ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document for the Paducah Gaseous Diffusion Plant – Site Description	Document Number: ORAUT-TKBS-0019-2 Effective Date: 05/07/2004 Revision No.: 00 Controlled Copy No.:____ Page 1 of 23
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RECORD OF ISSUE/REVISIONS

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Draft	10/29/2003	00-A	New technical basis document for the Paducah Gaseous Diffusion plant – Site Description. Initiated by Jay Maisler.
Draft	12/2/2003	00-B	Adds Glossary, makes minor revisions to the report and resolves NIOSH comments. Initiated by Jay Maisler.
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05/07/2004	05/07/2004	00	First approved issue. Initiated by Jay Maisler.

ACRONYMS AND ABBREVIATIONS

AEC Atomic Energy Commission
ASTM American Society of Testing and Materials

CIP cascade improvement program
CUP cascade upgrade program

DOD U.S. Department of Defense
DOE U.S. Department of Energy

FP fission products

HF hydrofluoric acid

KOW Kentucky Ordnance Works

MAC Maximum Air Concentration
MgF_2 magnesium fluoride

ORNL Oak Ridge National Laboratory

PGDP Paducah Gaseous Diffusion Plant
ppb parts per billion
ppm parts per million

RCRA Resource Conservation and Recovery Act
RU recycled uranium

TBD technical basis document
Th thorium
TNT trinitrotoluene
TRU transuranic
TVA Tennessee Valley Authority

U uranium
UF_4 uranium tetrafluoride (“green salt”)
UF_6 uranium hexafluoride
UO_2 uranium dioxide
UO_3 uranium trioxide (“yellow cake”)

2.1 INTRODUCTION

This technical basis document (TBD), which is part of the Paducah Gaseous Diffusion Plant (PGDP) Site Profile, provides the site description (Section 2.2), routine site activities (Section 2.3), and site processes by specific building (Section 2.4) most relevant to worker dose reconstruction.

The purpose of the gaseous diffusion plant has been and continues to be the enrichment of uranium, initially for military applications and subsequently for commercial nuclear reactor fuel. PGDP enriches feed material in the form of uranium hexafluoride (UF_6) gas from approximately 0.711% ^{235}U up to about 2.5% ^{235}U. The enriched product from PGDP was sent to other U. S. Department of Energy (DOE) gaseous diffusion plants at Portsmouth, Ohio, and Oak Ridge, Tennessee, for further enrichment.

TBDs and Site Profile Documents are general working documents that provide guidance concerning 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 in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy facility" as defined in the Energy Employee Occupational Illness Compensation Program Act of 2000 (42 U.S.C. § 7384l (5) and (12)).

2.2 SITE DESCRIPTION

PGDP was built on a portion of 16,126 acres of farmland acquired by the U.S. Department of Defense (DOD) during World War II. DOD acquired this land for a munitions facility, the Kentucky Ordnance Works (KOW), which was operated by Atlas Powder Company until it closed in 1946 (Lockheed Martin 1997a). The KOW included a trinitrotoluene (TNT) manufacturing area; an acid production area; coal, sulfur, toluene, and ordnance storage areas; a sewage treatment plant; a water treatment plant; and burning grounds. PGDP still uses the water treatment plant. In 1950, 7,556 acres of the land east of the former KOW were acquired by the U.S. Atomic Energy Commission (AEC) as a site for a uranium enrichment facility that became PGDP (see Figure 2-1). The plant began operating in 1952, but construction was not complete until 1954. The facility reservation covered a total of 3,424 acres, with about 750 acres within the security fence. The rest of the land was transferred to the Tennessee Valley Authority (TVA) for the Shawnee Steam Plant and to the Commonwealth of Kentucky for wildlife conservation and recreational purposes (Lockheed Martin 1997b). The site consisted of 161 buildings, four of which contain the gaseous diffusion process (see Figure 2-2).

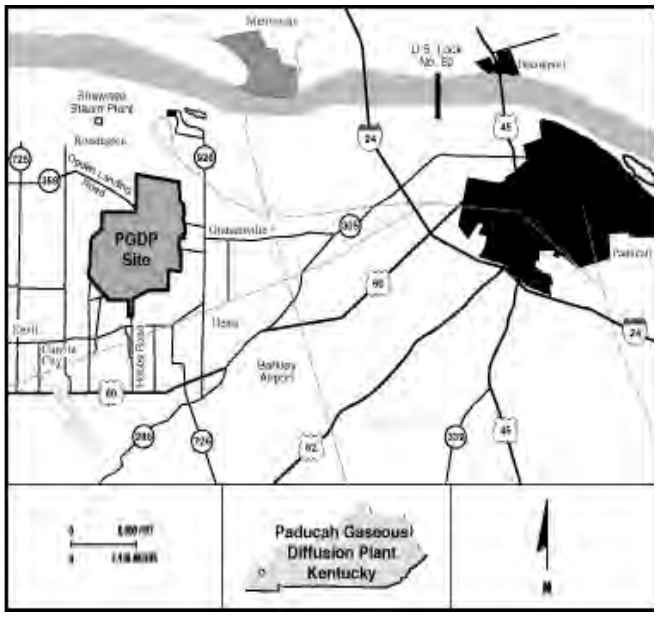

Figure 2-1. PGDP area map.

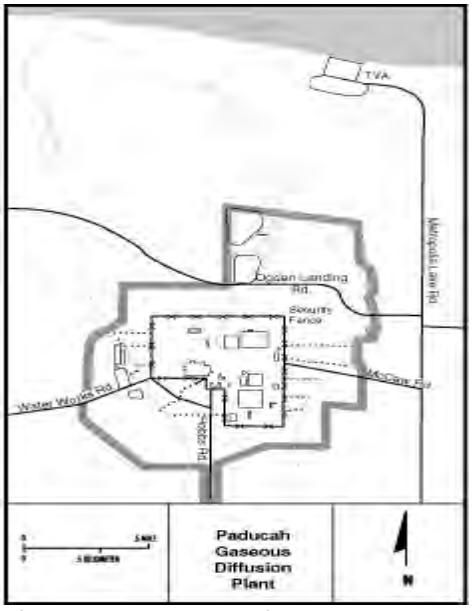

Figure 2-2. PGDP site map.

2.3 SITE ACTIVITIES

Originally, most UF_6 feed material came from the depleted tails produced during normal diffusion operations at PGDP and from the Oak Ridge and Portsmouth gaseous diffusion plants. In addition, from 1953 through 1977, UF_6 feed material was produced from uranium trioxide (UO_3), called *yellowcake*, at PGDP in Buildings C-410 and C-420. The UO_3 was supplied by sources such as El Dorado Mining and Refining, Mallinckrodt Chemical Works, and General Chemicals (now Allied Chemical), and comprised less than 10% of the UF_6 fed to the cascade. From 1953 through 1964 and intermittently from 1968 through 1977, the Feed Plant also produced UF_6 from UO_3 from spent reactor fuel processed at the Hanford and Savannah River Sites. After 1977, all feed came in the form of UF_6 from outside sources such as Oak Ridge, Portsmouth, and Allied Chemical (Bechtel Jacobs 2001).

Feed material was made from production reactor tails from 1953 until 1964 and intermittently from 1968 to 1977. The percentage of PGDP cascade feed material from reactor tails averaged 17% during the periods this material was used, ranging from 3% in 1975 to 65% in 1973. Processing of UO_3 to UF_6 was accomplished in three steps: reduction, hydrofluorination, and fluorination. The uranium exposure pathway of greatest concern at PGDP was inhalation of uranium dust.

Chemical reduction involved transforming UO_3 into uranium dioxide (UO_2) using hydrogen gas. Hydrofluorination of UO_2 into uranium tetrafluoride (UF_4), commonly referred to as *green salt*, was accomplished by adding anhydrous hydrofluoric acid (HF). Fluorination was conducted in Building C-410 using heated elemental fluorine gas in tower reactors. The first two steps were performed on vibration tray reactors (shaker trays) from 1953 to 1956. In 1956, due to frequent equipment failures, spills, leaks, and the increased demand for feed, Building C-420, commonly called the green salt plant, was completed and green salt production at Building C-410 was phased out. In Building C-420, reduction was performed in two-stage fluidized bed reductors; hydrofluorination was performed in three sets of horizontal screw reactors or in a two-stage fluidized bed hydrofluorinator. High Radiation Areas existed near the fluorination towers and ash receivers.

The main process buildings at PGDP (C-331, C-333, C-335, and C-337) contain the cascades, which are a series of compressor and converter stages and supporting equipment arranged in units and cells that progressively enrich UF_6 in its gaseous form. Enrichment occurs as UF_6 passes through barriers in the converters allowing isotopes of lower molecular weight to pass through. The series of converters results in two streams of UF_6 – one of progressively higher percentage ^{235}U that moves to the product withdrawal station in Building C-310, and one of progressively higher percentage ^{238}U that moves toward the tails withdrawal station in Building C-315. Both the enriched product and the depleted tails are fed as liquid into cylinders and allowed to cool until solid. The enriched product is shipped to Portsmouth for further enrichment. The depleted material was either re-fed to the cascade or is stored on the site. Figure 2-3 shows the uranium enrichment process.

There were two cascade improvement/upgrade programs (CIP/CUP) at PGDP. The first of these ran from 1958 to 1962 and the second was from 1973 to 1981. These were significant because of possible worker exposure to transuranics while the cascade systems were open. Other major events were the closing of feed plant operations from 1965 to 1969 and in 1971. Feed plant operations, in

Buildings C-410 and C-420, and the decontamination building, C-400, were permanently shut down in the late 1970s.

In 1957, the presence of ^{237}Np and ^{99}Tc was documented at PGDP; between 1959 and 1966 numerous studies related to the behavior, health effects, and controls for these radionuclides were conducted by PGDP and the AEC. The concentration of transuranic (TRU) elements, such as ^{237}Np and ^{239}Pu, and fission products (FP), such as ^{99}Tc, in the reactor tails material was small, estimated at approximately 0.2 part per million (ppm) neptunium, 4 parts per billion (ppb) ^{239}Pu, and 7 ppm ^{99}Tc. In

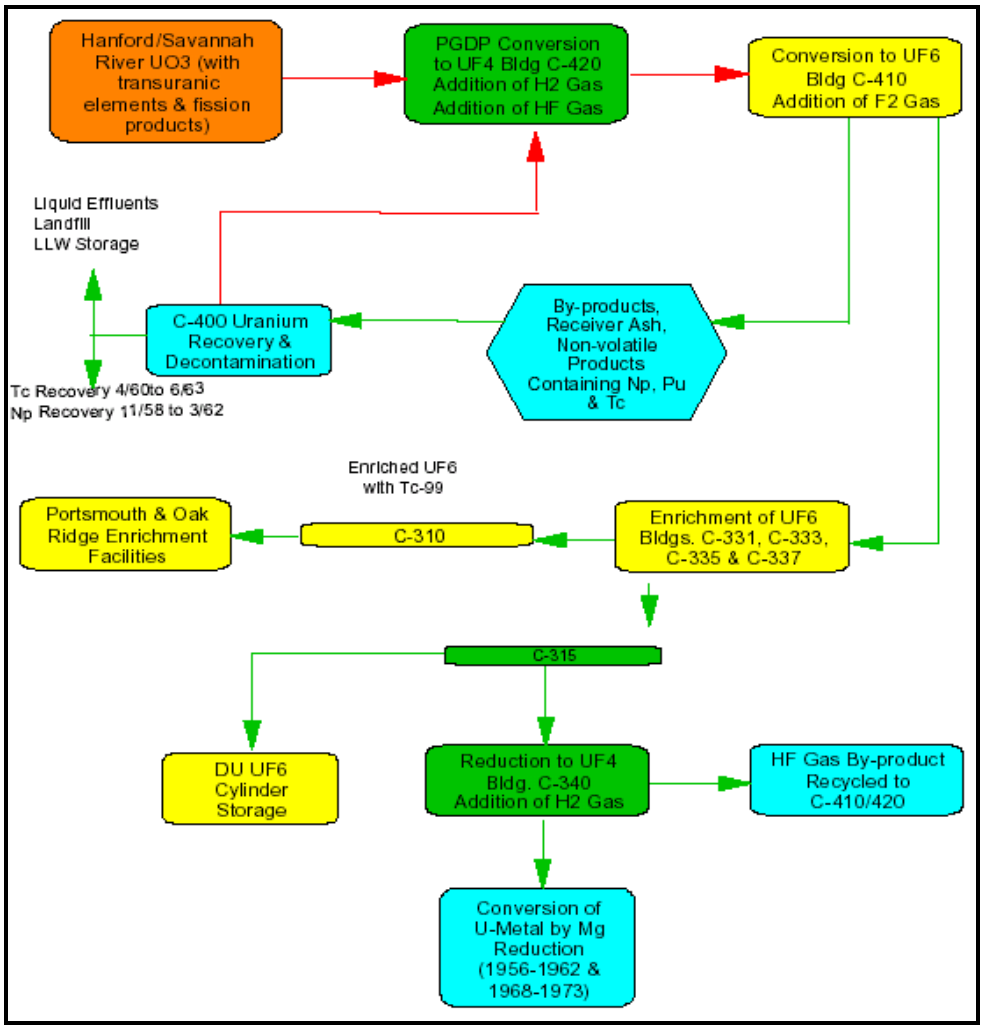

Figure 2-3. PGDP uranium enrichment process (Lockheed Martin 1997a).

addition, ^{241}Am, a decay product of ^{239}Pu, builds up as ^{239}Pu decays. These radionuclides were concentrated during processing at specific locations, which could increase radiation exposure to certain workers in these areas. (Bechtel Jacobs 2001).

Based on exposure records in the database, worker interviews, and health physics and inspection reports, an estimated 2,500 to 4,000 workers worked in areas with “moderate” to “high” potential for increased internal and external radiation exposures. This is based on a relative ranking of the potential of radiation exposures at PGDP. These areas included the feed plant (Buildings C-410 and -420) with operators and mechanics receiving the highest doses, respectively, decontamination building (C-400) with decontamination workers receiving the highest doses, and the cascade buildings

(C-331, C-333, C-335, and C-337) with operators receiving the highest doses. In addition, workers in Buildings C-340 and C-720 had a potential for increased external radiation exposures. Average doses per department are listed in Table 2-1 (for 1953-1988) (PACE/University of Utah 2000).

Data indicate that approximately 200 individuals received more than 1 rem external exposure in any one calendar year. Health physics reports documented that many workers exceeded the weekly plant action level of 300 mrem/week, but suggested that workers were kept below the annual regulatory limits by rotation of duties and limitations on stay time in areas of higher exposure. Average and maximum doses are listed in Table 2-2 (PACE/University of Utah 2000).

Table 2-1. Average external cumulative penetrating dose (deep dose equivalent) and number of workers assigned to each department during 1953-1988.

Dept. No.	Job description	Average cumulative dose (mrem)	Number of workers
5751	Feed plant operators	3,814	185
5760	Decontamination	2,788	116
5034	Feed plant mechanics	2,587	99
5015	Unknown	2,025	17
5676	Unknown	861	14
5730	Cascade operators	627	578
5785	Chemical operators	595	113
5075	Instrumentation	538	245
5020	Unknown	481	17
5008	Transportation pool	371	33
5002	Process maintenance	364	578
5108	Environmental control	338	48
5268	Unknown	316	236
5077	Electricians	298	318
5005	Material termination mgr.	295	90
5772	PEMU decontamination	253	22
5759	Unknown	220	4
5049	Unknown	182	12
5725	Unknown	175	20
5044	Mech. inspection	170	113
5021	Plant services	147	486
5770	Converter test	145	23
5035	Feed plant mechanics	143	160
5019	Unknown	142	13
5740	Nitrogen plant	142	22
5646	Metals building	132	95
5674	Unknown	129	8
5048	Fabrication shops	127	667
5023	Unknown	115	24
5675	Unknown	114	7
5743	Steam plant	111	61
5027	Unknown	110	282
	Total		4,706

Table 2-2. Average recorded external radiation doses (deep dose equivalent) per worker per year from 1953 to 1988 including maximum exposures recorded for any single worker for that year.

Year	Average recorded dose (mrem)*	Maximum recorded dose (mrem)	Number of workers
1953	139.8	820	223
1954	232.5	1,580	284
1955	241.9	2,500	417
1956	358.6	4,700	471
1957	251.7	3,190	669
1958	185.3	3,630	661
1959	201.5	2,360	570
1960	201.1	2,510	526
1961	177.0	2,530	1,690
1962	149.5	2,980	1,479
1963	144.1	3,040	1,311
1964	73.4	1,860	1,219
1965	34.1	1,610	1,128
1966	31.7	1,470	1,138
1967	49.8	1,120	1,143
1968	61.8	1,400	1,241
1969	73.3	1,970	1,270
1970	41.7	840	1,273
1971	62.4	1,380	1,254
1972	58.9	1,760	1,288
1973	53.0	1,830	1,404
1974	26.5	1,030	1,624
1975	50.1	1,049	2,013
1976	35.1	1,224	2,426
1977	23.2	742	2,643
1978	39.9	359	2,613
1979	8.2	364	2,487
1980	18.2	344	2,308
1981	7.6	420	1,840
1982	6.5	350	1,617
1983	6.7	340	1,452
1984	9.2	420	1,434

Year	Average recorded dose (mrem)*	Maximum recorded dose (mrem)	Number of workers
1985	6.1	350	1,365
1986	9.6	490	1,244
1987	8.0	470	1,275
1988	6.5	720	1,359

* The large number of zero values in the database reduces average values for radiation workers.

Approximately 10% of the 2,500 to 4,000 workers had a potential for higher than average radiation exposures. Reports that indicate extensive radioactive contamination in lunchroom areas, workers covered with black soot after ash-handling operations, Building C-410 floors routinely covered with visible green powder, and surveys indicating elevated concentrations of transuranics in almost all process buildings illustrate inadequacies in the PGDP contamination control program (PACE/ University of Utah 2000).

In general, job categories that had increased potential for exposures from external radiation were similar to those for internal radiation. The jobs and tasks that appear to involve the greatest potential for radiation exposure included ash handling (Building C-410), cylinder heel cleaning (Building C-400), derby processing (Building C-340), pulverizer operations (Building C-400), certain maintenance operations on the fluorination towers (Building C-410), maintenance on cascade equipment (cascades), cleaning of air filters (baghouses for Buildings C-400, C-410, C-420, and C-340), converter maintenance (Building C-720), flange grinding (Buildings C-340, C-400, C-410, and C-420), maintenance of the hydrogenation towers (Building C-340), and decontamination building cleaning operations (Building C-400). Jobs and tasks that were classified as having moderate potential radiation exposures include cascade operators and instrument mechanics (cascades), green salt sweeping (Buildings C-410 and C-420), disassembly of compressor (Building C-720), disassembly of block valves (Building C-720), drumming of green salt (Building C-340), and baghouse cleaning for cascades (Buildings C-310 and C-315). Other jobs and tasks were considered to have lower potential for worker radiation exposure. In addition, due to lack of aggressive contamination control programs, contamination from the operations identified above presented potential exposures to surrounding work areas. Further, legacy contamination generated from these operations could have posed a potential radiation exposure to individuals with access to the PGDP site in later years.

Special Incidences or Activities - High Potential for Increased Radiation Exposure

C-310 fire, 1956
C-337 fire, 1962
C-340, explosion and fire, 1962
Two workers overexposed, 1968 unknown location
C-315 fire, 1978
Cascade improvement program, 1954-1962 cascades
Cascade improvement program, 1973-1981 cascades
Neptunium production C-400

2.4 SITE PROCESSES

2.4.1 Key Uranium Processing Facilities

The major facilities at PGDP are:

- C-331, C-333, C-335, and C-337 – Gaseous Diffusion Process Buildings
- C-410/420 – UF_6 Feed Plant (currently inactive)
- C-300 – Central Control Building

- C-310 – Purge and Product Withdrawal Building
- C-315 – Surge and Tails Withdrawal Building
- C-340 – Metals Plant (currently inactive)
- C-400 – Decontamination and Cleaning Building

Other key facilities where moderate personnel radiation exposure occurred (e.g., C-404, C-409, C-710, and C-720) are included in this section.

NOTE: A complete list of radionuclides, quantities, chemical compounds, and inhalation class is not provided for every PGDP process and building discussed below. This Site Profile, in the TBD titled Occupational Internal Dose, provides a more complete description of this information.

2.4.2 C-310 – Purge and Product Withdrawal Building

In Building C-310, enriched UF_6 product was removed from the cascade and put in cylinders for transport. Building C-310 was approximately 53 x 30 feet in area and had two roll-up doors, one employee access door, and double doors to the storage room. The building was equipped to handle two 10- to 14-ton cylinders at a time.

Building C-310 received enriched UF_6 gas from the cascades product via pumps that discharged through a condenser, piping, and cylinder pigtails to the intended receiving UF_6 cylinder. Product cylinders were filled to no more than 95% (liquid) of capacity.

The manual valves on the UF_6 cylinder would occasionally be identified as defective and require replacement. This work was performed in Building C-310. According to procedures in effect in the 1970s, a UF_6 cylinder was required to cool at least 5 days before its valve was replaced. Those cylinders known to be above atmospheric pressure after the minimum cooling period would be vented and further cooled, if necessary, with cold water. Until the mid-1970s, defective UF_6 cylinder valves were routinely replaced by the mechanic standing upwind, with any escaping gases or fumes going the other way.

In 1980, the building was normally staffed by one to three workers with a crane operator on call if cylinder transfer involving crane movements was required. The workers were responsible for completing equipment checks, logging equipment data, preparing cylinders for filling, disconnecting and weighing full cylinders, transferring cylinders, and maintaining cylinder records. In 1997, the workforce consisted of operators (three to seven per shift), maintenance mechanics (four per shift), instrument mechanics (two per shift), electricians (two per shift), and foremen (four per shift).

Operations Performed in Building C-310 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Connecting and disconnecting UF_6 product cylinders and handling product UF_6 – 1953-1999
27 ppb ^{237}Np
0.06 ppb ^{239}Pu
20,000 ppb ^{99}Tc (UF_6)
Minimal external radiation exposure potential.

Changing/cleaning magnesium fluoride (MgF_2) traps – 1964-1966
1900 ppb ^{237}Np
0.01 ppb ^{239}Pu
2,266,000 ppb ^{99}Tc (MgF_2)
Moderate external radiation exposure potential.

2.4.3 C-315 – Surge and Tails Withdrawal Building

Building C-315 began operation in early 1953. The building was used for the removal of depleted UF_6 byproduct from a cascade and storage in cylinders. It was approximately 53 × 30 feet in area and contained four cart tracks and product equipment to accommodate four 10- to 14-ton cylinders. Four roll-up doors were in the east wall to permit the entry and exit of cylinders, while the west wall contained doors to the pump room and control room. Thus, six penetrations (doors) affected air flow in the building.

Liquefaction was accomplished by compression of UF_6 piped to the building from the enrichment operation (Buildings C-331, C-333, C-335, and C-337) at a pressure at which UF_6 gas can be conveniently liquefied. After condensing, the liquid was allowed to flow conveniently into cylinders. The product was drained as a liquid into the multiton cylinders through a copper tube referred to as a *pigtail*. When the cylinder was filled to capacity, the cylinder and drain valves were closed and the pigtail was evacuated and purged. The pigtail was disconnected at the cylinder valve (PACE/ University of Utah 2000).

In 1980, the building was normally staffed by one to three workers with a crane operator on call if cylinder transfer involving crane movements was required. The workers were responsible for completing equipment checks, logging equipment data, preparing cylinders for filling, disconnecting and weighing full cylinders, transferring cylinders, and maintaining cylinder records. By 1997, the workforce consisted of operators (two or three per shift), maintenance mechanics (four per shift), electricians (two per shift), janitor (one per shift), and foremen (four per shift) (PACE/University of Utah 2000).

Operations Performed in Building C-315 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Connecting and disconnecting UF_6 tails cylinders and handling tails UF_6 – 1953-1999
5 ppb ^{237}Np,
0.1 ppb ^{239}Pu,
20,000 ppb ^{99}Tc (UF_6)
Minimal external radiation exposure potential.

2.4.4 Gaseous Diffusion Process Buildings (C-331, C-333, C-335, and C-337)

The main process buildings at PGDP contain the cascades, which are a series of compressor and converter stages and supporting equipment arranged in units and cells that progressively enrich UF_6 in its gaseous form. The process buildings provide 74 acres under roof. Each process building has 1,812 enrichment stages.

PGDP construction, from 1951 through 1956, occurred in two phases. Construction of the first phase began January 2, 1951, and included Buildings C-331 and C-333. Authorization to proceed with the second phase of PGDP construction was received on July 15, 1952. Two additional enrichment facilities, Buildings C-335 and C-337, were added, and construction was completed in 1956. In September 1952, Buildings C-331 and C-333 began operation. In November 1952, the first product was withdrawn. In July 1953, the first reactor tails of UF_6 were fed to the enrichment cascade after conversion in Oak Ridge. In April 1954, Building C-335 began operations; and in July 1954, Building C-337 began operations (Bechtel Jacobs 2001).

Operations Performed in the Cascade Buildings and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Cascade operations – 1953-1964, 1969-1970, and 1972-1976
450 ppb ^{237}Np
0.09 ppb ^{239}Pu
23,000 ppb ^{99}Tc
Moderate external radiation exposure potential.

Cascade maintenance (cascade dust) – 1954-1961 and 1973-1981 (CIP/CUP)
2740 ppb ^{239}Pu
3,220,000 ppb ^{237}Np
Specific concentrations of ^{99}Tc not available for this operation
High external radiation exposure potential.
Isotopic concentrations in the reactor tails (approximate):
0.2 ppm ^{237}Np
4 ppb ^{239}Pu
7 ppm ^{99}Tc

2.4.5 Building C-340 – Metals Plant

Several operations were performed in this building, two of which had a high potential for increased worker radiation exposure. These were the conversion of depleted UF_6 to UF_4 using a hydrogenation process and the conversion of some UF_4 to uranium metal via a reaction with magnesium. The rationale for doing hydrogenation was to recover hydrofluoric acid for use in the oxide conversion process in Building C-420. Another reason might have been to convert UF_6 to a form that was easier to store. Both processes generated considerable amounts of dust.

Metals production involved several steps, each with its own unique hazards.

- The uranium metal production process involved reducing UF_6 (normally from the tails cylinder) to UF_4 by combining it with hydrogen in a heated tower. The UF_4 was mixed with magnesium and fed into lined firing reduction vessels, placed in furnaces, and heated until it fired into a metal ingot, called a *derby*. The next phase of the operation involved blending measured quantities of UF_4 (depleted uranium) with measured quantities of magnesium metal, and pouring this mixture into the reactor liner. A refractory cap was then poured, and a lid was bolted to the top of the charged reactor. The charged reactor was transferred to an induction furnace where it was heated to the point where the uranium reduction started.

  The primary hazard associated with this part of the process was exposure to airborne uranium dust during weighing, blending, and pouring. Respirators were required soon after initial production operations began. In addition, the reactors presented a significant hazard from burning magnesium and molten uranium metal. Phenomena described as "burnout" and "lid fires" occurred infrequently when the refractory liner was not correctly prepared. For example, burnouts occurred when burning magnesium came in contact with the steel shell, melting through the shell and releasing reactor contents to the furnace. Lid fires were similar, but occurred at the lid rather than the side of the shell. Such an occurrence led to a fatality (death was not due to radiological exposure) in March 1962. Burnouts resulted in significant contamination of the furnace refractory and would normally require relining of the entire furnace.

After the reactor was cooled, it was sent to the breakout area where the lid was removed, the shell was inverted, and the contents were dumped onto a grating, referred to as a *grizzly*. The slag material, at this point a hard ceramic, was broken into smaller pieces by beating it with a hammer. The pieces dropped through the grating into a jaw crusher and went to the slag plant. This operation was among the dirtiest jobs in Building C-340. Operators were sometimes covered with black dust; and, although respirators were required and generally worn, the extent of dust and contamination might have exceeded the protection factor of the respirator.

- The metal ingot, or derby, was freed from the slag and roasted to oxidize the surface and loosen remaining slag. Loose oxides that fell from the derbies during roasting were collected, put in drums, and sent to a burial yard.

- After roasting, the derbies were cleaned by hand in a cleaning booth using power brushes and grinders to remove remaining slag. The potential hazards for airborne contamination for this operation were similar to those for the breakout operation.

- After cleaning, the derbies could be shipped directly or sawed into smaller shapes, depending on customer requirements. Derby sawing generated large amounts of uranium metal "sawdust," which burns readily in air. This sawdust was collected in drums of oil and kept covered. Despite these measures, uranium metal fires were common (daily or weekly), resulting in elevated levels of airborne uranium oxides.

- The Building C-340 operation was capable of remelting uranium derbies and casting specific shapes. Operations were conducted in a furnace with a controlled atmosphere. Graphite crucibles were used to receive molten uranium. The primary hazard associated with these operations was cleaning the crucibles between pours. Over time, oxides of uranium and beta-emitting uranium decay products would impregnate a crucible. Because crucibles were cleaned by hand, operators received radiation doses to their hands, arms, and fingers.

- The MgF_2 reaction product remaining in the reactor was captured, crushed, ball milled, and sized to be recycled as refractory. Although this was primarily a hands-off operation, it generated significant quantities of dust. Over time, the slag became contaminated with significant quantities of uranium oxides (several percent) that could have contributed to worker intakes. Reject slag (too small or too large) was collected in a hopper, and periodically drummed. Operators did not wear dosimetry that would have measured these extremity exposures (see Part 6, External Dosimetry, of this PGDP Site Profile).

From 1978 to 1982, Building C-340 served as a shipping point for UF_4. In addition, the building contained a remelt furnace for recasting uranium. The workforce consisted of operators (10 to 20 per shift), maintenance mechanics (three to five per shift), instrument mechanics (three to five per shift), and electricians (three to five per shift) (PACE/University of Utah 2000). After enrichment operations were shut down in the late 1970s, the building was used for other activities (e.g., offices and training programs).

Operations Performed in Building C-340 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Production and handling of UF_4 produced from tails – 1957-1962 and 1967-1977
62.6 ppb ^{237}Np
0.063 ppb ^{239}Pu
49 ppb ^{99}Tc (UF_4)

Minimal external exposure potential

Connecting and disconnecting UF_6 tails cylinders and handling tails UF_6 – 1953-1999
5 ppb ^{237}Np
0.1 ppb ^{239}Pu
20,000 ppb ^{99}Tc (UF_6)
Minimal external exposure potential

Uranium-metal production from metal production, sawing, and metal handling – 1957-1962 and 1967-1977
2.7 ppb ^{237}Np,
0.0085 ppb ^{239}Pu,
10.6 ppb ^{99}Tc (uranium metal)
Minimal external exposure potential

Handling MgF_2 in uranium-metal manufacturing – cleaning, roasting, liner preparation, knock out and drumming – 1957-1962 and 1968-1977
2,400 ppb ^{237}Np,
1.2 ppb ^{239}Pu,
1,880 ppb ^{99}Tc (MgF_2)
High external exposure potential

2.4.6 Building C-400 – Decontamination and Cleaning Building/Uranium Recovery

Building C-400 was brought into service in April 1953. Its uranium recovery facilities were used to chemically separate and recover uranium from a variety of waste materials. Sources of feed material for this process included fluorination tower ash, sintered metal filters, decontamination solutions, UF_6 scrubber solutions, particulates from ventilation filters and vacuum cleaners, laboratory wastes, and materials from spills. Building C-400 was a site for potentially increased radiation exposures, primarily because the following operations were performed there: converter disassembly, pulverization of waste UF_4 and recycled UO_3 containing transuranics, cylinder heel cleaning, spray booth operation, and ^{237}Np and ^{99}Tc recovery. In addition, radiological hazards were associated with cleaning the building air filtering system (baghouses) (Bechtel Jacobs 2001).

Before the mid-1970s, a complex uranium recovery process was performed in Building C-400. Uranium was separated from waste and scrap materials, concentrated, and converted to an oxide. The process included the following steps: dissolution of feed materials, filtration, solvent extraction in pulse columns, concentration by evaporation, and denitration to an oxide. The aqueous raffinate waste from solvent extraction columns, which contained ^{237}Np, ^{239}Pu, and ^{99}Tc, was discharged to the environment (Bechtel Jacobs 2001).

In the mid-1970s, the solvent extraction process for uranium recovery was replaced with a simpler precipitation and filtration process. Steps in this new process included dissolution of feed materials in nitric acid, addition of lime to precipitate uranium, and recovery of precipitated uranium as a filter cake.

Maintenance on major components in the cascade (compressors, converters, and process block valves) presented some of the most significant opportunities for exposure of maintenance personnel. Work on these components required that they be removed from the system, cleaned, rebuilt or repaired, and reinstalled. To remove these components, process operators isolated and bypassed the cascade cell containing the component, reduced the UF_6 in the cell to less than 10 ppm equivalent

at atmospheric pressure, and purged the cell to minimize HF and UF_6 exposure to workers involved in opening, maintaining, or modifying cell components. Once a satisfactory UF_6 negative and HF purge were accomplished and the pressure of the isolated cell was raised to atmospheric pressure with dry air, the isolated cell was turned over to process maintenance for cell opening and disassembly.

Compressors were transported from the process buildings to Building C-400 (and Building C-720). The compressors were disassembled into major components in pits, the parts were spray-washed to remove uranium deposits, and the rotor was relocated as required for deblading in Building C-400. The barriers were washed and disassembled, and scrap recovery was performed.

Neptunium Recovery

Soon after ^{237}Np was identified at Paducah in 1957, the AEC placed a high emphasis on its recovery. A ^{237}Np recovery process developed at ORNL began operation at PGDP in November 1958 in Building C-400. The process used a solvent extraction and evaporation method to recover and concentrate ^{237}Np from receiver ash and cylinder heels wash solution. Receiver ash and solids that settled from cylinder wash water were dissolved in a nitric acid solution. Solids suspended in this solution were removed by filtration and discarded as solid waste. The filtrate was processed through solvent exchange pulse columns to separate uranium, thorium, and ^{237}Np. These columns, originally in Building C-710, were moved to Building C-400 sometime after July 1959. Raffinate from these columns was dumped to the building drain if it contained uranium and ^{237}Np concentrations less than 500 ppm and 2.0 mg/L, respectively. Uranium and thorium were recovered for future use. The ^{237}Np solution was concentrated to about 20 to 25 g/L by evaporation (Bechtel Jacobs 2001).

The relatively greater radiological hazards associated with ^{237}Np were understood at PGDP as early as 1959, and special practices for handling ^{237}Np solutions and ^{237}Np-contaminated equipment were recommended. Recommendations included using nonbreakable containers; maintaining tight systems; keeping lids on containers; preventing bubbling, frothing, or spraying of solutions; using rubber gloves; washing the gloves before using them in other areas; using respirators (or assault masks) for welding or burning; and performing alpha surveys of all equipment removed from ^{237}Np processing areas (Bechtel Jacobs 2001).

In 1958, ash and cylinder washings were processed through the Building C-400 ^{237}Np recovery process. The process used aqueous chemistry and ion exchange methods to recover 3.215 kg of ^{237}Np from the cylinder wash stream and 1.074 kg of ^{237}Np from the ash stream. The recovered materials were shipped to the Hanford Site. A program to recover ^{99}Tc from cylinder wash water and raffinate (e.g., solvents) from ^{237}Np recovery operations began in April 1960 (Bechtel Jacobs 2001).

Technetium Recovery

Technetium-99 is a fission product that PGDP received in recycled feed from the Hanford and Savannah River Sites. Technetium-99 passed through the cascade as a volatile compound of fluorine, depositing on internal surfaces of the cascade and contaminating the enriched uranium product. The AEC did not specify a limit for ^{99}Tc in UF_6 feed but indirectly controlled its concentration to about 10 ppm by limiting gross beta from fission products. A demand for ^{99}Tc in the early 1960s prompted PGDP to begin a process to recover 25 kg of this material from various effluent streams. In 1960, a process was begun to recover ^{99}Tc from UF_6 cylinder washwater and from raffinate generated during ^{237}Np recovery. Process steps included precipitation and removal of uranium from these solutions by adding sodium hydroxide. This solution was processed through an ion exchange column and elutriated with nitric acid to produce a concentrated solution of ^{99}Tc that was shipped to Oak Ridge National Laboratory (ORNL). Although the contribution to radiation dose from ^{99}Tc was not of concern during most PGDP operation and maintenance activities, the isolated activity required

specific monitoring considerations for both internal exposure and external skin exposure (Bechtel Jacobs 2001).

Cylinder Cleaning
With repeated reuse, UF_6 cylinders collected deposits that did not completely volatilize in the autoclave. Periodically these deposits, called *cylinder heels*, had to be dissolved and removed, and the cylinder was then cleaned, refurbished as necessary, reinspected, hydrostatically tested, and weighed for subsequent use. Cylinder heels were composed of corrosion products, uranium salts and oxides, and TRU and uranium daughter product compounds. With regard to the contaminants of the process gas, some of the ^{237}Np and much of the ^{99}Tc was volatilized to the cascade, while most ^{239}Pu remained behind in the cylinder heels, creating a significant radiological hazard. Cylinder cleaning was performed at Building C-400, where the heels were dissolved and the rinse water was collected in a large pan (Bechtel Jacobs 2001).

Operations Performed in Building C-400 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Cascade maintenance - 1954-1961 and 1973-1981 (CIP/CUP)
450 ppb ^{237}Np
0.09 ppb ^{239}Pu
Specific concentrations of ^{99}Tc not available for this operation
High external radiation exposure potential.

Uranium/neptunium recovery - 1957-1990 and 1956-1976
25,000,000 ppb ^{237}Np
100,000 ppb ^{239}Pu
Specific concentrations of ^{99}Tc not available for this operation (solutions)
Moderate external radiation exposure potential.

2.4.7 C-404 – Solid Radioactive Waste Disposal Area

This area was the primary disposal site for radioactive waste at PGDP. It was constructed as a holding pond for Building C-400 liquid waste. The pond was 380 by 140 feet, with 6-foot-high dikes. In 1957, the C-404 Holding Pond was converted to a solid radioactive waste burial area. By 1977, approximately 6,400,000 pounds of materials contaminated with uranium had been drummed and placed in the holding area. Waste streams included incinerator ash, contaminated alumina, highly contaminated roofing waste, and gold recovery sludge. This area continued in use into the mid-1980s. It was later determined to contain sludge that was chemically hazardous, thus requiring closure under the Resource Conservation and Recovery Act (RCRA) in 1987 (Bechtel Jacobs 2001).

Reported activities or concentrations for other radionuclides were not found for this area.

2.4.8 Building C-409 – Stabilization Building

Cascade Maintenance
Once compressors had been overhauled and reassembled in Building C-400 or C-720, compressor openings were covered for transportation to storage or reinstallation. Converters were transported from the process buildings to Building C-409 for decontamination.

During the 1973-1981 cascade improvement, a shop for reassembling and testing converters was located in Building C-409. In addition, the building had a small spray booth for minor cleaning jobs. The number of personnel involved is not known. The spray booth in C-409 was used in the initial

stages of tearing down converters. The waste from this spray booth was piped to C-400 for removal of uranium oxides. It is not clear, but apparently the C-409 spray booth was operated by C-400 personnel.

Operations Performed in Building C-409 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Cascade maintenance – 1954-1961 and 1973-1981 (CIP/CUP)
450 ppb ^{237}Np
0.09 ppb ^{239}Pu
Specific concentrations of ^{99}Tc not available for this operation
High external radiation exposure potential.

2.4.9 Building C-410 – Feed Plant

From July 1953 through 1977, UF_6 feed material was produced from UO_3 (yellowcake) at PGDP in Buildings C-410 and C-420. This feed material was supplied by sources such as El Dorado Mining and Refining, Mallinckrodt Chemical Works, and Allied Chemical and comprised less than 10% of the UF_6 fed to the cascade. From 1953 through 1964 and intermittently from 1968 through 1977, the Feed Plant produced UF_6 from UO_3 obtained from spent reactor fuel processed at the Hanford and Savannah River Sites. After 1977, all feed came in the form of UF_6 from outside sources such as Oak Ridge, Portsmouth, and Allied Chemical.

The next stage of the enrichment operation was to convert solid UF_4 to gaseous UF_6. This was done using heated elemental fluorine gas in the Building C-410 fluoridation towers. The operation consisted of introducing UF_4 at the top of the tower while fluorine gas was introduced from below. The resulting UF_6 gas/liquid was removed in large cylinders and the solid waste products were collected in ash receivers at the bottom. The external radiological concerns were from beta and gamma emissions from transuranics, fission products, and accumulated uranium daughter products, which were concentrated by the process in the ash at the bottom of the fluoridation towers. In addition to external radiation sources, inhalation of radioactive dust while cleaning plugged equipment, changing out the ash receivers, and cleaning of the building air filters was possible. The potential for radiation exposure was particularly increased for work around and with ash receivers. Workers in the fluorination tower area were exposed to UF_4 and UO_2F_2 (PACE/University of Utah 2000).

Exposure to uranium powder dusts was prevalent in operations and maintenance activities. For example, plugging of conveyers, hoppers, and screws with UO_3 or UF_4 routinely required physical agitation with sledgehammers or metal rods. In many cases, shear pins or chains on the associated drive mechanisms broke, requiring operations personnel to clean the product out of the jammed equipment and maintenance personnel to disassemble and repair the equipment.

Operations Performed in Building C-410 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Cascade operations – 1953-1964, 1969-1970, and 1972-1976
450 ppb ^{237}Np
0.09 ppb ^{239}Pu
23,000 ppb ^{99}Tc
Moderate external radiation exposure potential.

Feed plant operations, recycled uranium (RU) to UF_6 - $UO_3 \rightarrow UO_2$ UF_4 UF (handling, drumming, bag changing, etc. (tower ash) – 1953-1964 and 1969-1977
25,602 ppb ^{237}Np

8,000 ppb ^{239}Pu
4,600 ppb ^{99}Tc
High external radiation exposure potential

Changing/cleaning magnesium fluoride (MgF_2) traps – 1964-1966
1,900 ppb Np
0.01 ppb Pu
2,266,000 ppb Tc (MgF_2)
Moderate external radiation exposure potential.

2.4.10 Building C-420 – Oxide Conversion Plant (UF_4 – Green Salt Plant)

In August 1956, the Building C-420 expansion to the feed plant was complete. Building C-420 was a comparatively small building attached to the west side of Building C-410. It contained fluidizing beds that were used in the conversion processes. This was where U_3O_8 was converted to uranium oxide and then to UF_4 for use as feed stock for the fluorination towers in Building C-410. The ore was run through two sets of fluidized beds, the first of which converted UO_3 (yellow powder) to UO_2 (black powder), while the second converted UO_2 to UF_4 by reaction with hydrofluoric acid. The primary potential for radiation exposure to operators was the inhalation of dust generated while unplugging converters or while cleaning the building air filtering system (baghouse). Maintenance mechanics had a potential for inhalation exposure while working on the equipment.

The equipment used for the conversion processes consisted of a series of hoppers, conveyer belts, screws, chutes, etc., which were susceptible to mechanical failure. When a failure occurred, the system would be opened and the operators and maintenance mechanics would do what was necessary to get things going again. Routine operations in Building C-420 do not appear to have had the potential for increased radiation exposure; however, the workers in this building were rotated with those in Building C-410 to reduce individual radiation exposure.

The workforce consisted of operators (four per shift), maintenance mechanics (two per shift), electricians (two per shift), instrument mechanics (two per shift), and janitors (one per shift) (PACE/ University of Utah 2000).

Operations Performed in Building C-420 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Feed plant operations, RU to UF6 - UO3 → UO2 UF4 UF (handling, drumming, bag changing, etc. (tower ash) - 1953-1964, 1969-1977, and 1982-1983
25,602 ppb 237Np
8,000 ppb 239Pu
4,600 ppb 99Tc
High external radiation exposure potential

2.4.11 Building C-710 – Analytical Laboratories

The PGDP analytical laboratories are in Building C-710. The laboratories, which have been in operation since plant startup, consist of the ASTM, Industrial Hygiene, Infra-Red Spectrometry, Emission Spectrometry, Sampling, Uranium Analysis, Trouble Shooting, Quality Control, Radiochemistry, Metallurgy, Mass Spectrometry, Counting Preparation, Alpha and Beta Counting, and Fission Training Laboratories.

The ^{99}Tc recovery operation, initially in Building C-710, was moved to Building C-400 sometime after 1959.

A ^{237}Np recovery process originally in Building C-710, Room 32, was transferred to Building C-400 sometime after July 1959 (see Section 2.4.6). After processing in Building C-400, the concentrate was sent to a laboratory in Building 710 for additional separation and concentration in ion exchange columns. The final product was siphoned into glass carboys on the loading dock at Building C-710 and shipped to ORNL.

A Health Physics and Industrial Hygiene Department report for the first quarter of 1959 stated that continuous air samples collected near the ^{237}Np recovery operation in Building C-710 averaged slightly above the maximum air concentration (MAC, a term used for airborne radioactivity concentrations in 1959) assumed for ^{237}Np. Later analysis indicated that 29% of the alpha activity was attributable to ^{237}Np. There is no indication that respiratory protection was used during these activities. Urine samples that were collected and sent to ORNL for analysis tested positive for ^{237}Np (PACE/University of Utah 2000).

Operations Performed in Building C-710 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Uranium/neptunium recovery - 1952-1990 and 1956-1976
25,000,000 ppb 237Np
100,000 ppb 239Pu
Specific concentrations of 99Tc not available for this operation (solutions)
Moderate external radiation exposure potential.

2.4.12 Building C-720 – Maintenance Building

Building C-720 contained the compressor, converter, and machine shops. Machinists, maintenance mechanics, instrument mechanics, sheet metal workers, electricians, and inspection workers performed the following functions: disassembly of compressors, converter maintenance, disassembly of block valves, machining, fabrication, welding, and grinding. In addition, stores workers and janitors were assigned to the building. Supervisory offices were in the middle of the building.

The primary structure of interest from the standpoint of radiation safety was the compressor disassembly area. This was in a pit at one end of the building and was several stories high. Occasional releases of UF_6 occurred during compressor disassembly.

Compressors were transported from the process buildings to Building C-720. The compressors were disassembled into major components in pits, the parts were transported to Building C-400 for spray washing to remove uranium deposits, and the rotor and stator were relocated as required for deblading in Buildings C-400 and C-410, respectively. Reusable washed parts were returned to their respective maintenance buildings for modification, refurbishment, degreasing, and reassembly. Following washing in Building C-400, the converters were modified, refurbished, and reassembled in Building C-720. Prior to removal from the system, block valves were slightly opened (where possible), inspected, cut out of the system, lifted free of process piping, decontaminated, covers installed, and shipped to Building C-400 for preliminary disassembly and decontamination to the limits allowed in Building C-720. Once decontaminated, the valve was covered and transported to Building C-720 for final repair and reassembly, and staged in the process building for reinstallation.

Support operations involved the following exposure pathways:

- Cleaning of cylinder heels (potentially involving feed, product, or tails cylinders)
- Decontamination of equipment associated with feed, cascade, and other operations
- Routine and emergency maintenance operations at ancillary support facilities
- Uranium recovery from oils, cleaning solutions, and other wastes
- Effluent, sludge, and other wastes from decontamination processes
- Incineration of certain wastes
- Scrap from equipment
- Removal or drainage of sludge from waste ponds
- Analytical laboratory sampling

Operations Performed in Building C-720 and Maximum Radionuclide Concentrations Expected: (Bechtel Jacobs 2001).

Cascade maintenance -- 1954-1961 and 1973-1981 (CIP/CUP)
450 ppb 237Np
0.09 ppb 239Pu
Specific concentrations of 99Tc not available for this operation
High external radiation exposure potential.

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GLOSSARY

cascade

A series of compressor, heat exchanger, control valve and motor, converter stages, and supporting piping arranged in stages, cells, and units that progressively increase the concentration of ^{235}U isotope in the uranium hexafluoride (UF_6) feed. Enrichment occurs as UF_6 passes through semiporous barriers in the converter stage. These barriers allow the lighter ^{235}U molecules to pass through more easily, which results in a gas with a slightly higher percentage of ^{235}U (enriched) on one side of the barrier and a slightly lower percentage (depleted) gas on the other side. The enriched UF_6 gas flows toward the top of the cascade while the depleted UF_6 gas travels toward the bottom of the cascade.

contamination control program

A system of controls used to reduce and confine radioactive contamination. These systems include contamination surveys; posting; leak prevention, detection (surveillance), and timely repair; and use of containment devices.

derby

A molded uranium metal ingot made from UF_4 and magnesium.

dosimetry

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

enrichment

Process that occurs as UF_6 passes through barriers in converters allowing isotopes of lower molecular weight to pass through.

enriched uranium

Uranium that has a higher concentration of ^{235}U. A 2 to 4% enrichment is used in commercial power reactors. Greater than 20% enrichment is considered highly enriched uranium (HEU).

external radiation exposures

Exposure to a penetrating radiation source(s) that is external to the body.

fission products

Isotopes formed during fission of uranium or plutonium.

High Radiation Areas

Areas where the radiation dose rate could exceed 100 millirem in 1 hour at 30 centimeters from the radiation source.

inhalation class

The respiratory tract inhalation classification scheme developed in ICRP Report 30 for inhaled material according to its rate of clearance from the pulmonary region of the respiratory tract. Materials are classified as D (days), W (weeks), or Y (years), according to how fast they clear the lungs; Class D in less than 10 days; Class W in 10 to 100 days; Class Y in more than 100 days. Recent recommendations in ICRP Report 66 replaced classes D, W, and Y with lung absorption Types F (fast), M (moderate), and S (slow).

internal radiation exposures

Radiation exposure absorbed by the body resulting from radioactive material taken into the body.

liquefaction

The process of causing a gas or solid to become a liquid, usually by condensing the gas or melting the solid.

natural uranium

Uranium is a naturally occurring radioactive element consisting of three isotopes: ^{238}U (99.276%), ^{235}U (0.719%), and a trace amount of ^{234}U (0.0057%).

pigtail

A flexible connecting device.

spent reactor fuel

Reactor fuel that has been used in a reactor to the point that the amount of fissionable uranium (^{235}U) has been depleted.

transuranic (TRU) elements

Elements with an atomic number greater than uranium (92).

weekly plant action level

A radiation exposure value/airborne radioactivity value that, when reached by an individual, would result in some compensatory action being taken for that individual, such as reassigning the individual to a work detail involving no or reduced radiation exposure/airborne radioactivity.