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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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## PUBLICATION RECORD

| EFFECTIVE DATE | REVISION NUMBER | DESCRIPTION |
|---|---|---|
| 05/07/2004 | 00 | New technical basis document for the Paducah Gaseous Diffusion plant – Site Description. First approved issue. Initiated by Jay J. Maisler. |
| 08/21/2006 | 01 | This revision addresses comment #2 from the meeting with United Steelworkers Local 5-550 (formerly PACE) and SPFPA Local 111 held on 02/10/2005. Approved issue of Revision 01. 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 Paul A. Szalinski. |
| 05/08/2007 | 02 | Approved Revision 02 initiated to incorporate Attributions and Annotations section. No changes occurred as a result of formal internal review. Incorporates NIOSH formal review comments. Constitutes a total rewrite of the document. 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

| | |
|---|---|
| AEC | U.S. Atomic Energy Commission |
| CIP | Cascade Improvement Program |
| CUP | Cascade Upgrade Program |
| d | day |
| DOE | U.S. Department of Energy |
| EEOICPA | Energy Employees Occupational Illness Compensation Program Act |
| ft | foot |
| g | gram |
| HF | hydrofluoric acid |
| kg | kilogram |
| KOW | Kentucky Ordnance Works |
| L | liter |
| lb | pound |
| $MgF_2$ | magnesium fluoride |
| mg | milligram |
| mrem | millirem |
| ORNL | Oak Ridge National Laboratory |
| PEMU | Process Equipment Modification and Uprating Program |
| PGDP | Paducah Gaseous Diffusion Plant |
| POC | probability of causation |
| ppb | parts per billion |
| ppm | parts per million |
| RU | recycled uranium |
| TBD | technical basis document |
| TRU | transuranic |
| $UF_4$ | uranium tetrafluoride (“green salt”) |
| $UF_6$ | uranium hexafluoride |
| $UO_2$ | uranium dioxide |
| $UO_2F_2$ | uranyl fluoride |
| $UO_3$ | uranium trioxide (yellowcake) |
| $U_3O_8$ | triuranium octaoxide |
| U.S.C. | United States Code |

## 2.1 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.

### 2.1.1 Purpose

The purpose of the Paducah Gaseous Diffusion Plant (PGDP) 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% $^{235}U$ (Bechtel Jacobs 2000). The enriched product from PGDP was sent to other DOE gaseous diffusion plants at Portsmouth, Ohio, and Oak Ridge, Tennessee, for further enrichment [1].

### 2.1.2 Scope

This 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.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 2.5.

## 2.2 SITE DESCRIPTION

PGDP was built on a portion of 16,126 acres of farmland acquired by the U.S. War Department [the U.S. Department of Defense did not exist until 1947] during World War II. The War Department 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 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 KOW were acquired by the U.S. Atomic Energy Commission (AEC; a DOE predecessor agency) 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 3,424 acres, with about 750 acres inside the security fence. The rest of the land was transferred to the Tennessee Valley Authority 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).

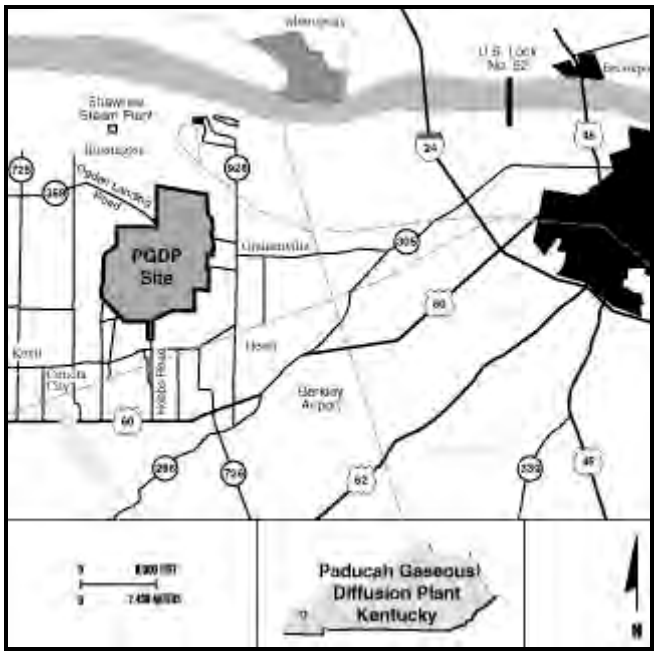

Figure 2-1. PGDP area map.

## 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

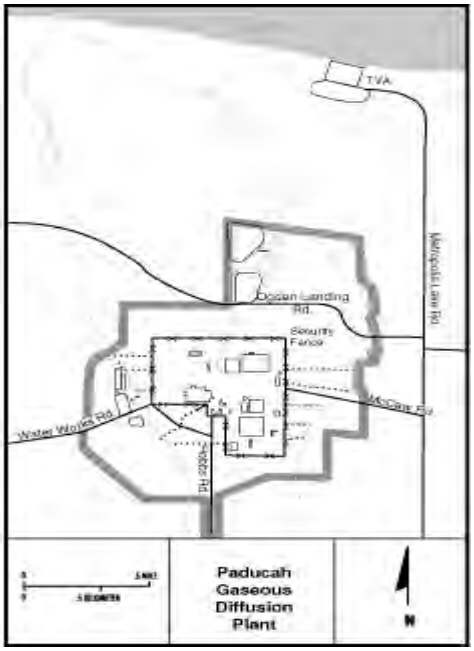

Figure 2-2. PGDP site map.

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 produced $UF_6$ from $UO_3$ from spent reactor fuel processed at the DOE 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 2000).

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 (Bechtel Jacobs 2000). Processing of $UO_3$ to $UF_6$ occurred in three steps: reduction, hydrofluorination, and fluorination. The uranium exposure pathway of greatest concern at PGDP was inhalation of uranium dust (Bechtel Jacobs 2000).

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 occurred 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 (Bechtel Jacobs 2000).

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 either was re-fed to the cascade or is stored on the site. Figure 2-3 shows the uranium enrichment process (Bechtel Jacobs 2000).

There were two cascade improvement/upgrade programs at PGDP – the Cascade Improvement Program (CIP) and the Cascade Upgrade Program (CUP). The first ran from 1958 to 1962 and the second from 1973 to 1981. These programs were significant because of possible worker exposure to transuranic (TRU) elements 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 (PACE/University of Utah 2000).

PGDP processed recycled uranium (RU) from initial startup in fiscal year 1953 through fiscal year 1989 (excluding fiscal years 1965 through 1968, 1976, and 1977 through 1985) [2]. In 1957, the

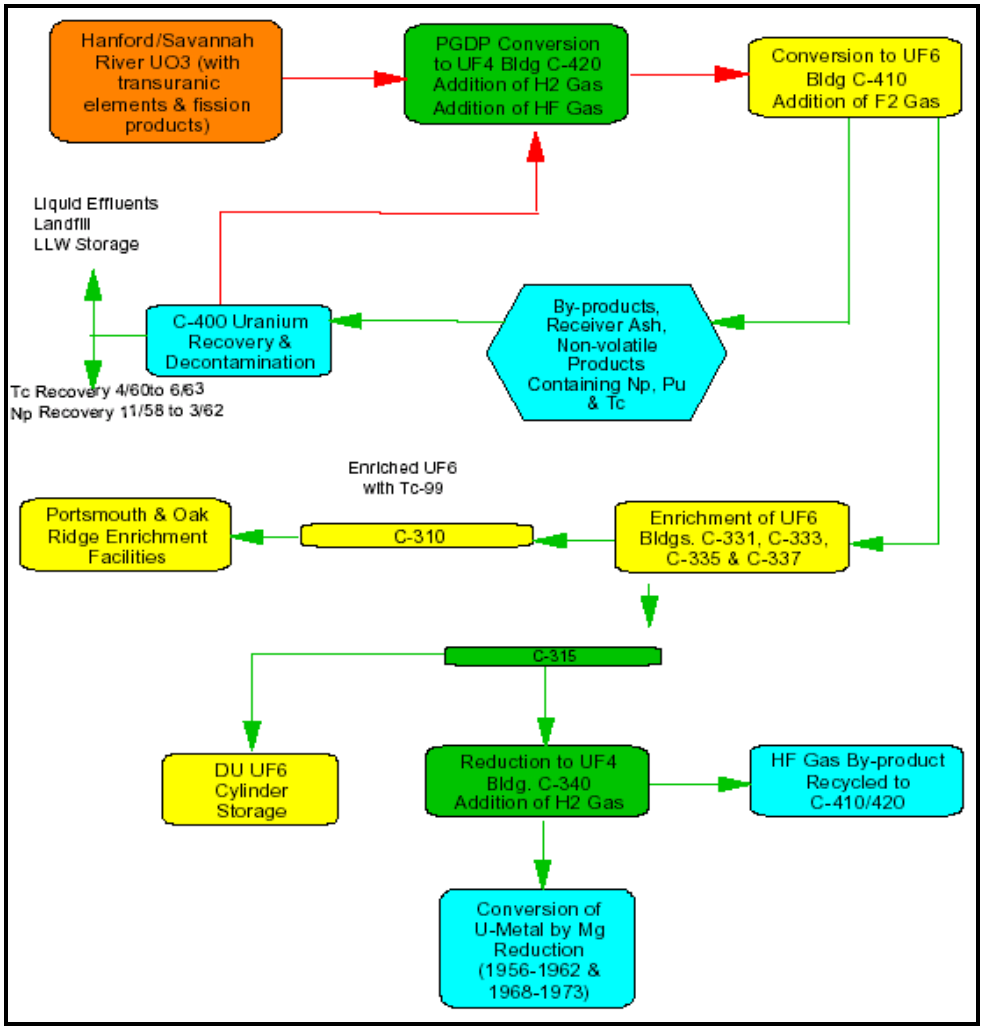


Figure 2-3. PGDP uranium enrichment process (Lockheed Martin 1997a).

presence of $^{237}$Np and $^{99}$Tc was documented; between 1959 and 1966, PGDP and the AEC conducted studies related to the behavior, health effects, and controls for these radionuclides (Bechtel Jacobs 2000). The concentration of TRU elements, such as $^{237}$Np and $^{239}$Pu, and fission products, and $^{99}$Tc, in the reactor tails material was small, estimated at approximately 0.2 ppm neptunium, 4 ppb $^{239}$Pu, and 7 ppm $^{99}$Tc (Bechtel Jacobs 2000). In addition, $^{241}$Am, a decay product of $^{241}$Pu, builds up as $^{241}$Pu decays. These radionuclides were concentrated during processing at specific locations, which could increase radiation exposure to certain workers in these areas (Bechtel Jacobs 2000). Table 2-1 lists assessments of activities that are assumed to have probably involved potential worker exposure to RU constituents. In some cases, concentrations for $^{99}$Tc were not provided in the source reference (Bechtel Jacobs 2000) and are listed as “XX” (Bechtel Jacobs 2000).

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 C-420) with operators and mechanics receiving the highest doses, respectively; the 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

Table 2-1. Buildings and potential exposures to recycled uranium.[a]

| Location | Activity | Time Period | Maximum radionuclide concentrations expected | Radiological risk |
|---|---|---|---|---|
| C-333<br>C-337<br>C-410 | **Cascade operations–**Operators could have been exposed to gaseous $UF_6$ when connecting or disconnecting feed cylinders containing recycled uranium. | 1953–1964<br>1969–1970<br>1972–1976 | 450 ppb Np<br>0.09 ppb Pu<br>23,000 Tc-99<br>($UF_6$) | 2<br>Moderate |
| C-331<br>C-333<br>C-335<br>C-337<br>C-400<br>C-409<br>C-720 | **Cascade maintenance–**Maintenance workers could have been exposed to constituents of interest when working on or removing interior surfaces of cascade equipment near recycled uranium feed points (cascade dust). | 1954–1961<br>1973–1981<br>(CIP/CUP) | 2740 ppb Pu<br>3,220,000 ppb Np<br>XX Tc-99<br>(cascade dust) | 3<br>High |
| C-410<br>C-420 | **Feed plant operations, RU to $UF_6$–**<br>$UO_3 \rightarrow UO_2$ $UF_4$ UF<br>(handling, drumming, bag changing, etc.) (tower ash) | 1953–1964<br>1969–1977<br>1982–1983<br>(shipped) | 25,602 ppb Np<br>8,000 ppb Pu<br>4,600 ppb Tc-99<br>(tower ash) | 3<br>High |
| C-400<br>C-710 | **Uranium/neptunium recovery–**Workers salvage uranium from cleaning solutions and waste products (cylinder wash, ash, dust). Aqueous solutions containing >2 mg/L Np were reprocessed, <2 mg/L were discarded. | 1958 to late 1970's | 25,000,000 ppb Np<br>100,000 ppb Pu<br>XX ppb Tc-99<br>(solutions) | 2<br>Moderate |
| C-340 | **Production and handling of $UF_4$ produced from tails–**<br>$UF_6$, $UF_6 \rightarrow UF_4$ | 1957–1962<br>1967–1977 | 62.6 ppb Np<br>0.063 ppb Pu<br>49 ppb Tc-99<br>($UF_4$) | 1<br>Low |
| C-405 | **Handling ash from contaminated items–**Incinerator (filter bags, etc.) | 1953–1990 | 3,512 ppb Np<br>56 ppb Pu<br>921 ppb Tc-99<br>(ash) | 3<br>High |
| C-315<br>C-340 | **Connecting and disconnecting $UF_6$ tails cylinders and handling $UF_6$ tails** | 1953–1999 | 5 ppb Np<br>0.1 ppb Pu<br>20,000 ppb Tc-99<br>($UF_6$) | 1<br>Low |
| C-310 | **Connecting and disconnecting $UF_6$ product cylinders and handling $UF_6$ product** | 1953–1999 | 27 ppb Np<br>0.06 ppb Pu<br>20,000 ppb Tc-99<br>($UF_6$) | 1<br>Low |
| C-410<br>C-310 | **Changing/cleaning $MgF_2$ traps** | 1964–1966 | 1,900 ppb Np<br>0.01 ppb Pu<br>2,266,000 ppb Tc-99<br>($MgF_2$) | 2<br>Moderate |
| C-340 | **Uranium metal production from metal production, sawing, and metal handling** | 1957–1962<br>1967–1977 | 2.7 ppb Np<br>0.0085 ppb Pu<br>10.6 ppb Tc-99<br>(U metal) | 1<br>Low |
| C-340 | **Handling $MgF_2$ in uranium metal manufacturing–**<br>Cleaning, roasting, liner preparation, knock out, and drumming. | 1957–1962<br>1968–1977 | 2,400 ppb Np<br>1.2 ppb Pu<br>1,880 ppb Tc-99<br>($MgF_2$) | 3<br>High |

a. Source: Bechtel Jacobs (2000, Table 2.4-1)

Buildings C-340 and C-720 had a potential for increased external radiation exposures. Table 2-2 lists average doses per department (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 PGDP kept workers below the annual regulatory limits by rotation of duties and limitations on stay time in areas of higher exposure (PACE/University of Utah 2000). Table 2-2 lists the average external cumulative penetrating dose (deep dose equivalent) and number of workers

Table 2-2. Average external cumulative penetrating dose (deep dose equivalent) and number of workers assigned to each department, 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 | Mechanical 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 |

assigned to each department, 1953–1988 (PACE/University of Utah 2000), while Table 2-3 lists average and maximum doses (PACE/University of Utah 2000).

Table 2-3. 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)[a] | 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 |
| 1985 | 6.1 | 350 | 1,365 |
| 1986 | 9.6 | 490 | 1,244 |
| 1987 | 8.0 | 470 | 1,275 |
| 1988 | 6.5 | 720 | 1,359 |

a. 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 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 had lower potential for worker radiation exposure. In addition, due to the lack of aggressive contamination control programs, contamination from the operations discussed 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 (PACE/University of Utah 2000).

**Special Incidences or Activities – High Potential for Increased Radiation Exposure (PACE/University of Utah 2000)**

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
Cascade Improvement Program, 1973–1981
C-400 neptunium production

## 2.4 SITE PROCESSES

### 2.4.1 Key Uranium Processing Facilities

The major facilities at PGDP are:

- C-300 – Central Control Building
- C-310 – Purge and Product Withdrawal Building
- C-315 – Surge and Tails Withdrawal Building
- C-331, C-333, C-335, and C-337 – Gaseous Diffusion Process Buildings
- C-340 – Metals Plant (currently inactive)
- C-400 – Decontamination and Cleaning Building
- C-410/C-420 – $UF_6$ Feed Plant (currently inactive)

This section includes other key facilities where moderate personnel radiation exposure occurred (e.g., C-404, C-409, C-710, and C-720). Table 2-4 lists the processes and facilities involving potential worker exposures (Bechtel Jacobs 2000).

Table 2-4. Processes and facilities involving potential worker exposure.

| Process | Facilities | Time Period | Potential RU exposure | Notes |
|---|---|---|---|---|
| Unpacking, feeding of $UO_3$ to feed production, reduction of $UO_3$ to $UO_2$, hydrofluorination to $UF_4$. | C-420 | 1953 – 1964<br>1969 – 1977 | RU constituents of concern not concentrated at this point in process. | |
| Flame tower fluorination of $UF_4$ to $UF_6$, including generation of ash and filter residue. | C-410,<br>C-420 | 1953 – 1964<br>1968 – 1977 | Pu and Np and some Tc-99 were concentrated in ash and residue. | |
| Venting to atmosphere from flame tower fluorination. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Venting did not involve concentrated RU. | Filters were potential point for concentration. |
| Collection of ash for U recovery and cleaning of tower filters. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Pu and Np and some Tc-99 were concentrated in ash and residue. | Potential for worker exposure to concentrated RU constituents. |
| Pulverization of tower ash and other recovery processes. | C-410,<br>C-420 | 1953 – 1964<br>1968 – 1976 | Pu and Np and some Tc-99 were concentrated in ash and residue. | Potential for worker exposure to concentrated RU constituents. |
| Recycling of U in ash through fluorination. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Pu and Np and some Tc-99 were concentrated in ash and residue. | Potential for worker exposure to concentrated RU constituents. |
| Packing of waste ash for storage prior to shipping. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Pu and Np and some Tc-99 were concentrated in ash and residue. | Potential for worker exposure to concentrated RU constituents. |
| Transfer of $UF_6$ to cylinder from fluorination process. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Pu and Np and some Tc-99 became further concentrated in cylinder heels. | |
| Withdrawing $UF_6$ from cylinder and feeding into cascade. | Cascade feed points | 1953 – 1964<br>1969 – 1970<br>1972 - 1976 | Pu and Np and some Tc-99 were concentrated in cylinder heels. Np and smaller amounts of Pu exiting cylinder with $UF_6$ collected at feeder head leading to cascade and in cascade near feed point. | |
| Venting to atmosphere from cascade. | Cascade purge locations;<br>C-331,<br>C-333,<br>C-335,<br>C-337,<br>C-310 | 1952 - 1985 | As RU moved higher in cascade, Tc-99 became concentrated, but Pu and Np were much diminished. Venting at higher points in cascade involved concentrated Tc-99. | Traps were used to remove Tc-99 before venting. |
| CIP/CUP equipment removal and other equipment removal, maintenance, and decontamination. | Cascade buildings<br>C-270 Scrap Yard Burial Grounds | 1954 - 1962<br>1973 - 1981 | Np and lesser amounts of Pu collected near cascade feed points. | Removal, handling, and decontamination of equipment near feed points could have exposed workers to concentrations of small percentages of Np and Pu that actually entered cascade. |

| Process | Facilities | Time Period | Potential RU exposure | Notes |
|---|---|---|---|---|
| Unpacking, feeding of $UO_3$ to feed production, reduction of $UO_3$ to $UO_2$, hydrofluorination to $UF_4$. | C-420 | 1953 – 1964<br>1969 – 1977 | RU constituents of concern not concentrated at this point in process. | |
| Flame tower fluorination of $UF_4$ to $UF_6$, including generation of ash and filter residue. | C-410,<br>C-420 | 1953 – 1964<br>1968 – 1977 | Pu and Np and some Tc-99 were concentrated in ash and residue. | |
| Venting to atmosphere from flame tower fluorination. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Venting did not involve concentrated RU. | Filters were potential point for concentration. |
| Collection of ash for U recovery and cleaning of tower filters. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Pu and Np and some Tc-99 were concentrated in ash and residue. | Potential for worker exposure to concentrated RU constituents. |
| Pulverization of tower ash and other recovery processes. | C-410,<br>C-420 | 1953 – 1964<br>1968 – 1976 | Pu and Np and some Tc-99 were concentrated in ash and residue. | Potential for worker exposure to concentrated RU constituents. |
| Recycling of U in ash through fluorination. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Pu and Np and some Tc-99 were concentrated in ash and residue. | Potential for worker exposure to concentrated RU constituents. |
| Packing of waste ash for storage prior to shipping. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Pu and Np and some Tc-99 were concentrated in ash and residue. | Potential for worker exposure to concentrated RU constituents. |
| Transfer of $UF_6$ to cylinder from fluorination process. | C-410,<br>C-420 | 1953 – 1964<br>1969 – 1977 | Pu and Np and some Tc-99 became further concentrated in cylinder heels. | |
| Withdrawing $UF_6$ from cylinder and feeding into cascade. | Cascade feed points. | 1953 – 1964<br>1969 – 1970<br>1972 - 1976 | Pu and Np and some Tc-99 were concentrated in cylinder heels. Np and smaller amounts of Pu exiting cylinder with $UF_6$ collected at feeder head leading to cascade and in cascade near feed point. | |
| Venting to atmosphere from cascade. | Cascade purge locations;<br>C-331,<br>C-333,<br>C-335,<br>C-337,<br>C-310 | 1952 - 1985 | As RU moved higher in cascade, Tc-99 became concentrated, but Pu and Np were much diminished. Venting at higher points in cascade involved concentrated Tc-99. | Traps were used to remove Tc-99 before venting. |
| CIP/CUP equipment removal and other equipment removal, maintenance, and decontamination. | Cascade buildings<br>C-270 Scrap Yard Burial Grounds. | 1954 - 1962<br>1973 - 1981 | Np and lesser amounts of Pu collected near cascade feed points. | Removal, handling, and decontamination of equipment near feed points could have exposed workers to concentrations of small percentages of Np and Pu that actually entered cascade. |

NOTE: A complete list of radionuclides, quantities, chemical compounds, and inhalation class is not provided for every PGDP process and building listed above. ORAUT (2005a) 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 ft by 30 ft 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 (PACE/University of Utah 2000).

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 (Bechtel Jacobs 2000).

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 d 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 (Bechtel Jacobs 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. 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) (PACE/University of Utah 2000).

**Operations Performed in Building C-310 and Maximum Radionuclide Concentrations Expected (Bechtel Jacobs 2000):**

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 $MgF_2$ traps – 1964–1966
1,900 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 ft by 30 ft in area and contained four cart tracks and product equipment to accommodate four 10- to 14-ton cylinders. Four roll-up doors in the east wall permitted 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 (PACE/University of Utah 2000).

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 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 2000):**

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 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 encompass 74 acres under roof. Each process building has 1,812 enrichment stages (Bechtel Jacobs 2000).

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 and July 1954, Buildings C-335 and C-337, respectively, began operations (Bechtel Jacobs 2000).

**Operations Performed in the Cascade Buildings and Maximum Radionuclide Concentrations Expected (Bechtel Jacobs 2000):**

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)
2,740 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 (PACE/University of Utah 2000).

Metals production involved several steps, each with its own hazards (Bechtel Jacobs 2000):

- 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 on 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. 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 ORAUT 2005b).

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 2000):**

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 $UF_6$ tails – 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 occurred there: converter disassembly, pulverization of waste $UF_4$ and recycled $UO_3$ containing TRU elements, 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 2000).

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 2000).

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 (Bechtel Jacobs 2000).

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, that cell was turned over to process maintenance for opening and disassembly (Bechtel Jacobs 2000).

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 (Bechtel Jacobs 2000).

**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 Oak Ridge National Laboratory (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 washwater 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 2000).

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 2000).

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 washwater and raffinate (e.g., solvents) from $^{237}$Np recovery operations began in April 1960 (Bechtel Jacobs 2000).

**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 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 2000).

**Cylinder Cleaning**
With repeated reuse, $UF_6$ cylinders collected deposits that did not completely volatilize in the autoclave. These deposits, called *cylinder heels*, had to be dissolved and removed periodically, 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 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 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 2000).

**Operations Performed in Building C-400 and Maximum Radionuclide Concentrations Expected (Bechtel Jacobs 2000):**

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 – 1958 to the late 1970s
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 Building 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 ft by 140 ft, with 6-ft-high dikes. In 1957, the C-404 Holding Pond was converted to a solid radioactive waste burial area. By 1977, approximately 6,400,000 lb 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, requiring closure under the Resource Conservation and Recovery Act in 1987 (Bechtel Jacobs 2000).

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 (Bechtel Jacobs 2000).

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 was used in the initial stages of tearing down converters. The waste from this booth was piped to Building C-400 for removal of uranium oxides. It is not clear, but apparently the Building C-409 spray booth was operated by Building C-400 personnel (Pace/University of Utah 2000).

**Operations Performed in Building C-409 and Maximum Radionuclide Concentrations Expected (Bechtel Jacobs 2000):**

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 (Bechtel Jacobs 2000).

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 of the towers. The external radiological concerns were from beta and gamma emissions from TRU elements, fission products, and accumulated uranium daughter products, which were concentrated by the process in the ash. In addition to external radiation sources, inhalation of radioactive dust while cleaning plugged equipment, changing the ash receivers, and cleaning 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 uranyl fluoride $UO_2F_2$ (PACE/University of Utah 2000).

Exposure to uranium powder dusts was prevalent in operations and maintenance activities. For example, the 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 (Bechtel Jacobs 2000).

**Operations Performed in Building C-410 and Maximum Radionuclide Concentrations Expected (Bechtel Jacobs 2000):**

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, 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 $MgF_2$ 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 used in the conversion processes. This was where triuranium octaoxide ($U_3O_8$) 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 ran through two sets of fluidized beds, the first of which converted $UO_3$ (yellowcake) 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 (Pace/University of Utah 2000).

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 operators and maintenance mechanics would open the system and the operators and maintenance mechanics did what was necessary to resume operations. Routine operations in Building C-420 do not appear to have had the potential for increased radiation exposure; however, workers in this building were rotated with those in Building C-410 to reduce individual radiation exposure (Pace/University of Utah 2000).

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 2000):**

Feed plant operations, RU to $UF_6$ - $UO_3 \rightarrow UO_2$ $UF_4$ UF (handling, drumming, bag changing, etc. (tower ash) - 1953–1964, 1969–1977, and 1982–1983
25,602 ppb $^{237}Np$
8,000 ppb $^{239}Pu$
4,600 ppb $^{99}Tc$
High external radiation exposure potential

### 2.4.11 Building C-710 – Analytical Laboratories

The PGDP analytical laboratories are in Building C-710. These facilities, which have been in operation since plant startup, consist of the American Society of Testing and Materials, 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 (Bechtel Jacobs 2000).

The $^{99}Tc$ recovery operation, initially in Building C-710, moved to Building C-400 after 1959 (Pace/University of Utah 2000).

A $^{237}Np$ recovery process originally in Building C-710, Room 32, transferred to Building C-400 sometime after July 1959 (see Section 2.4.6). After processing in Building C-400, the concentrate went 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 Building C-710 loading dock and shipped to ORNL (Bechtel Jacobs 2000).

A Health Physics and Hygiene report (Paducah 1959) 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, a term used for airborne radioactivity concentrations 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 2000):**

Uranium/neptunium recovery - 1958 to late 1970's
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

### 2.4.12 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 (Pace/University of Utah 2000).

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 (Pace/University of Utah 2000).

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, and, after covers were installed, 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 (Bechtel Jacobs 2000).

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 2000):**

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

## 2.5 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this document, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in the process of worker dose reconstruction. These callouts are listed here in the Attributions and Annotations section, with information to identify the source and justification for each associated item. Conventional References, which are provided in the next section of this document, link data, quotations, and other information to documents available for review on the Project's Site Research Database.

[1] Turpin, Baynard. Integrated Environmental Management. Consultant. PGDP was designed to enrich uranium to 2.5% $^{235}U$ which is used for commercial purposes. Higher enrichments are needed for military uses. The higher enrichment produces a higher specific activity and more dose per unit mass.

[2] Turpin, Baynard. Integrated Environmental Management. Consultant. Paraphrased dates found in Table 2.4-1 of (Bechtel Jacobs 2000), Assessment of Activities at Paducah where workers were most likely to come into contact with Recycled Uranium as a means to introduce the Table in the Technical Basis Document.

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Paducah, 1959. *Quarterly Report – January, February, March, 1959, Health Physics and Hygiene Report*, Author not given, SRDB No. 18755.

## GLOSSARY

**absorption type**
Categories for materials according to their speed of absorption in the body, which replaced the earlier inhalation clearance classes. Defined by the International Commission on Radiological Protection, the absorption types are F for fast absorption (formerly inhalation class D), M for moderate absorption (formerly inhalation class W), and S for slow absorption (formerly inhalation class Y). Also called solubility type. See *inhalation class*.

**cascade**
At PGDP, 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 $^{235}U$ in a 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) 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**
System of controls to reduce and confine radioactive contamination. These systems include contamination surveys, posting, containment devices, and the prevention, detection, and timely repair of leaks.

**depleted tails**
Material that has passed through one of the cascade stages that has been depleted of some of its $^{235}U$.

**derby**
At PGDP, molded uranium metal ingot of $UF_4$ and magnesium.

**dosimetry**
Measurement and calculation of internal and external radiation doses.

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

**external radiation**
Radiation from sources outside the body.

**feed material**
At PGDP, $UF_6$ used in the cascade systems for the enrichment process.

**fission product**
Radionuclide produced by fission or by the subsequent radioactive decay of radionuclides.

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

**High Radiation Area**

Area with dose rates greater than 100 millirem (1 millisievert) in 1 hour at 30 centimeters from the source or its container. HRAs require posted signs and strict access control.

**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 (ICRP 1979). 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. More recent recommendations in ICRP Report 66 replaced classes D, W, and Y with lung absorption Types F (fast), M (moderate), and S (slow), respectively (ICRP 1994).

**internal radiation exposures**

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

**liquefaction**

Process of causing a gas or solid to become a liquid, usually through condensing a gas or melting a solid.

**natural uranium**

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

**pigtail**

At PGDP, a flexible connecting device for draining depleted liquefied $UF_6$ gas into storage cylinders.

**production reactor tails**

At PGDP, uranium reprocessed from spent reactor fuel used in a plutonium production reactor (e.g., at the Hanford and Savannah River Sites).

**reactor tails**

At PGDP, uranium reprocessed from spent reactor fuel, normally from production reactors, but some from reactors in foreign countries.

**reactor vessel**

At PGDP, hollow receptacle in which a chemical reaction takes place.

**refractory cap**

At PGDP, cover of highly heat-resistant material underneath the reactor vessel lid.

**roasting**

At PGDP, process of heating derbies to remove all the slag produced during the reduction process (heating $UF_4$ and magnesium to form uranium derbies).

**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 atomic numbers above 92 (uranium). Examples include plutonium and americium. All isotopes of the transuranic elements are radioactive, they are naturally either rare or nonexistent on Earth, and most are known only as a result of research using nuclear reactors and particle accelerators because of extremely short half-lives.

**weekly plant action level**

At PGDP, radiation exposure or 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 or airborne radioactivity.