDE) 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 from PGDP influence the gradual reduction in the air concentration over the 50-year history of PGDP. The records show that releases fell by five orders of magnitude while concentrations decreased by less than three 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 (see the reference list at the end of this document). Measurements from the air-monitoring locations were collected from these documents and applied using the method described. Attachment 4A provides an expanded version of this 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 (the current DOE environmental restoration contractor at PGDP), or the United States Enrichment Corporation.

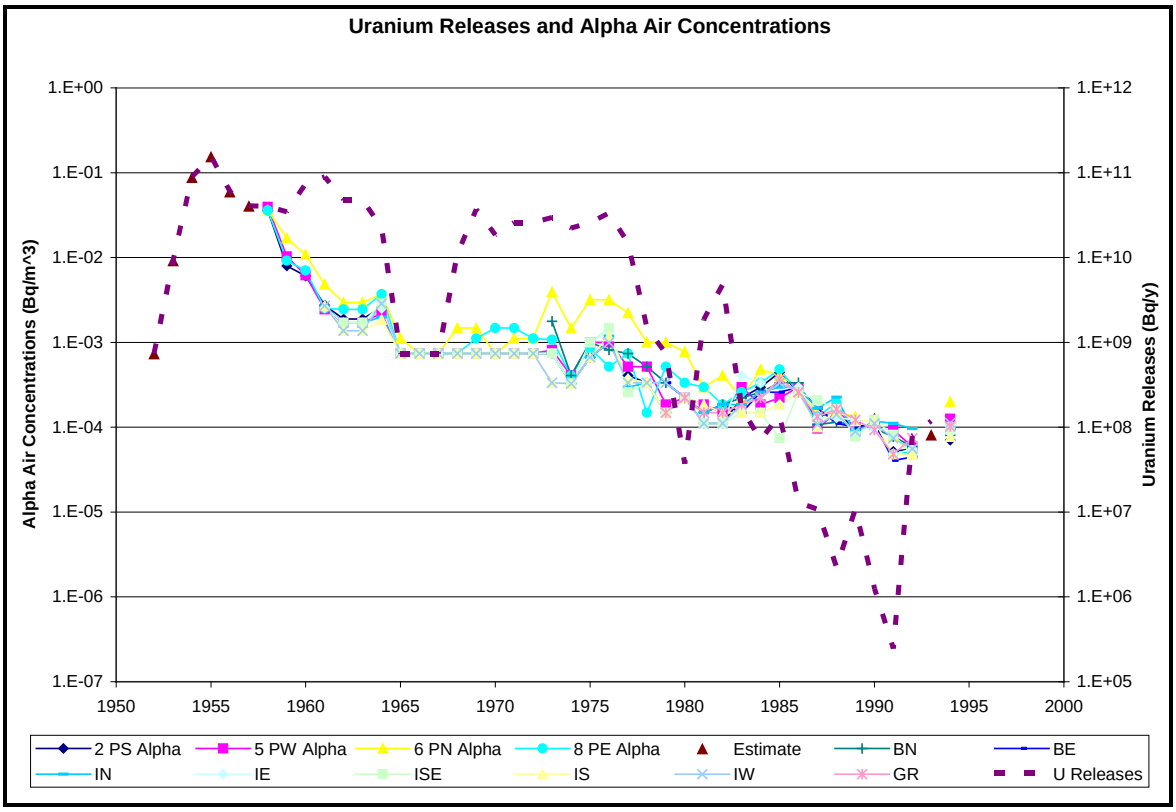

Figure 4-2. Alpha air concentrations.

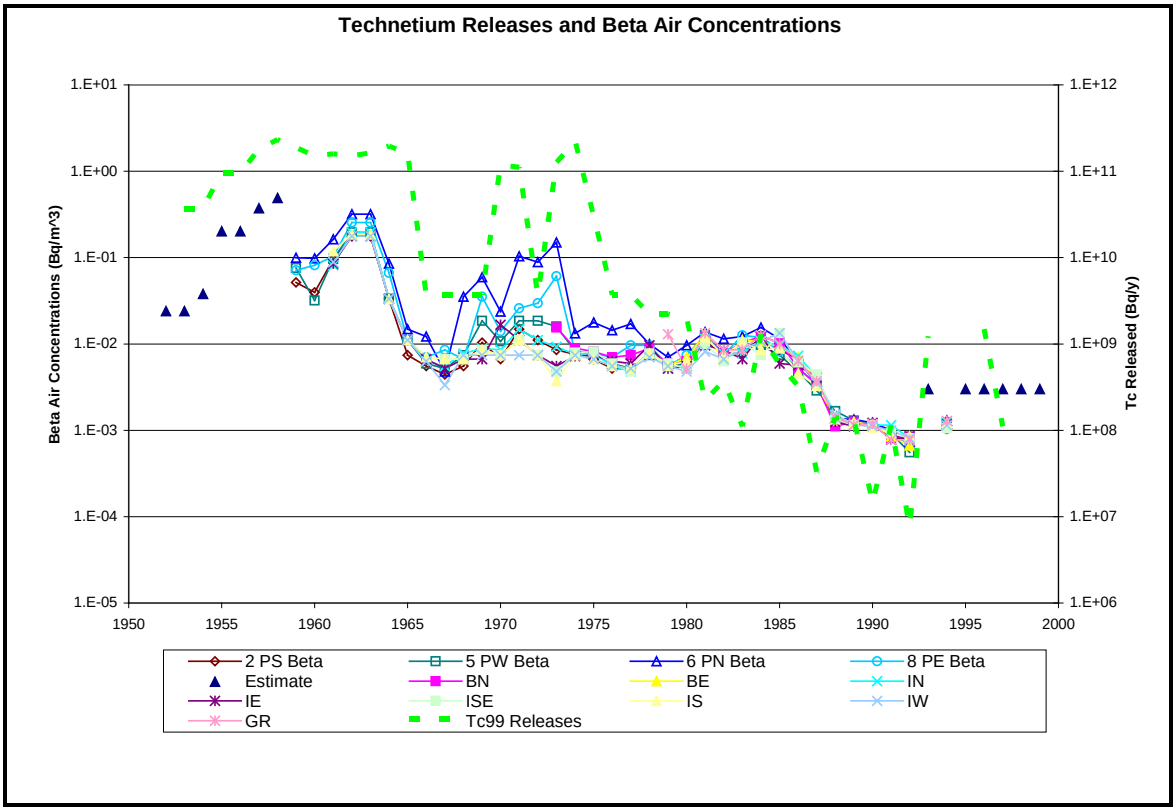

Figure 4-3. Beta air concentrations.

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.

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) (Miners 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, in the cascade (PACE 2000, DOE 2000b). There was a period when neptunium-237 (^{237}Np) was recovered from feed plant ash and shipped to the Oak Ridge National Laboratory (DOE 2000a).

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. Note that 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 1960).

A paper prepared for the 1964 Bioassay Conference reports these findings (Baker 1964). 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 two upgrade programs that replaced barrier material.

In 1987, *Exposure Assessment – Uranium Recycle Material in the Paducah Feed Plant*, 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 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.* (Baker 1987).

Further:

> *In 1962, 15 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 to be counted. None of the employees had detectable ^{237}Np* (Baker 1987).

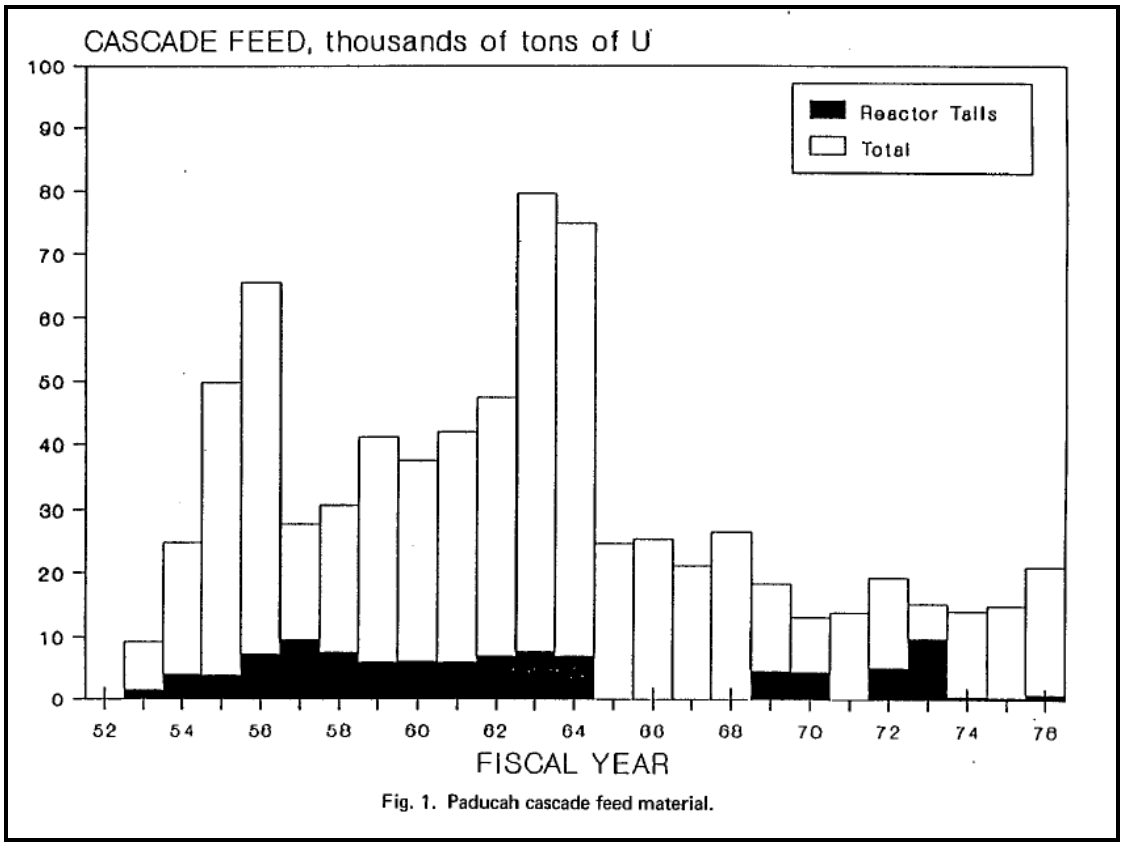

Figure 4-4. Cascade feed in thousands of tons of uranium, 1952 to 1978 (Miners 1990).

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 Cascade Improvement Program and Cascade Upgrade Program (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 *Neptunium Experience at PGDP*:

> *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* (Miners 1990).

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* (Miners 1990).

Table 4-2 lists the uranium releases, alpha airborne concentrations, and intakes from 1952 to 2001. Table 4-3 lists the ^{99}Tc releases, beta airborne concentrations, and intakes for the same period.

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
1994		7.0E-05	1.3E-04	2.0E-04	9.3E-05		2.0E-04	2.0E-04	4.8E-01
1995									
1996	1.1E+08								
1997									
1998									
1999									
2000									
2001									

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	
1952									
1953									
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 fission product exposures, an analysis was performed to determine the relative intake of TRU materials and ^{99}Tc to uranium. PACE (2000) reports ^{99}Tc as the fission product of concern. Tables 4-4a and 4-4b are derived from Barton (2006) and ORAUT (2006a). 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 (DOE 2000a; PACE 2000).

Table 4-4a. 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 4-4b. 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 5-2 converted from pCi/g U (2% enriched) to pCi/pCi U (Natural). Conservative assumption when U basis by weight is 2% enriched since the activity is higher, however when U 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-Muller (GM) counter three feet 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 considered 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 194 mrem deep dose equivalent for 2,000 hours. This occurred in 2001, the most recent year during which results were from the modern monitoring techniques.

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 fence line monitoring. No other significant sources of external exposure are associated with the PGDP operations. An assumed deep dose equivalent rate of 200 mrem/yr for all years would be reasonable, and deficiencies in earlier measurement techniques thereby become immaterial [13].

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. Ambient radiation includes natural background and that from the facility. Data in these documents (see the reference list for citations) include TLD radiation measurements. Table 4-5 lists TLD results and Figure 4-5 shows the locations of TLDs at PGDP.

The ambient radiation measured by TLDs near the security fence included natural background radiation, fallout, and cosmic radiation. The TLDs provided an indication of worker exposure levels in the general proximity of the security fence, but not inside the buildings. Table 4-5 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.

Table 4-5. External dose equivalent rates, PGDP external gamma exposure rate of mrem/2,000 hr.

TLD location	1	2	3	4	5	6	7	8	9	10	11	12	13	25	30	47	48	50	51	52	53	Reported background
1961	42			42															42	63		
1986	31	25	25	23	14																	
1989	112			10				9			5	8	6		10				28	114		
1990	98			14				16			17	18	15		13				35	15		
1991	92			12				14			10	14	11		13				40	19		
1992	84			12				14			10	9	11		13				40	58		
1993	110			21				20			21	20	18		21				39	20		10
1998	120	106	234																			28
1999	101	174	180											26								24
2000	101	179	112	23	24	22	27	18	25	21	23	22	26	29	20							25
2001	120	194	103	26	27	24	29	20	26	23	25	24	28		23	56	35	41	39	31	71	27

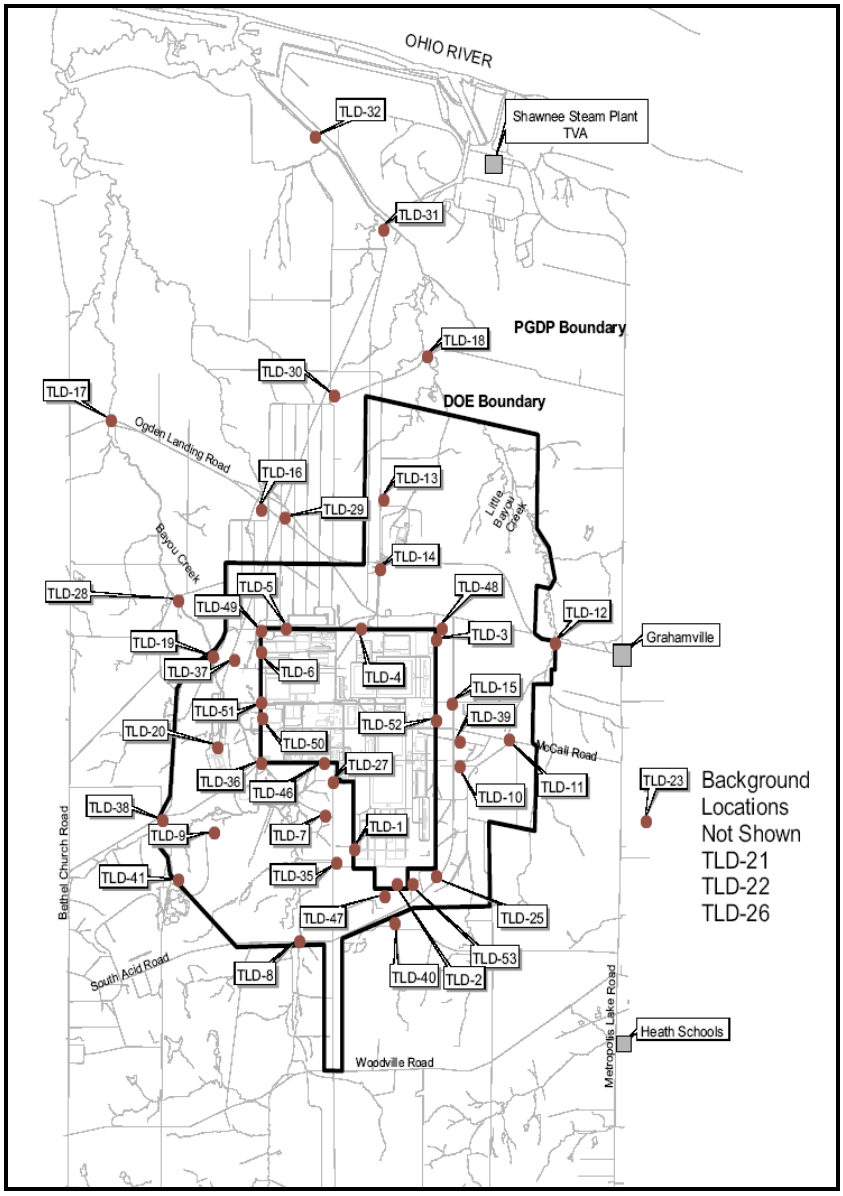

Figure 4-5. 2001 TLD locations.

Observations reported in the early environmental reports, based on surveys with portable instruments, reported 0.02 mrem/hr at all locations. For a 2,000-hr 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 [14].

PGDP personnel have annually compared these data with TLD data from offsite locations and literature values for State 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 [15]. 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.

4.3.2 Radiological Conditions in Cylinder Storage Yards

Several fenceline TLDs were adjacent to the UF_6 cylinder 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 [16]. 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 any significant time in the area to zero [17].

Missed and unmonitored neutron dose is discussed in the External Dosimetry Section for this site (ORAUT 2006b.)

Given this information, an ambient annual radiation dose equivalent of 200 mrem should be applied to unmonitored workers [18].

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 [19].

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 were adjusted to reflect a 2,000-hour work year. The data were originally reported in site environmental reports 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 [20].

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 [21].

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 will 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 were 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 1960) 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 being 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.
Other locations had higher external dose rates, but the workers in those areas were monitored, and therefore outside the scope of this section. The cylinder storage yards are an area where unmonitored personnel might have visited. The assignment of 200 mrem/yr minimizes the likelihood of underestimating the dose to an unmonitored worker.

[14] 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.

[15] 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 the PGDP, with the exception of areas within a few meters of the depleted uranium storage cylinders.

[16] 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.

[17] 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.

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

[19] East, James E. PrSM Corporation. Senior Health Physicist. July 2006.
Specific studies of area dose rates and incident investigations could be utilized 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.

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

[21] 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.

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GLOSSARY

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. Alpha particles have low penetrating power and a short range (a few centimeters in air). Outside the body, the most energetic alpha particle generally fails to penetrate the dead layers of cells covering the skin or a sheet of paper. Alpha particles emitted by radionuclides inside the body are a more significant health risk.

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. Most of the direct fission products are (negative) beta emitters. Exposure to large amounts of beta radiation from external sources can cause skin burns (erythema), and beta emitters can be harmful inside the body. Thin sheets of metal or plastic can stop beta particles.

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*.

In general, the effects of ionizing radiation in terms of the specific amount of energy 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. Various terms narrow the type of dose, and some are additive:

- Absorbed dose is the amount of energy deposited in a substance by ionizing radiation.
- Collective dose is the sum of the doses to a specific population.
- Committed dose is the dose over time (usually 50 years for workers) to a specific organ or tissue from an intake of radioactive material.
- Cumulative dose is the sum of all doses to the same portion of the body or to the whole body over time.
- Deep dose is the dose at a 1-centimeter depth in tissue (1,000 milligrams per square centimeter).

- Effective dose is the sum of the equivalent doses in the principal tissues and organs of the body, each weighted by a tissue weighting factor that accounts for the probabilities of fatal and nonfatal cancers according to severity and the average length of life lost due to an induced cancer. It indicates the biological effect of the radiation exposure in that tissue.

- Equivalent dose or dose equivalent is the absorbed dose in a tissue or organ multiplied by a weighting factor for the particular type of radiation.

- Organ dose is the dose to a specific organ.

- Penetrating dose is that from higher energy photon (gamma and X-ray) radiation and neutron radiation that penetrates the outer layers of the skin. Nonpenetrating dose is that from beta and lower energy photon radiation.

- Personal dose equivalent is the dose equivalent in soft tissue below a specified point on the body at a specified depth.

- Shallow dose is the dose at a 0.07-centimeter depth in tissue (7 milligrams per square centimeter).

- Skin dose is the dose to the skin.

- Whole-body dose is the dose to the entire body excluding the contents of the gastrointestinal tract, urinary bladder, and gall bladder.

dosimetry

Measurement and calculation of internal and external radiation doses.

exposure

1) In general, the act of being exposed to ionizing radiation. 2) Measure of the ionization produced by X- and gamma-ray photons in air in units of roentgens.

radioactivity

Disintegration of certain elements (e.g., radium, actinium, uranium, and thorium) accompanied by the emission of alpha, beta, gamma, and/or neutron radiation from unstable 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.

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.

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 PGDP and the Oak Ridge K-25 site.

ATTACHMENT 4A
OUTDOOR BETA AND ALPHA CONCENTRATIONS

Table 4A-1 lists outdoor beta concentrations, and Table 4A-2 lists outdoor alpha concentrations.

ATTACHMENT 4A
OUTDOOR BETA AND ALPHA CONCENTRATIONS

Table 4A-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	
1952																	
1953																	
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 4A
OUTDOOR BETA AND ALPHA CONCENTRATIONS

Table 4A-2. Outdoor alpha concentrations.

Year	Release (Bq/yr) U	Outdoor alpha concentrations (Bq/m^3) at each monitoring location															(Bq/yr)
		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	Annual uranium intake
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
1995																	
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				
1997																	
1998																	
1999																	
2000																	
2001																	