ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document for Portsmouth Gaseous Diffusion Plant – Site Description	Document Number: ORAUT-TKBS-0015-2 Effective Date: 11/21/2003 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 33
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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
Ci	curie
cpm	counts per minute
DAC	Derived Air Concentration
DOE	United States Department of Energy
DU	depleted uranium (uranium with less than 0.7% ^{235}U)
ERP	Extended Range Product
FGR	Federal Guidance Report
FY	Fiscal Year
GDP	Gaseous Diffusion Plant
HASA	High Assay Sampling Area
HEU	highly enriched uranium (over 20% ^{235}U)
LAW	Low Assay Withdrawal
MTU	metric tons of uranium
MeV	Million electron volts
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyl
PORTS	Portsmouth Gaseous Diffusion Plant
PPE	personal protective equipment
RPM	Radiation Protection Manual
RU	recycled uranium
TPW	Top Product Withdrawal
TRU	transuranic (elements with an atomic number greater than uranium i.e., <92)
UF_6	uranium hexafluoride
UF_4	uranium tetrafluoride
U.S. DOE	United States Department of Energy
USEC	United States Enrichment Corporation
U.S.C.	United States Code

2.1 INTRODUCTION

This part of the Portsmouth Gaseous Diffusion Plant (PORTS) technical basis document describes the site (Section 2.2), the site facilities (Section 2.3), and historic site processes (Section 2.4).

2.2 SITE DESCRIPTION

PORTS is in Pike County, Ohio, approximately 112 kilometers (70 miles) south of Columbus, Ohio. The federal reservation covers approximately 3,714 acres and contains 109 buildings and individual plants with approximately 500 acres of roofed area.

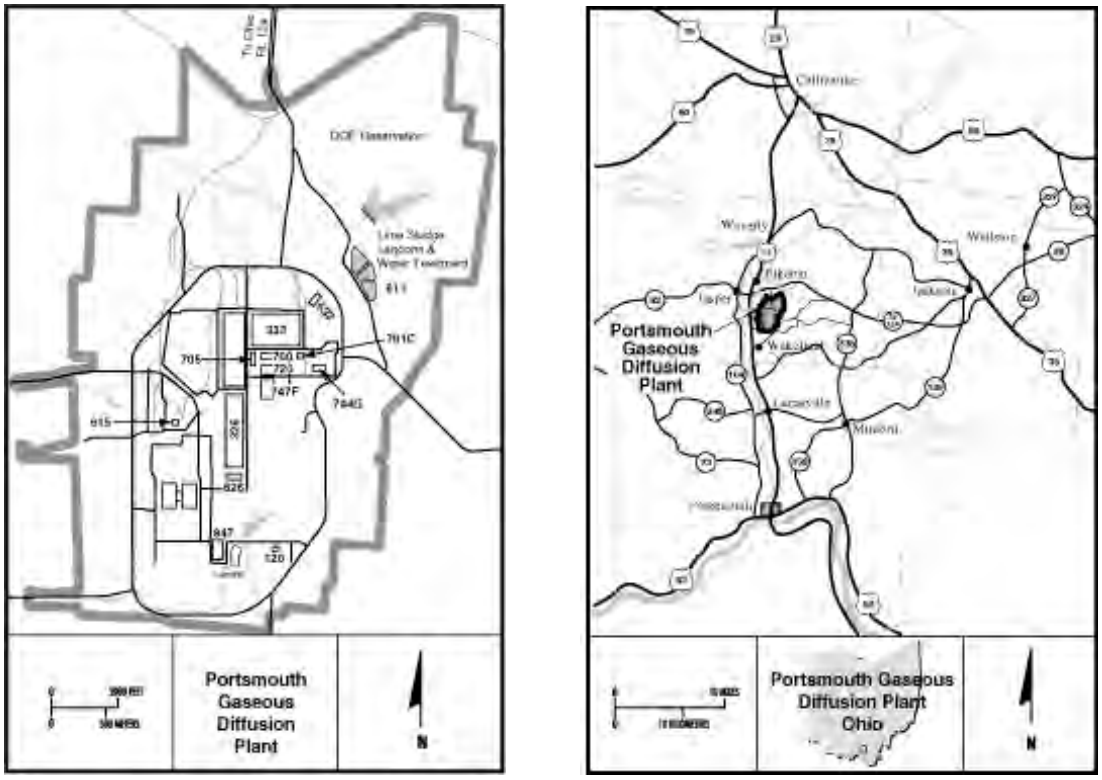

Figure 2.2-1. Portsmouth Gaseous Diffusion Plant

Uranium enrichment was the primary activity at PORTS. Uranium is a naturally occurring radioactive element that consists of three isotopes: ^{238}U (99.276%), ^{235}U (0.719%), and a trace amount of ^{234}U (0.0057%) (DOE 1997, p. 20). The enrichment process increases the concentration of ^{235}U which is needed to manufacture low enriched (less than 20% ^{235}U) nuclear fuel necessary for commercial nuclear power plants and highly enriched (more than 20% ^{235}U) material for the U.S. Navy propulsion program and atomic weapons. In 1952, construction began on the gaseous diffusion plant in Piketon, Ohio, which later became known as the Portsmouth Gaseous Diffusion Plant. Uranium enrichment began in 1954 and continued until May 2001 when operations were consolidated at the Paducah plant (USEC 2003).

The historical records indicate that the plant enriched uranium for government programs and commercial nuclear power plants at levels ranging from a few to up to 97 percent ^{235}U. In 1991, production of the highly enriched uranium (HEU) stopped and the plant mission changed to uranium enrichment for commercial reactors. From its initial construction until 1986, the site was operated by Goodyear Atomic Corporation. In 1986 Martin Marietta Energy Systems, Inc. took over operation of

the facility after Goodyear decided not take part in the rebid. The Energy Policy Act of 1992 (Public Law 102-486) transferred responsibility for Portsmouth from the U.S. Department of Energy (DOE) to a newly created entity, the United States Enrichment Corporation (USEC), which has leased and operated the facility since July 1, 1993 (USEC 2003).

There are four main facilities at PORTS: the Feed Manufacturing Plant, Oxide Conversion Facility, Cascades, and Decontamination and Recovery Facility. The feed plant, oxide conversion facility, and uranium recovery operation all support the enrichment cascade. Between 1955 and 2001, PORTS processed over 300,000 metric tons of uranium (MTU) through its cascade (DOE, 2000a, p. 16).

Figure 2.2-2. Photograph of PORTS from about 1988.

2.3 SITE ACTIVITIES

Plant Facilities

Table 2.3-1 shows the major facilities at PORTS. Each of these areas was critical to the operation of the plant.

2.3.1 Gaseous Diffusion Cells – Buildings X-326, X-330, and X-333

The main process buildings at PORTS (X-326, X-330, and X-333) contain the cascades, which are 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 the ^{235}U isotope in the uranium hexafluoride (UF_6) feed.

Enrichment occurs as the UF_6 passes through semi-porous barriers in the converter stage. These barriers allow the lighter ^{235}U 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 up towards the top of the cascade while the depleted UF_6 gas flows toward the bottom.

An individual converter stage enriches the UF_6 gas stream approximately 0.0043%. The PORTS cascade consists of 4,080 stages in the three process buildings. The facility was able to enrich uranium to nearly 100% ^{235}U.

2.3.1.1 Building X-333

The initial enrichment process occurred in Building X-333. It is equipped with 80 enrichment cells, each of which has eight isotopic stages, for a total of 640 stages. All cells contain the largest-size converter in the system (designated X-33 or 000). As with all the cascade buildings, the enrichment stages are installed on the second floor with the auxiliary systems and control rooms on the ground floor. The two floors provide approximately 65 acres of floor space. Reactor-grade material can be drawn off through the Low Assay Withdrawal (LAW) station in the west-central section of the building (DOE 2000a, p. 17). Table 2.3.1-1 shows the radionuclides of concern associated with Building X-333.

X-333 Internal Dose Issues: Most uptakes of uranium indicate a fast absorption type unless otherwise identified in the bioassay records. Because the concentration of both the ^{235}U and ^{234}U are increased by the enrichment process, and the ^{234}U has a shorter half-life than the ^{235}U, most of the annual internal dose will be from ^{234}U.

X-333 External Dose Issues: There is a potential for exposure to technetium-99 (^{99}Tc) when conducting maintenance of cascades due to plating out within the system. Because X-333 is used as a back-up to the X-330 tails facility, depleted uranium (DU) may concentrate in this facility (see Section 2.3.1.2) (High and Strom 1993, p. 16.6). The secular equilibrium pair $^{234}Th/^{234m}Pa$ is an external skin dose hazard if no personal protective equipment (PPE; e.g., gloves, coveralls, or full face respirators) is used. A 2,000 cpm limit to the skin amounting to about 20 mrem of skin exposure was used as a screening action limit (HP-103, p1-RPM).

2.3.1.2 Building X-330

The X-330 process building carried out the intermediate stages of the enrichment process. It is equipped with 1,100 stages. Five hundred stages (50 cells) have the X-31 or 00-size equipment, six hundred stages (60 cells) are equipped with X-29 or 0-size converters. The two floors provide a total of 55 acres of floor space. The original tails withdrawal station is in the northeast corner of the building. It has been modified to allow the withdrawal of product as well as tails (DOE 2000a, p. 18). Table 2.3.1-2 identifies the radionuclides of concern for Building X-330.

X-330 Internal Dose Issues: Most uptakes of uranium indicate a fast absorption type unless otherwise indicated in the bioassay records. Most of the annual internal dose will be from ^{234}U.

X-330 External Dose Issues: There is a potential for exposure to ^{99}Tc during maintenance of cascades due to plating out within the system. Due to the tails or DU concentrating in this facility the $^{234}Th/^{234m}Pa$ secular equilibrium pair fed by ^{238}U could be an external dose issue. That pair is an external skin dose hazard if no PPE is used. A 2,000-cpm limit to the skin amounting to about 20 mrem of skin exposure was used as a screening action limit (HP-103, p. 1-RPM).

2.3.1.3 Building X-326

The PORTS cascade is able to enrich uranium to more than 97 percent ^{235}U. The X-326 building is the final and highest stage enrichment cascade. The building is equipped with 2,340 stages, 720 stages (60 cells) with X-27 size equipment and 1,620 stages, including the purge stages, with X-25 size equipment. The two floors have a total of 58 acres of floor space. A withdrawal station is in the southwest corner of the ground floor, it is designed to withdraw the highly enriched uranium (HEU) product (BJC 2000, p. 20).

The purge facilities are in the south end of the X-326 building. They were used to vent light contaminants in the UF_6 stream before the flow entered the high assay enrichment equipment. The purge systems vented entrapped air, Freon, and such lightweight isotopes as ^{99}Tc from the UF_6 stream. Because of its low atomic weight and relative volatility, technetium tends to concentrate at the top of the gaseous diffusion cascade, where it becomes an inhalation, ingestion, and effluent concern when the cascade is vented or opened for maintenance. Technetium as pertechnetate (TcO_4) is also difficult to remove from skin and can therefore cause significant skin dose from contamination. Detection and classification of Technetium exposure is difficult because its low energy beta (Max. 0.293 MeV) is often masked by the higher energy (Max. 2.29 MeV) beta from ^{234m}Pa (DOE 2000c, p. 2-16).

Facilities in Building X-326 include the Extended Range Product (ERP) Station, the High Assay Sampling Area (HASA), the Top Product Withdrawal (TPW) Station, mobile side withdrawals, side feeds, and light gas purge stages. Radiochemicals including UF_6, U_3O_8, and uranyl fluoride (UO_2F_2) are likely (High and Strom 1993, p14.7). In addition, contaminated waste is currently stored in the X-326 L Cages under special security requirements. Table 2.3.1-3 identifies the radionuclides of concern in Building X-326.

X-326 Internal Dose Issues: As in the other cascade buildings, most uptakes of uranium indicate a fast absorption type unless otherwise documented in the bioassay records. Most of the annual internal dose will be from ^{234}U. In addition, Table 2.3.1-3 shows time and sources for processing of HEU. Intake of ^{99}Tc should be considered during maintenance of cascades due to plating out within the system or in the maintenance of the purge equipment. ^{99}Tc was a significant environmental release radionuclide from 1975 to 1994.

X-326 External Dose Issues: Consider exposure to ^{99}Tc from maintenance of cascades due to plating out within the system. During times of processing HEU, neutron radiation may have been present in higher than average amounts due to the alpha–neutron reaction on fluorine, (75 mrem yr^{-1} (Cardarelli 1997; CDC, p. 8).

In general, all the process building work areas were physically hot, but normally clean and uncontaminated, except when equipment was opened for repair, maintenance, or modifications. Multiple small “puff” or “jet” releases of UF_6 occurred during connection and disconnection of feed and

product storage cylinders or from broken instrument lines or connection piping. In general, PPE was used only for specific maintenance activities and not during the connection or disconnection of cylinders. The majority of contamination and personnel exposure to UF_6 and hydrogen fluoride (HF) gas in the process buildings occurred during cylinder moves (DOE 2000a, p. 18).

2.3.2 Fluorine Generation Facility and Fixed Feed Facility – Building X-342 & X-342A

The X-342 facility contains equipment to vaporize and sample UF_6 before feeding it to the cascades and to generate pure fluorine gas (F_2) for the uranium recovery operations. Fluorine is generated by the electrolytic conversion of hydrogen fluoride, which also produces sodium fluoride, lithium fluoride, and potassium fluoride as waste products. While chemically hazardous, the fluorine generation operation presented little or no radiological hazard to the workers. Table 2.3.2-1 identifies the radionuclides of concern for Building X-342 and the Fixed Feed Facility in Building X-342A.

X-342 & X-342A Internal Dose Issues: Vaporization of UF_6 from transport cylinders would allow for the uptake of uranium as a fast absorption type unless otherwise documented in the bioassay records. Most of the annual internal dose will be from ^{234}U. In addition, Table 2.3.2-1 shows time and sources for processing of feed materials.

X-342 & X-342A External Dose Issues: Ambient gamma, beta, and neutron radiation may be of concern in this area.

2.3.3 Fixed Feed Facility – Building X-343

At first, UF_6 feed and product material could be input or withdrawn from the cascades at virtually any point. Later, fixed feed facilities were installed in X-342A and X-343 using autoclaves to heat the cylinders and feed UF_6 gas into the cascade. The mobile input and withdraw facilities have not been used since 1991. Contamination and exposure in the fixed feed facility was more chemical than radiological in nature and occurred during cylinder connection and disconnections. Table 2.3.3-1 shows the radionuclides of concern in Building X-343, and Table 2.3.2-1 shows the radionuclides of concern in Building X-342A and X-342.

X-343 Internal Dose Issues: As in X-342 uranium uptake should be considered as a fast absorption issue unless otherwise documented in bioassay records. Most of the annual internal dose will be from ^{234}U.

X-343 External Dose Issues: Ambient gamma, beta, and neutron radiation may be of concern in this area.

2.3.4 Feed Manufacturing Plant – Building X-344

Uranium tetrafluoride (UF_4; green salt) was converted to UF_6 in the X-344 Feed Manufacturing Plant. The UF_4 feedstock used in X-344 was of normal enrichment from either Mallinckrodt Chemical Works or National Lead of Ohio (Fernald). According to plant records, none of the UF_4 contained recycled uranium (RU) (BJC 2000, p. 42). The plant used direct fluorination tower reactors to convert UF_4 to UF_6 before feeding it into the cascade. The Feed Manufacturing Plant operated from May 1958 until February 1962, producing a total of 11,890 MTU of UF_6 feed for the cascade (BJC 2000, p. 36).

The direct fluorination towers operated by dropping powdered green salt through a rising column of hot elemental fluorine gas (F_2). The resultant UF_6 gas was drawn off, filtered, condensed, and transferred to storage cylinders to be fed into the cascade. Excess F_2 was recovered and unreacted

material (ash) was collected and re-fed to the tower. Working conditions in the area were harsh. During operation, the area around the towers was hot and noisy and the air was filled with dust and smoke. Because fluorine is such an extremely reactive gas, the towers were high maintenance items that required constant repair and upkeep.

In the mid-1950s, PORTS evaluated the seriousness of contamination in work areas by calculating a "Contamination Index" based on the level of contamination and square footage of the work area. A three-tiered approach categorized work areas as Red, Orange, or Clean. An index of greater than 75 was designated a "Red Job" assignment, an index of 10 to 75 was considered "Orange," and anything less than 10 was considered "Clean." The specific formula used for determining the contamination index was not available however, Building X-344 was designated a permanent Red job assignment in 1955, and employees were furnished company-issued undergarments, coveralls, head covers, and shoe covers or shoes. Showering was also a post-job requirement for any Red job assignments. Despite these formal controls, inspection reports and appraisals indicate that the requirements were not enforced and that adherence was inconsistent (DOE, 2000a, p. 40).

Building X-344 houses the feed autoclaves for natural assay as well as the sampling facility for large UF_6 cylinders. Radiochemicals including UF_6, U_3O_8, and UO_2F_2 were likely sources for both internal and external exposure.

Uranium recovery material from X-705 was transferred to X-344 in the form of UO_2F_2 to blend with the UF_4 steam. Although no direct use of RU occurred in Building X-344, recovered uranium from building X-705 may have contained transuranic (TRU) isotopes from the small quantity of RU processed by PORTS. Additionally, because purge gas from the cascades was processed in X-344, ^{99}Tc could have been present (DOE 2000a, p. 95). Facilities in this building include feed autoclaves for natural assay. Sampling of large UF_6 cylinders also occurred here (Hill and Strom 1993, p. 16.6). Table 2.3.4-1 shows the nuclides of concern for Building X-344.

X-344 Internal Dose Issues: Uranium intakes indicate type S for these facilities; see the Internal Dose section of this TBD for further information.

X-344 External Dose Issues: Exposure to ^{99}Tc is a potential from maintenance of cascades due to plating out within the system. Fluorination towers were 100 mR/hr on contact during normal operations and 50 mR/hr at 12 in. High beta fields are possible due to accumulation of progeny. Ash tower spills of 6 R/hr beta/0.7 R/hr gamma at contact are an issue. This exposure rate could have occurred during clearing of ash plugs from the towers (DOE 2000a, p. 45).

2.3.5 Special Nuclear Materials Storage – Building X-345

The vaults on the north and south sides of Building X-345 store or stored highly enriched uranium. The central area houses a HASA and a small laboratory. The entire building has been designated as having fixed radiological contamination (Yggdrasil Institute 2003). DOE describes the sampling facility as a source of fluoride and uranium emissions (DOE 2000a, p. 43). Table 2.3.5-1 identifies the radionuclides of concern for Building X-345.

Due to its high atomic weight, and because thorium-230 (^{230}Th) is a decay product of ^{234}U, it tends to concentrate with the highly enriched ^{235}U stored in Building X-345. This makes the alpha emitting ^{230}Th an inhalation hazard for workers in the area. The NRC has given ^{230}Th a lung clearance classification of S (slow), which is equivalent to the Federal Guidance Report (FGR) No. 11 class Y (years) (NRC 1992, p. 2).

X-345 Internal Dose Issues: Most uptakes of uranium indicate a fast absorption type unless otherwise indicated in the bioassay records. Note that both ^{230}Th and ^{234}U should be considered as predominant radionuclides.

X-345 External Dose Issues: Ambient gamma and neutron radiation are of concern.

2.3.6 Maintenance – Building X-700

The building is used for equipment maintenance support for non-radioactive or low-level radioactively contaminated equipment from the diffusion cascade. It houses the Chemical Cleaning and Operations, the Converter/Weld Shop, and the Radiation Calibration Laboratory. The Calibration Laboratory housed sealed sources of ^{137}Cs, ^{226}Ra and an X-Ray machine for component repair inspections. It operated as long as the cascades were in use. The major use of the Barrier Shop was final assembly and repair of converters. The Converter Shop performed welding operations on the converters. Contaminated equipment could be repaired in the maintenance areas of the shops. Radiochemicals such as UF_6, U_3O_8, and UO_2F_2 are likely, as well as hazardous chemicals such as hydrogen fluoride, trichloroethylene, other solvents; polychlorinated biphenyl (PCB) contaminated oils, welding gases, mercury, and toxic metals (High and Strom 1993, p. 16.7). Work techniques and procedure requirements for the use and availability of PPE improved through the years, but a lack of compliance and enforcement was a recurring problem (DOE 2000a, p. 28). Table 2.3.6-1 identifies the radionuclides of concern in Building X-700.

X-700 Internal Dose Issues: Most uptakes of uranium indicate a fast absorption type unless otherwise indicated in the bioassay records.

X-700 External Dose Issues: ^{99}Tc deposits along with TRU elements and uranium progeny were likely present, as well as ambient gamma and neutron radiation.

2.3.7 Decontamination, Cleaning, and Recovery – Building X-705

The uranium recovery facility recovered approximately 38.2 MTU of triuranium octoxide (U_3O_8) during its period of operation (1958 to 2001). Although the facility underwent many safety and process improvements, the basic operation remained unchanged. Uranium-bearing solutions, scrap, and waste materials were dissolved and chemically treated to extract the uranium. The uranium bearing slurry was kiln-dried to form U_3O_8, which was sent to the oxide conversion plant in Building X-705E for conversion to UF_6 for cascade feed. A very small percentage of impurities and radioactive isotopes traveled with the U_3O_8 and concentrated in the ash from the oxide converter. Most impurities and metals remained in solution and concentrated in the sludge of the X-701B settling pond or in the precipitate of the heavy metals recovery operation (BJC 2000, pp. 36-–39). Contaminants in X-705 such as UF_6, UO_2F_2 (fine dust), uranyl nitrate, and U_3O_8 (from calciners) are likely. TRU elements such as ^{237}Np, ^{228}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am were present from flame tower ash and the MgF_2 traps from the oxide conversion facility (X-705E) (Hill and Strom 1993, p. 16.8). Table 2.3.7-1 identifies the radionuclides of concern for Building X-705.

X-705 Internal Dose Issues: Uranium intakes indicate class S for these facilities, (Thomson 2003); see Internal and External Dose chapters of this TBD for additional information. All TRU elements along with ^{99}Tc are of concern in this area. Uranium bearing solutions, scrap, and waste materials were dissolved and chemically treated to extract uranium. A flame tower operated in the facility from 1958 to 1965. Although an Oak Ridge National Laboratories report indicated potential internal exposures to insoluble and enriched oxides, monitoring at the time was not adequate (DOE 2000a, p. 46). In vivo monitoring (lung counting) for insoluble uranium and ^{237}Np began in 1965.

X-705 External Dose Issues: Ambient gamma, beta, and neutron radiation may be of concern in this area.

2.3.8 Oxide Conversion Facility – Building X-705E

The Oxide Conversion Facility in Building X-705E provided the capability to generate UF_6 directly from uranium oxide (U_3O_8). The first conversion process used screw-fed, stirred-bed reactors that proved difficult to maintain and had inadequate production capabilities. They were replaced in 1959 with a direct fluorination flame tower, which was improved and enlarged in 1967. The enlarged conversion facility operated until 1978. In sum, the Oxide Conversion Facility operated from 1957 to 1978 and produced about 233 MTU of UF_6 (DOE 2000a, p. 18). Operation of the oxide conversion facility required continual maintenance and repair. The system was beset with airborne uranium contamination, burn-through of the fluorination towers, leakage from the cold traps and product withdrawals, and system breaches (DOE 2000a, p. 20).

X-705E Internal Dose Issues: Uranium intakes indicate class S for these facilities. (Thomson, 2003) All TRU elements along with ^{99}Tc are of concern in this area. Permissible air levels were exceeded during handing of oxide powders, changing the tower feed screw, connecting and disconnecting pigtails, and performing maintenance on cold traps plugged with foreign materials (DOE 2000a, p. 46). In vivo monitoring for insoluble uranium and ^{237}Np began in 1965.

X-705E External Dose Issues: Ambient gamma, beta, and neutron radiation may be of concern in this area.

2.3.9 Analytical Labs, Process and Materials – Building X-710

The facilities in this area include electrical substations, special analytical labs, and process and materials technology areas. Sealed radioactive sources containing ^{22}Na, ^{99}Tc, ^{252}Cf (40.2 mCi – 1999), ^{133}Ba, or ^{137}Cs were used for instrument calibration and may be found in the instrument technology area. A small radiographic room was used to test welds, small valves, sample containers, and other components for internal soundness and integrity. The presence of UF_6, UO_3, and UO_2F_2 along with TRU elements is also likely due to the handling of enriched product (High and Strom 1993, p. 16.10). Table 2.3.9-1 shows the radionuclides of concern for Building X-710.

X-710 Internal Dose Issues: Most uptakes of uranium should be considered a fast absorption type unless otherwise documented in the bioassay records.

X-710 External Dose Issues: Ambient gamma, X-ray, beta, and neutron radiation may be of concern in this area. Calibration sources including ^{22}Na, ^{99}Tc, ^{133}Ba, ^{137}Cs, or ^{252}Cf were used for instrument calibrations.

2.3.10 Compressor Shop – Building X-720

Each cell in the cascade contained a compressor, heat exchanger, and converter. The compressor shop was a precision machine shop where compressors could be disassembled, decontaminated, repaired, and modified. The concrete pad outside the compressor shop served as an outdoor cleaning and decontaminating area for compressors and other large equipment from the cascades. Steam, high-pressure water, degreasers, and chemical solvents were sprayed to clean and decontaminate the equipment before moving it into the shop. Runoff from the cleaning pad entered the storm drain system. Table 2.3.10-1 shows the radionuclides of concern for Building X-720.

X-720 Internal Dose Issues: Most uptakes of uranium indicate a fast absorption type unless otherwise indicated in the bioassay records.

X-720 External Dose Issues: Ambient gamma and beta radiation may be of concern in this area.

2.3.11 Aluminum Smelter and Recovery – Building X-744G

Facilities include an aluminum smelter to extract aluminum from process equipment. Waste and scrap was stored pending offsite disposal. Uranium in the form of UF_6, UO_3, and UO_2F_2 along with TRU elements are expected (Hill and Strom 1993, p. 16.9; DOE 2000a, p. 52). Table 2.3.11-1 shows the radionuclides of concern for Building X-744.

X-744G Internal Dose Issues: Most uptakes of uranium indicate a fast absorption type unless otherwise indicated in the bioassay records.

X-744G External Dose Issues: Ambient gamma and neutron radiation may be of concern in this area.

2.4 SITE PROCESSES

2.4.1 Recent History of the Cascade

Production of HEU ended in 1991 when 1,680 cascade stages were retired in place. They were cleaned of large deposits and mothballed between fiscal year (FY) 1993 and FY 1998. A total of 240 X-27 and 180 X-25 cascade stages remained in operation through 2001; they were used for product withdrawal and side feeding.

All enrichment operations were halted in 2001 when USEC transferred enrichment operations to the Paducah Gaseous Diffusion Plant (Paducah GDP). Operating equipment was cleaned of gross contamination and large deposits before being placed in dry storage.

From 1997 to mid-1998, the active stages in Building X-326 were used to down-blend 14 MTU of HEU stored on site. The HEU-UF_6 in storage was diluted as part of a memorandum of understanding between DOE and USEC. Other uranium-bearing materials with greater than 20% enrichment were shipped off site (BJC 2000, p. 24).

A fire on December 9, 1998 destroyed one and damaged two other cells in the purge cascade in Building X-326. The accident investigation team hypothesized that a loss of cooling to aluminum process equipment caused the fire. The equipment became so hot that an aluminum–uranium hexafluoride reaction (which is highly exothermic) took place. The fire released an undetermined quantity of radiological materials (NRC, 1999).

2.4.2 Feed Material for the Cascade

During operations, more than 330,000 MTU of UF_6 passed through the PORTS cascades (BJC 2000, p. 22). The major source of feed material was Paducah GDP and K-25. The feed manufacturing plant in Building X-344 and Oxide Conversion Plant in Building X-705 produced a small percentage of the UF_6 feed stock and some UF_6 was received directly from commercial sources.

Of the 330,000 MTU fed to the PORTS cascade, 1,094.66 MTU contained RU from spent nuclear fuel (BJC 2000, p. 22). The RU came from many sources over many years of operation. Table 2.4.2-1 shows the source and quantity of reactor returns fed to the cascade.

RU was first fed to the cascade during start-up in 1955 when UF_6 feed was manufactured at Paducah GDP from UO_3 received from Hanford and Savannah River reactor tails. In addition, the normal Paducah GDP feed material contained an estimated 1-ppm ^{99}Tc contamination. The UO_3 from the Savannah River and Hanford Canyon systems were contaminated before 1967 with ^{237}Np, plutonium, and ^{99}Tc at an estimated 0.18 ppm, 0.4 ppm, and 6.65 ppm, respectively, and after 1967 at 0.068 ppm, 0.021 ppm, and 6.65 ppm, respectively (BJC 2000, p. 19).

2.4.3 Atmospheric Emissions from the Cascade

Cascade operation released a variety of contaminants to the air. Chief among them was uranium, fluorine, fluorides, and Freon. A May 2000 DOE report identifies the following contaminants released through the top and side purge cascades in Building X-326: Uranium, ^{99}Tc, HF, F_2, chlorine (Cl), SO_4, SO_2F_2, Freon 114, ClF_4, and CF_4 (DOE 2000b). Uranium and technetium were the major release elements from the cold recovery and wet air evacuation systems in Buildings X-330 and X-333 (DOE 2000a, p. 72).

Because of the lack of air sampling data, the full quantity of uranium, fluorine, and other atmospheric discharges from the cascade operation cannot be known. In addition, the design of PORTS facilitated accidental or intentional venting through unregulated and unmonitored outlets. One source estimates that 20 to 30 tons of fluorine was vented annually during operation of the facility (DOE, 2000a, p. 72). While fluorine releases may have some correlation with uranium releases because airborne UF_6 hydrolyzes with atmospheric water to form hydrogen fluoride, UO_3, and U_3O_8, however a close correlation is not possible because the plant design required the use of free fluorine and fluoride compounds, which were vented to atmosphere. It is therefore impossible to estimate the radiological impacts resulting from the release of 20 to 30 tons of fluorine.

PORTS did not perform continuous vent monitoring of radionuclides or fluorides until the middle of the 1980s. Grab samples and some space recorders were used to estimate the quantity of released materials, but the unreliability of space recorders and inaccuracy of grab sampling when compared to continuous monitoring systems indicate that emissions may have been underestimated. Accidents and deliberate events resulted in several large atmospheric releases at the facility. A cylinder rupture in 1978 vented more than 6,000 kg (13,000 lb) of UF_6 inside the fixed feed facility. In 1985, operators released over 50 kg (110 lb) of uranium into the atmosphere from X-333 when the wet traps overloaded and operators ignored alarms (BJC 2000, pp. 20-–27).

2.4.4 Liquid Discharge from the Facility

Liquid effluents from PORTS contributed a large portion of total emissions from the facility. Water and degreasing solvents from the decontamination facilities were sent to the X-701B holding pond at rates as high as 500,000 gallons per month until the pond was closed in 1988. An active uranium recovery program in X-705 used nitric acid to dissolve uranium-bearing solids and produce U_3O_8 feed for the oxide converters. Effluents from the uranium recovery operation and decontamination activities were routed to the X-701B holding pond, which drained through a small stream to the Scioto River.

During FY 1975, sludge sample from the bottom of X-701 showed concentrations of ^{99}Tc, uranium, plutonium, neptunium, and various heavy metals. It was estimated that 1,415 grams of ^{99}Tc as well as 0.03 grams of plutonium and 3.3 grams of neptunium were present in the sludge (BJC 2000, pp. 32-–36). Once or twice each year the pond was dredged and the sludge was dumped in containment ponds on either side of X-701B to dry before being shipped off the site. Airborne exposure could have occurred during the drying and handling operations.

2.4.5 Solid Waste Generation

The PORTS facility had a continuing program to recover as much uranium as possible from all scrap materials. A strict Go-NoGo criterion was used to evaluate all solid and liquid waste products; all material with sufficient uranium content was sent to the uranium recovery operation in Building X-705. Filter media, incinerator ash, magnesium fluoride traps, and scrap metals with recoverable uranium went through a solvent extraction process which involved dissolving the uranium (and other metals) in nitric acid then separating the uranium by solvent extraction and drying. The dried U_3O_8 was fed to the oxide converters where it was converted to UF_6 and fed to the cascades (DOE 2000a, pp. 18-–20; BJC 2000, pp. 35-–37).

Oxide conversion work in X-705 presented the most hazardous radiological and chemical exposures to PORTS workers. The original plant design was inefficient and generated large quantities of airborne and surface contamination from the manual handling of uranium powder. A design change in 1965 installed additional glove boxes and automated controls to grind the U_3O_8 into a fine powder and feed it to the fluorination towers. However, leaks and equipment maintenance problems still generated large uranium contamination and exposure problems for the workers.

Early exposure levels were so high that, in 1965, two oxide conversion workers were found to have high enough insoluble uranium lung burdens that they were put on permanent restricted duty. One worker still had significant lung burden when he retired in 1985 (DOE 2000a, p. 18).

Table 2.3-1. Major facilities at PORTS.

Building No.	Name	Dates of Operation	Activities
X-326	Gaseous Diffusion Process Bldg.	1954–1991	High Assay Product
X-330	Gaseous Diffusion Process Bldg.	1954–2001	Intermediate process & tails withdrawal
X-333	Gaseous Diffusion Process Bldg.	1954–2001	Initial enrichment & reactor product
X-342A	Fixed Feed Facility	1954–2001	Feed UF_6 to Process line
X-342	Fluorine Generation Facility	1954–2001	Generate elemental F_2 for converters
X-343	Fixed Feed Facility	1954–2001	Feed UF_6 to Process line
X-344	UF_6 Feed Manufacturing Plant	1958–1962	Conversion of UF_4 to UF_6
X-345	Special Nuclear Material Storage	1978–2003	Highly enriched uranium storage
X-700	Maintenance Building	1954–2003	Large component repairs
X-705	Decontamination & Cleaning Bldg.	1954–2003	Equipment wash & uranium recovery
X-705E	Oxide Conversion Plant	1957–1978	Convert U_3O_8 to UF_6
X-710	Labs, Electrical and I&C Shops	1954–2003	Testing, Calibration, & Repair
X-720	Compressor Shop	1954–2003	Disassembly & repair of compressors
X-744G	Smelter & Aluminum Recovery	1954–1978	Recover aluminum from scrap

(Source: DOE 2000b, p. 16)

Table 2.3.1-1. Radionuclides of concern in Building X-333 .

Facility/process	**X-333 LAW Area**			
Years of operation	**1954 – 2001**			
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	F	F-S	5.03×10^{-1}	
^{235}U	F	F-S	2.83×10^{-2}	
^{236}U	F	F-S	1.74×10^{-3}	
^{238}U	F	F-S	4.67×10^{-1}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	6.81×10^{-5}	
^{238}Pu[c]	S	M-S	4.29×10^{-5}	X
^{239}Pu[c]	S	M-S	4.29×10^{-5}	X
^{240}Pu[c]	S	M-S	4.29×10^{-5}	X
^{241}Am[c]	S	M-S	4.29×10^{-5}	X
^{228}Th	S	F-S	4.42×10^{-5}	
^{230}Th	S	F-S	8.23×10^{-5}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	1.04×10^{-5}	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are absorption type M for GDPs. ^{99}Tc is type F for GDPs that based their derived air concentration (DAC) on conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and d plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available

Table 2.3.1-2. Radionuclides of concern in Building X-330.

Facility/process	**X-330 process facilities and tails withdrawal**			
Years of operation	**1954 – 2001**			
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	F	F-S	7.44×10^{-1}	
^{235}U	F	F-S	3.33×10^{-2}	
^{236}U	F	F-S	2.46×10^{-3}	
^{238}U	F	F-S	2.20×10^{-1}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	8.22×10^{-5}	
^{238}Pu[c]	S	M-S	1.03×10^{-5}	X
^{239}Pu[c]	S	M-S	1.03×10^{-5}	X
^{240}Pu[c]	S	M-S	1.03×10^{-5}	X
^{241}Am[c]	S	M-S	1.03×10^{-5}	X
^{228}Th	S	F-S	1.51×10^{-5}	
^{230}Th	S	F-S	8.36×10^{-5}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	1.66×10^{-5}	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available.

Table 2.3.1-3. Radionuclides of concern in Building X-326.

Facility/process	**X-326 process facilities and ERP, HASA and PW**			
Years of operation	**1954 – 2001 (1991 for HASA)**			
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U[a]	F	F-S	9.12×10^{-1}	
^{235}U[a]	F	F-S	3.16×10^{-2}	
^{236}U[a]	F	F-S	2.64×10^{-3}	
^{238}U[a]	F	F-S	5.33×10^{-2}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	9.58×10^{-5}	
^{238}Pu[c]	S	M-S	1.79×10^{-5}	X
^{239}Pu[c]	S	M-S	1.79×10^{-5}	X
^{240}Pu[c]	S	M-S	1.79×10^{-5}	X
^{241}Am[c]	S	M-S	1.79×10^{-5}	X
^{228}Th	S	F-S	1.15×10^{-4}	
^{230}Th	S	F-S	3.47×10^{-4}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	3.6×10^{-6}	
^{234}Th	M	F-S	Trace	X
^{234m}Pa	M	M-S	(In equilibrium with ^{234}Th)	X

a. UF_6 and UO_2F_2 are considered type F materials (Hill, p. 14.7). U_3O_8 is considered type S (Hill, p. 14.7). Most material should be UF_6 feed. Most bioassay results indicate that uranium acts as a type F material (Hill, p. 14.5). To be claimant favorable assume type S unless otherwise indicated in the bioassay records.
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption class, when available

Table 2.3.2-1. Radionuclides of concern for Buildings X-342 and X-342A.

Facility/process			**X-342 Fluorine Generation Facility and X-342A Fixed Feed Facility**	
Years of operation			**1954 – 2001**	
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	F	F-S	8.46×10^{-1}	
^{235}U	F	F-S	3.48×10^{-2}	
^{236}U	F	F-S	4.69×10^{-3}	
^{238}U	F	F-S	1.14×10^{-1}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	3.35×10^{-4}	
^{238}Pu[c]	S	M-S	1.33×10^{-5}	X
^{239}Pu[c]	S	M-S	1.33×10^{-5}	X
^{240}Pu[c]	S	M-S	1.33×10^{-5}	X
^{241}Am[c]	S	M-S	1.33×10^{-5}	X
^{228}Th	S	F-S	1.05×10^{-4}	
^{230}Th	S	F-S	1.06×10^{-4}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	Trace	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs, based on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available

Table 2.3.3-1. Radionuclides of concern for Building X-343.

Facility/process		**X-343 Fixed Feed Facility**		
Years of operation		**1954 – 2001**		
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	F	F-S	8.06×10^{-1}	
^{235}U	F	F-S	3.45×10^{-2}	
^{236}U	F	F-S	2.31×10^{-3}	
^{238}U	F	F-S	1.57×10^{-1}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	8.78×10^{-5}	
^{238}Pu[c]	S	M-S	6.26×10^{-5}	X
^{239}Pu[c]	S	M-S	6.26×10^{-5}	X
^{240}Pu[c]	S	M-S	6.26×10^{-5}	X
^{241}Am[c]	S	M-S	6.26×10^{-5}	X
^{228}Th	S	F-S	2.49×10^{-5}	
^{230}Th	S	F-S	1.95×10^{-4}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	Trace	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available

Table 2.3.4-1. Radionuclides of concern for Building X-344.

Facility/process		X-344 UF_4 conversion to UF_6 conversion facility Cylinder Transferring and Transfer Facility		
Years of operation		**1958 – 1962 and 1962 – 2001**		
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	S[e]	F-S	7.44×10^{-1}	
^{235}U	S[e]	F-S	3.20×10^{-2}	
^{236}U	S[e]	F-S	4.9×10^{-4}	
^{238}U	S[e]	F-S	2.23×10^{-1}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	2.37×10^{-5}	
^{238}Pu[c]	S	M-S	3.48×10^{-6}	X
^{239}Pu[c]	S	M-S	3.48×10^{-6}	X
^{240}Pu[c]	S	M-S	3.48×10^{-6}	X
^{241}Am[c]	S	M-S	3.48×10^{-6}	X
^{228}Th	S	F-S	9.95×10^{-6}	
^{230}Th	S	F-S	1.42×10^{-4}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	Trace	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available
e. Absorption type for this facility has indicated class S in many bioassay results (Thomson 2003)

Table 2.3.5-1. Radionuclides of concern in Building X-345.

Facility/process		**X-345 SNM Storage Area – HEU storage**		
Years of operation		**1954 – 2003**		
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	F	F-S	9.78×10^{-1}	
^{235}U	F	F-S	1.68×10^{-2}	
^{236}U	F	F-S	1.19×10^{-3}	
^{238}U	F	F-S	2.16×10^{-3}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	2.04×10^{-3}	
^{238}Pu[c]	S	M-S	Trace	X
^{239}Pu[c]	S	M-S	Trace	X
^{240}Pu[c]	S	M-S	Trace	X
^{241}Am[c]	S	M-S	Trace	X
^{228}Th	S	F-S	Trace	
^{230}Th[e]	S	F-S	1.2×10^{-1}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	Trace	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available.
e. ^{230}Th is a significant inhalation hazard in this building, see section 2.3.5.

Table 2.3.6-1. Radionuclides of concern in Building X-700.

Facility/process	**Converter Shop and Cleaning Area**			
Years of operation	**1954 – 2003**			
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	S[e]	F-S	5.97×10^{-1}	
^{235}U	S[e]	F-S	3.14×10^{-2}	
^{236}U	S[e]	F-S	2.55×10^{-3}	
^{238}U	S[e]	F-S	3.64×10^{-1}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	1.37×10^{-3}	
^{238}Pu[c]	S	M-S	5.24×10^{-5}	X
^{239}Pu[c]	S	M-S	5.24×10^{-5}	X
^{240}Pu[c]	S	M-S	5.24×10^{-5}	X
^{241}Am[c]	S	M-S	5.24×10^{-5}	X
^{228}Th	S	F-S	3.74×10^{-4}	
^{230}Th	S	F-S	3.17×10^{-3}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	3.23×10^{-4}	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available
e. Absorption type for this facility has indicated class S in many bioassay results. (Thomson 2003)

Table 2.3.7-1. Radionuclides of concern in Building X-705.

Facility/process		**X-705 Decontamination and Recovery**		
Years of operation		**1954 – present**		
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	S[e]	F-S	8.87×10^{-1}	
^{235}U	S[e]	F-S	3.43×10^{-2}	
^{236}U	S[e]	F-S	1.86×10^{-2}	
^{238}U	S[e]	F-S	5.88×10^{-2}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	1.60×10^{-4}	
^{238}Pu[c]	S	M-S	8.79×10^{-5}	X
^{239}Pu[c]	S	M-S	8.79×10^{-5}	X
^{240}Pu[c]	S	M-S	8.79×10^{-5}	X
^{241}Am[c]	S	M-S	8.79×10^{-5}	X
^{228}Th	S	F-S	1.30×10^{-4}	
^{230}Th	S	F-S	6.66×10^{-4}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	3.37×10^{-5}	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are class M for GDPs. ^{99}Tc is class F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine solubility class, when available.
e. Absorption type for this facility has indicated class S in many bioassay results. (Thomson 2003)

Table 2.3.8-1. Radionuclides of concern for Building X-705E.

Facility/process		**X-705E Oxide Conversion**		
Years of operation		**1957 – 1978**		
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	S[e]	F-S	8.87×10^{-1}	
^{235}U	S[e]	F-S	3.43×10^{-2}	
^{236}U	S[e]	F-S	1.86×10^{-2}	
^{238}U	S[e]	F-S	5.88×10^{-2}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	1.60×10^{-4}	
^{238}Pu[c]	S	M-S	8.79×10^{-5}	X
^{239}Pu[c]	S	M-S	8.79×10^{-5}	X
^{240}Pu[c]	S	M-S	8.79×10^{-5}	X
^{241}Am[c]	S	M-S	8.79×10^{-5}	X
^{228}Th	S	F-S	1.30×10^{-4}	
^{230}Th	S	F-S	6.66×10^{-4}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	3.37×10^{-5}	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234Th})	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are class M for GDPs. ^{99}Tc is class F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine solubility class, when available.
e. Absorption type for this facility has indicated class S in many bioassay results. (Thomson 2003)

Table 2.3.9-1. Radionuclides of concern for Building X-710.

Facility/process		**X-710 Analytical Labs, Process and Materials**		
Years of operation		**1954 – 2003**		
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	F	F-S	9.18×10^{-1}	
^{235}U	F	F-S	2.70×10^{-2}	
^{236}U	F	F-S	1.75×10^{-2}	
^{238}U	F	F-S	4.69×10^{-2}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	1.80×10^{-3}	
^{238}Pu[c]	S	M-S	7.25×10^{-4}	X
^{239}Pu[c]	S	M-S	7.25×10^{-4}	X
^{240}Pu[c]	S	M-S	7.25×10^{-4}	X
^{241}Am[c]	S	M-S	7.25×10^{-4}	X
^{228}Th	S	F-S	3.49×10^{-4}	
^{230}Th	S	F-S	3.94×10^{-3}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	4.61×10^{-5}	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available

Table 2.3.10-1. Radionuclides of concern for Building X-720.

Facility/process		**X-720 Compressor Shop& High Bay**		
Years of operation		**1954 – 2003**		
Radionuclides of concern	**Most Probable Absorption Type**	**Absorption Type range[d]**	**Activity fraction**	**Significant to external exposure[b]**
^{234}U	F	F-S	7.77×10^{-1}	
^{235}U	F	F-S	3.45×10^{-2}	
^{236}U	F	F-S	8.9×10^{-4}	
^{238}U	F	F-S	1.86×10^{-1}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	Trace	
^{238}Pu[c]	S	M-S	3.08×10^{-4}	X
^{239}Pu[c]	S	M-S	3.08×10^{-4}	X
^{240}Pu[c]	S	M-S	3.08×10^{-4}	X
^{241}Am[c]	S	M-S	3.08×10^{-4}	X
^{228}Th	S	F-S	5.64×10^{-4}	
^{230}Th	S	F-S	4.68×10^{-4}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	Trace	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption type, when available

Table 2.3.11-1. Radionuclides of concern in Building X-744G.

Facility/process		X-744G Smelter for Aluminum recovery		
Years of operation		1961 – 1983		
Radionuclides of concern	Most Probable Absorption Type	Absorption Type range[d]	Activity fraction	Significant to external exposure[b]
^{234}U	F	F-S	9.44×10^{-1}	
^{235}U	F	F-S	3.26×10^{-2}	
^{236}U	F	F-S	2.57×10^{-3}	
^{238}U	F	F-S	1.88×10^{-2}	X
^{99}Tc	M	F-M	Trace	X
^{237}Np	S	M-S	4.61×10^{-4}	
^{238}Pu[c]	S	M-S	2.21×10^{-4}	X
^{239}Pu[c]	S	M-S	2.21×10^{-4}	X
^{240}Pu[c]	S	M-S	2.21×10^{-4}	X
^{241}Am[c]	S	M-S	2.21×10^{-4}	X
^{228}Th	S	F-S	3.08×10^{-4}	
^{230}Th	S	F-S	1.04×10^{-3}	
^{231}Th	S	F-S	Trace	
^{232}Th	S	F-S	4.92×10^{-5}	
^{234}Th[a]	M	F-S	Trace	X
^{234m}Pa[a]	M	M-S	(In equilibrium with ^{234}Th)	X

a. $^{234}Th/^{234m}Pa$ are found in equilibrium and are type M for GDPs. ^{99}Tc is type F for GDPs that based their DAC on the more conservative modes (RPM, p. 15).
b. ^{238}U feeds ^{234m}Pa with a high-energy beta that is also of concern.
c. Americium and plutonium not distinguished in analysis.
d. Always use bioassay information to determine absorption class, when available.

Table 2.4.2-1. Reactor returns fed to cascade.

Fiscal year	Amount fed (MTU)	Enrichment (% ^{235}U)	Source	Remarks
1955	105.8	0.64 – 0.68	Paducah	Fed May – Sept. 1955
1956	54.5	0.64 – 0.68	Paducah	
1956	293.4	0.64 – 0.68	Oak Ridge	
1957	6.2	0.64 – 0.68	Paducah	
1958	64.2	0.64 – 0.68	Paducah	
1970	168.1	0.64 – 0.68	Paducah	Fed Oct. & Nov. 1969
1974	398.8	0.64 – 0.68	Paducah	Fed Jan. 1974
1974 – 1978	1.86	2 – 50	PORTS Oxide Conversion	
1968 – 1977	0.15	78 – 80	Division of International Affairs	
1977 – 1998	0.15	78 – 97	Babcock & Wilcox	
1969 – 1993	0.07	78	AEC Office of Safeguards & Materials Management	
1997 – 1998	1.10	56 – 82	France	
1997 – 1998	0.33	80	NUMEC	
TOTAL	1,094.66			

Source: Table 2.2.2.5-1, BJC (2000, p. 22).

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GLOSSARY

ALARA

Acronym for "As Low As Reasonably Achievable," means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest (see 10 CFR 20.1003).

Alpha radiation

A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. It is identical to a helium nucleus that has a mass number of 4 and an electrostatic charge of +2. It has low penetrating power and a short range (a few centimeters in air). The most energetic alpha particle will generally fail to penetrate the dead layers of cells covering the skin and can be easily stopped by a sheet of paper. Alpha particles are hazardous when an alpha-emitting isotope is inside the body.

Background radiation

Radiation from cosmic sources; naturally occurring radioactive materials, including radon (except as a decay product of source or special nuclear material) and global fallout as it exists in the environment from the testing of nuclear explosive devices. It does not include radiation from source, byproduct, or special nuclear materials regulated by the Nuclear Regulatory Commission. The typically quoted average individual exposure from background radiation is 360 millirems per year.

Becquerel

The derived SI unit of radioactive decay equal to 1 disintegration per second. 37 billion (3.7x1010) becquerels = 1 curie (Ci).

Beta particle (Beta Radiation)

A charged particle emitted from a nucleus during radioactive decay, with a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Large amounts of beta radiation may cause skin bums, and beta emitters are harmful if they enter the body. Beta particles may be stopped by thin sheets of metal or plastic.

Cascade

The process system that is used to separate the isotopic streams of uranium-235 and uranium-238 in gaseous diffusion plants.

Cylinder

A large steel container used to store UF_6. Cylinders are typically about 3.7 m (12 ft) long by 1.2 m (4 ft) in diameter and weigh about 9.1 to 12.7 metric tons (10 to 14 tons) when full of depleted UF_6.

Deep dose equivalent

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

Depleted UF_6

UF_6 with a lower isotopic fraction of ^{235}U than found in natural uranium.

Depleted Uranium

Uranium having a percentage of uranium-235 smaller than the 0.7 percent found in natural uranium. It is obtained from spent (used) fuel elements or as byproduct tails, or residues, from uranium isotope separation.

Derived Air Concentration (DAC)

The concentration of radioactive material in air and the time of exposure to that radionuclide, in hours. An NRC licensee may take 2,000 hours to represent one ALI, equivalent to a committed effective dose equivalent of 5 rems (0.05 sievert).

Derived concentration guidelines (DCG)

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

Dose Equivalent

The product of absorbed dose in tissue multiplied by a quality factor, and then sometimes multiplied by other necessary modifying factors at the location of interest. It is expressed numerically in rems or sieverts (see 10 CFR 20.1003).

Dosimeter

A small portable instrument (such as a film badge, thermoluminescent or pocket dosimeter) for measuring and recording the total accumulated personnel dose of ionizing radiation.

Dosimetry

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

Enriched UF_6

UF_6 with a higher isotopic fraction of ^{235}U than found in natural uranium.

Enrichment

An isotopic separation process that increases the portion of the ^{235}U isotope in relation to ^{238}U in natural uranium. In addition to the enriched uranium, this process also produces uranium depleted in ^{235}U (see depleted UF_6 and tails).

Exposure

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

Film Badge

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

Gamma Radiation (Gamma Rays)

High-energy, short wavelength, electromagnetic radiation emitted from the nucleus. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded by dense materials, such as lead or depleted uranium.

Gaseous Diffusion Plant

A facility where uranium hexafluoride gas is filtered, uranium-235 is separated from uranium-238, increasing the percentage of uranium-235 from 1 to about 3 percent. The process requires enormous amounts of electric power.

Halflife

The time in which one half of the atoms of a particular radioactive substance disintegrates into another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical or radiological halflife

Halflife, biological

The time required for the body to eliminate one half of the material taken in by natural biological means.

Halflife, effective

The time required for a radionuclide contained in a biological system, such as a human or an animal, to reduce its activity by one-half as a combined result of radioactive decay and biological elimination.

In vitro

From the Latin, in glass, isolated from the living organism and artificially maintained, as in a test tube.

In vivo

From the Latin, in one that is living, occurring within the living.

Monitoring of Radiation

Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in a region, as a safety measure, for the purpose of health or environmental protection. Monitoring is done for air, surface, & ground water, soil & sediment, equipment surfaces, and personnel (for example, bioassay or alpha scans).

Neutron

An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen.

Non-stochastic effect

The health effects, the severity of which vary with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a non-stochastic effect (also called a deterministic effect) (see 10 CFR 20.1003).

Rad

The special unit for radiation absorbed dose, which is the amount of energy from any type of ionizing radiation (e.g., alpha, beta, gamma, neutrons, etc.) deposited in any medium (e.g., water, tissue, air). A dose of one rad means the absorption of 100 ergs (a small but measurable amount of energy) per gram of absorbing tissue (100 rad = 1 gray).

Radiation

Alpha, beta, neutron, and gamma ray (i.e., photon) radiation.

Radiation Exposure Monitoring System (REMS)
An online DOE database that contains records of personal dosimetry information.

Radioactivity
The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nucleus of an unstable isotope. Also, the rate at which radioactive material emits radiation. Measured in units of becquerels or disintegrations per second.

rem
(1) The amount of ionizing radiation required to produce the same biological effect as one rad of high-penetration x-rays. (2) A unit for measuring absorbed doses of radiation, equivalent to one roentgen of x-rays or gamma rays.

Rotengen
A unit of radiation exposure equal to the quantity of ionizing radiation that will produce one electrostatic unit of electricity in one cubic centimeter of dry air at 0°C and standard atmospheric pressure.

Sievert (Sv)
The international system (SI) unit for dose equivalent equal to 1 Joule/kilogram. 1 sievert = 100 rem.

Shallow Dose Equivalent (SDE)
The dose equivalent at the respective depth of 0.07 mm of the skin or an extremity.

Tails
The product stream of depleted UF_6 (i.e., lower isotopic fraction of ^{235}U than found in natural uranium) that results from the enrichment process. For gaseous diffusion at PORTS, tails are loaded into cylinders and placed in a UF_6 cylinder storage yard.

Thermoluminescent dosimeter (TLD)
A small device used to measure radiation by measuring the amount of visible light emitted from a crystal in the detector when exposed to ionizing radiation.

Uranium hexafluoride (UF_6) cylinder storage yard
Storage yards at the Paducah and Portsmouth Gaseous Diffusion Plants and Oak Ridge K-25 site. These yards maintain cylinders containing depleted UF_6. The cylinders, which typically weigh 10 and 14 tons, contain depleted UF_6 that has cooled to a solid form.