



# ORAU TEAM Dose Reconstruction Project for NIOSH

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## ACRONYMS AND ABBREVIATIONS

Ci	curie
D&D	Decontamination and Decommissioning
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EBR II	Experimental Breeder Reactor II
FFTF	Fast Flux Test Facility
FP	Fission Products
g	gram
GETR	General Electric Test Reactor
HEPA	high-efficiency particulate air
hr	hour
HTLTR	High Temperature Lattice Test Reactor
HTR	High Temperature Reactor
in	inch
kVp	applied kilovoltage; peak kilovoltage
kCi	kilocurie
kg	kilogram
kW	kilowatt
L	liter
lb	pound
m	meter
MeV	mega-electron volt, Million electron Volts
Mint	tritium
mL	milliliter
MTR	Materials Test Reactor
MW	megawatt
n	neutron
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
P-10	tritium
pCi	picocurie
PCTR	Physical Constants Test Reactor
PFP	Plutonium Finishing Plant
PFPP	Plutonium Fuels Pilot Plant
POC	probability of causation
ppb	parts per million

PNNL Pacific Northwest National Laboratory  
PRCF Plutonium Recycle Critical Facility  
PRF Plutonium Reclamation Facility  
PRTR Plutonium Recycle Test Reactor  
PUREX Plutonium-Uranium Extraction Plant

QA Quality Assurance

RECUPLEX Recovery of Uranium and Plutonium by Extraction  
REDOX Reduction Oxidation Plant  
RG Rubber Glove  
RMA Remote Mechanical A Line  
RMC Remote Mechanical C Line

s second

TRIGA Training Research Isotopes, General Atomics Reactor  
TTR Thermal Test Reactor

U.S.C. United States Code

W watt

μCi microcurie

§ section or sections

## 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 for 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<sup>1</sup>] 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

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<sup>1</sup> The U.S. Department of Labor is ultimately responsible under the EEOICPA for determining the POC.

### 2.1.1 Purpose

The purpose of this TBD is to provide a Hanford site profile that contains technical basis information used by the Oak Ridge Associated Universities (ORAU) Team to evaluate the total occupational dose for EEOICPA claimants. This section provides information on Hanford facilities and operations.

### 2.1.2 Scope

The Hanford Site played an important role in the development of the U.S. nuclear weapons program. Operations at the Site included the construction of nine production reactors to produce plutonium for weapons and seven physical testing, research and demonstration reactors. Facilities for the separation of uranium and plutonium, uranium and tritium extraction facilities and many support facilities evolved over the years. This TBD is part of the Hanford Site Profile, which provides a description of all the facilities and processes, radionuclides significant for dose reconstruction, and historical information related to the programs and operations on the Hanford Site. It contains technical information to assist the dose reconstructors in the historical development of radiological doses received by the workers dating back to the 1940s.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 2.9.

## 2.2 **Site Activities and Processes**

Construction of facilities at the Hanford Site, an area of approximately 600 square miles, commenced in March 1943 when several major nuclear facilities were started. These included 105-B (Production Reactor); 221-T (Separation Facility); 305 (Test Pile); and 313 (Fuel Element Fabrication). The production reactors, designed to produce plutonium by irradiating metallic uranium, were constructed in the 100 Areas located along the Columbia River on the north side of the Site. The separation facilities were built in the 200 Areas located on a high plateau in the center of the Site. The fuel fabrication facilities, test reactors, and research and development laboratories were built in the 300 Area located on the south side of the Site. The facilities discussed in subsequent sections represent those facilities out of more than 500 major facilities where nuclear activities were conducted. Note: Throughout this document, where a "\*" is included with a date indicates either there were two dates found (the most provided is the most favorable to claimants) or the actual year in the decade was not found in the documents. If "UNK" is used, a date has not been found.

## 2.3 **REACTORS**

Nine graphite-moderated, light-water-cooled reactors were constructed near the Columbia River in the Hanford 100 Areas over a period of 20 years commencing in 1943 [1]. The production reactors were used to produce plutonium by irradiating metallic uranium fuel elements with neutrons during the fission reaction in the reactor core. Other defense-related radionuclides that were experimented with included irradiation of thorium to produce  $^{233}\text{U}$ , irradiation of depleted uranium to produce  $^{240}\text{Pu}$ , irradiation of neptunium targets to produce  $^{238}\text{Pu}$ , and irradiation of americium to produce medical-grade  $^{238}\text{Pu}$ . These nine production reactors, designated 100-B, C, D, DR, F, H, KW, KE, and N, were constructed in the B, D, F, H, K, and N Areas, respectively, from 1944 to 1963. The first eight reactors at Hanford, designated 105-B, C, D, DR, F, H, KW, and KE, were similar in design, utilizing a once-through, light-water cooling system. The ninth reactor, 105-N, utilized a closed-loop, light-water cooling system. The years of operation and radionuclides of concern are listed in Tables A-1 and A-2 respectively, in Attachment A. External exposures are primarily due to the presence of activation and fission products (FPs). During operation, entry was controlled into areas where high direct dose rates

from photons and neutrons could occur. Internal exposures involving uranium, activation products, and fission products, were primarily limited to maintenance and refueling activities.

In addition, seven physical testing, research, and demonstration reactors were operated at Hanford over a period of 40 years [2]. Six Research and Test Reactors, located in the 300 Area, were constructed and operated from 1943 to 1978. These include the 305 Hanford Test Reactor (HTR), Physical Constants Test Reactor (PCTR), Thermal Test Reactor (TTR), Plutonium Recycle Test Reactor (PRTR), Plutonium Recycle Critical Facility (PRCF), and High Temperature Lattice Test Reactor (HTLTR) (Newman 1989). The Fast Flux Test Facility (FFTF Reactor) was constructed and operated from 1980 to 1993 in the 400 Area. The years of operation and radionuclides of concern are listed in Tables A-3 and A-4 in Attachment A.

### **2.3.1 105-B, C, D, DR, F, H, KW, and KE Production Reactors**

The first three reactors (100-B, D, and F) were built in B, D, and F Areas starting in August, November, and December 1943. The B reactor commenced operation in September 1944. The D and F Reactors commenced operation in December 1944 and February 1945, respectively. In addition to producing plutonium for nuclear weapons, the reactors produced polonium for use as a neutron source trigger or initiator in the weapons. By May 1945, four of the tubes in D Reactor were charged with bismuth slugs for polonium production. Construction of DR Reactor, located in D Area, was started in December 1947 with startup commencing in October 1950. The H Reactor was constructed in H Area starting in March 1948 with startup in October 1949. Construction of C Reactor in B Area commenced in June 1951 with startup in November 1952. The KW and KE Reactors were constructed in KW and KE Areas starting in November 1952 and January 1953. They commenced operation in December 1954 and February 1955 respectively. These eight reactors were graphite-moderated and single-pass-cooled using treated river water. The first three reactors (B, D, and F) had the same design. The remaining five reactors (DR, H, C, KW, and KE) were similar in design with the KE and KW reactors differing primarily in the number, size, and type of process tubes; the size of the graphite stack; and the type of shielding.

The fuel elements were metallic uranium clad with aluminum [3]. In 1960, confinement systems were incorporated in the first eight reactors and these reactors were shut down over a period of years starting in 1964 and ending in 1971. See Table A-1 for shutdown dates.

### **2.3.2 105-N Production Reactor**

Construction of 105-N (the ninth production reactor) was started in N Area in 1959. The N Reactor design was based on the original graphite production reactors. However, it differed substantially from the first eight because it incorporated closed-loop cooling and it was the first Hanford reactor to incorporate a confinement system in the original design. It was designed to be a dual-purpose reactor (i.e., to produce both plutonium and steam to be used to generate power). The dual-purpose reactor started producing plutonium in March 1964 and electrical power some time later. The N Reactor fuel was a tube-in-tube design consisting of a metallic uranium core surrounded by a thin Zircaloy-2 cladding. The core consisted of an inner tube enriched to 0.95%  $^{235}\text{U}$  and an outer tube enriched to either 0.95% or 1.25%  $^{235}\text{U}$ . From 1965 to 1967, tritium was produced at N Reactor using fuel elements manufactured in the 333 facility. The N Reactor was shut down in 1987.

### **2.3.3 305 Hanford Test Reactor**

The 305 HTR (also called the Test Pile) located in the 305 Building was the first reactor to operate at Hanford, starting in 1943. It was operated until 1972 at a very low critical level (usually less than 50

W) to test fuel elements, fuel configuration, graphite samples, and other materials for the production reactors. It was used as a quality assurance (QA) tool to house testing of samples of each lot of graphite, uranium, aluminum jacketing material, and other materials used in the large production reactors. The reactor consisted of a graphite pile and was air-cooled. It was removed from the 305 Building in 1976 and 1977.

#### **2.3.4 305-B Physical Constants Test Reactor**

The PCTR started operation in 1954. The 800 W test reactor was located in a shielded room in the 305-B Building. The mission of the PCTR was to measure reactor changes as a result of use of different reactor fuels. Some plutonium contamination that occurred in the reactor room as a result of an accident could have been the source of minor internal exposure during cleanup. External exposure was negligible because the reactor was located in a shielded underground room and operated remotely. Operation was terminated in 1970.

#### **2.3.5 305-B Thermal Test Reactor**

The TTR started operation in 1954. The 1-KW reactor was located in a shielded underground room in the 305-B Building and operated remotely. The mission of the TTR was to measure thermal impact on fission cross-sections. It functioned as an early and small version of the HTLTR. External exposure was minimized because the reactor was operated remotely. Operation was terminated in 1978.

#### **2.3.6 309 Plutonium Recycle Test Reactor**

The PRTR, located in the 309 Building, started operating in 1960. The PRTR was a 40-MW, heavy-water-cooled and heavy-water-moderated reactor. The reactor was chosen for a large fuels diversification program known as the Plutonium Fuels Utilization Program. Tests were to be performed with various mixed oxide fuels using various methods of manufacture. As an example, tests were performed on a variety of powdered and pelletized fuels using plutonium oxide blended with uranium oxide and other metallic oxides. The fuel was a nominal 96% depleted uranium oxide and 4% plutonium oxide powder that was vibration-compacted within the fuel pin. External exposure was minimized as a result of the remote operation and the shielding. Maintenance operations resulted in external exposure from activation and fission products. A high extremity exposure occurred when a worker picked up an irradiated steel pin. Tritium ( $^3\text{H}$ ) oxide was the principal internal exposure contaminant during normal operation. This whole-body exposure was added into the external whole-body dose summary (see ORAUT 2004 and ORAUT 2006b). The reactor was shut down in 1969 after an accident resulted in contamination in the reactor. A sample of the contamination showed the major contaminant was  $^{95}\text{Zr/Nb}$ . Other contaminants included  $^{60}\text{Co}$ ,  $^{103}\text{Ru}$ ,  $^{106}\text{Ru}$ ,  $^{106}\text{Rh}$ ,  $^{140}\text{Ba/La}$ ,  $^{141}\text{Ce}$ ,  $^{144}\text{Ce}$ , and  $^{144}\text{Pr}$ .

#### **2.3.7 309 Plutonium Recycle Critical Facility**

The PRCF, which was located in the 309 Building, began operating in 1962. Tests were conducted in the PRCF to determine which geometric arrangement of fissionable materials would work in a reactor. It was shut down in 1976.

#### **2.3.8 318 High Temperature Lattice Test Reactor**

The HTLTR was a 2-MW test reactor built in the 318 Building in 1967 with operation commencing in 1968 (Newman 1989). The reactor consisted of a graphite cube located in a large shielded room; it

was operated at elevated temperatures up to 1,000°C. The mission was to advance reactor physics technology. It was shut down in 1971 after 3 years of operation over 4 years, during which time it operated with six different cores (i.e., three -  $^{233}\text{U}$ , one -  $^{235}\text{U}$ , one -  $^{238}\text{U}$ , and one -  $^{239}\text{Pu}$ ). Because the reactor was heavily shielded and operated remotely, external exposure was at background levels. There were no contamination incidents so internal exposure was negligible. The building and the shielded room were modified in the early 1980s and used as the new Hanford Radiation Calibration Facility (see Section 2.7.8).

### **2.3.9 405 Fast Flux Test Facility**

The FFTF was a 400-MW sodium-cooled test reactor located in the 405 Building. It began startup operations in February 1980 in support of the fast breeder reactor program. The FFTF was used to test the irradiation of fuels and materials that would be used in a breeder reactor and to perform long-term testing of reactor components and systems. It was also used for the production of medical isotopes and research on space power systems. The external and internal exposures were at background levels. The facility was shut down in 1994 and currently is awaiting decontamination and decommissioning (D&D).

## **2.4 FUEL SEPARATIONS FACILITIES**

Seven separation facilities, B Plant, T Plant, U Plant, Reduction/Oxidation (REDOX), Plutonium-Uranium Extraction (PUREX) Facility,  $\text{UO}_3$ , and C Plant, were constructed and operated in the 200-W and 200-E Areas from 1943 to 1993 [4]. The tritium processing facility was operated from 1949 to 1955 in the 108-B Building located in the 100-B Area. Natural uranium and thorium fuel elements and lithium-aluminum (Li-Al) target elements were irradiated to produce  $^{239}\text{Pu}$ ,  $^{233}\text{U}$ , and tritium, respectively. The spent reactor fuel was transported to the 200 Areas (i.e., Separations Areas) for processing. Initially spent fuel was stored in the reactor storage basins and the 212-N, 212-P, and 212-R Buildings in the 200-N Area before processing in the fuel separations facilities (e.g., 221-B, 221-T, REDOX, and PUREX). The irradiated lithium-aluminum target elements were transferred to the 108-B Building in the 100-B Area for processing. Irradiated thorium fuel elements were processed in the PUREX Plant to recover  $^{233}\text{U}$  in two separate campaigns that occurred in 1966 and 1971. External exposures were primarily high-energy betas and photons in the separations facilities associated with FP. Internal exposures, primarily associated with contamination incidents, could be due either to FP and/or plutonium. The years of operation and radionuclides of concern are listed in Tables A-5 and A-6, respectively, in Attachment A.

### **2.4.1 Original Fuel Separations Facilities**

Three large canyon buildings – 221-T, 221-B, and 221-U – were originally constructed in the 200 Area in 1943 (?) to chemically separate plutonium from uranium and fission products. These buildings were massive rectangular canyons that housed the chemical separations equipment. This equipment was operated remotely to provide protection to the workers from the high radiation fields. The T Plant was started up in December 1944 and shut down in August 1956, while B Plant started up in April 1945 and shut down in October 1952. Because the capacity was not needed, the startup of U Plant was delayed until 1952 when the mission was changed (see Section 2.4.4). The 221-T and 221-B Buildings, known as the T and B Plants, utilized a bismuth phosphate precipitation batch process to separate plutonium from the uranium and fission products after the aluminum jackets were dissolved in sodium hydroxide solution and the uranium metal slugs were dissolved in nitric acid. The dilute plutonium solution from T and B Plants was transferred to the 224 Concentration Buildings (e.g., 224-B and 224-T) located behind each canyon building, where the product was purified, the product volume was reduced, and the carrier was changed from bismuth phosphate to lanthanum fluoride.

The final plutonium product was concentrated in the 231-Z Building. The B Plant was closed in 1952. Starting in 1954 and 1955, the processing capacity was increased in both facilities. The 221-B and 221-T Plants were not restarted because of the success of PUREX.

In March 1956, 221-T was converted to perform equipment decontamination (Gerber 1994). In 1959, the 2706 T Decon Annex was added to the 221-T Building to enhance the equipment decontamination capabilities, particularly for pieces of equipment too large to take into T Plant. The T Plant is still in operation.

The B Plant facilities were modified in 1968 to remove  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  from high-level wastes from the single and double-shell waste tanks. This was in support of a new mission "to isolate the longer-lived fission products by fractionalization for storage in a safer form and to return the short-lived fractions to underground storage and ultimate solidification." The purified  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  solutions were transferred to the 225-B Waste Encapsulation Storage Facility (see Section 2.4.6). The  $^{137}\text{Cs}$  and the  $^{90}\text{Sr}$  recovery operations at the B Plant were completed in September 1983 and February 1985, respectively [5].

#### **2.4.2 202-S REDOX Plant**

Construction of the REDOX Facility (S Plant) was started in 1949. In January 1952, REDOX started up in the 200-W Area utilizing the reduction/oxidation process as a replacement for the bismuth phosphate process. This new REDOX process differed from the process used in B and T Plants in that, with the exception of the metal dissolving and feed preparation steps, all steps were continuous rather than batch. The new process, which involved solvent extraction utilizing hexone, resulted in improved throughput, recovery of uranium, improved recovery of plutonium, and a decrease in the amount of high-level liquid waste generated. The aqueous plutonium product was concentrated for shipment to the plutonium finishing facilities. In 1950\* processing of irradiated 94 metals (0.947 enrichment) was assigned to REDOX. Shutdown of this facility occurred in December 1967.

In an effort to enhance production capacity, the 233-S Building was constructed in 1957 to contain the third and final concentration cycle at 202-S. This building was shut down in July 1967 after a major fire resulted in extensive plutonium contamination. The facility is currently undergoing decontamination and decommissioning [6].

#### **2.4.3 202-A PUREX Plant**

Construction of the PUREX Facility (A Plant) commenced in 1953. It was started up in January 1956 utilizing the PUREX process (Gerber 1993a; Marceau et al. 2002). The PUREX process was an organic solvent extraction process that utilized tributyl phosphate in kerosene instead of hexone, nitric acid as a salting agent, pulse column contractors, and nitric acid recovery by distillation. The nominal design capacity was 8.33 short tons uranium per day as opposed to 2.5 for the REDOX Plant. In 1955, due to the development of more restrictive  $^{131}\text{I}$  release limits, the 293-A facility was constructed between PUREX and the 291 A stack. In 1958, PUREX initiated  $^{237}\text{Np}$  recovery activities. Equipment was added in 1962 to permit continuous recovery of  $^{237}\text{Np}$ . In 1963, the processing of e-metal fuel containing  $^{235}\text{U}$  was enriched to 1.75%. The processing of irradiated powdered thorium oxide targets to recover  $^{233}\text{U}$  commenced in 1965 and 1966. In 1970, the targets were changed to pelletized thorium oxide. The PUREX Plant was shut down in June 1972 and restarted in November 1983. During the shutdown, a new process was added to convert plutonium nitrate to plutonium oxide. The Plant was started up and shut down several times between 1983 and 1992, with final closure announced in December 1992.

A 500-ft railroad tunnel that extended south from PUREX was designed and constructed to permit the remote storage of highly contaminated processing equipment. In 1964, a new 1,500-ft tunnel was added to PUREX to accommodate the storage of additional equipment.

#### **2.4.4 221-U U Plant**

As noted in Section 2, the U Plant was constructed in 1943. The U Plant startup was delayed until March 1952 when it was reconfigured for use in the recovery of uranium from process waste. The high-level liquid wastes from the B and T Plants, which were stored in single-shell tanks, contained large quantities of uranium. The uranium-bearing sludge from the underground storage tanks was pumped to process vessels in the U Plant. The sludge was dissolved in nitric acid and the uranium extracted by solvent extraction using tributyl phosphate in kerosene. The recovered uranium was shipped off the site for reuse. The U Plant was shut down in January 1958.

#### **2.4.5 224-U UO<sub>3</sub> Plant**

The 224-U Bulk Reduction Building (known as UO<sub>3</sub> Plant) was constructed in the 1940s. In 1951, it was converted to process the liquid uranium nitrate solution from U Plant to produce a powdered uranium oxide (UO<sub>3</sub>) using a calcination process. It was started up in January 1952. The product was shipped off the site for reuse. A major addition (224-UA) was added to the UO<sub>3</sub> Plant in the fourth quarter of 1956 to house three new calciners. It was shut down in 1972 and opened again in 1983 (there were 17 startups and shutdowns between 1984 and 1992 corresponding to activities at PUREX) and was deactivated in the summer of 1993.

#### **2.4.6 225 Waste Encapsulation and Storage Facility**

The 225-B Waste Encapsulation and Storage Facility is located in the 200-E Area near the 221-B Building. In 1978, as a part of the effort to "isolate the longer-lived fission products from high-level waste tanks," the <sup>137</sup>Cs and <sup>90</sup>Sr solutions were transferred to 225-B from 221-B for conversion to a solid, encapsulation, and storage (see Section 2.4.1 for more details). A large amount of encapsulated <sup>137</sup>Cs and <sup>90</sup>Sr was stored in the 225 Building as a result of this operation. External exposures that were associated with the high-energy photons and beta particles from the large quantities of strontium and cesium processed were minimized as a result of remote operation. Internal exposures from the operation were minimal due to the remote operation.

#### **2.4.7 201-C C Plant or Hot Semiworks**

The Hot Semiworks (also known as hot sloppy) started up in 1949 as a pilot plant (Marceau et al. 2002) to develop REDOX reprocessing technologies. The REDOX process was tested in the 201-C reprocessing pilot plant starting in 1952, with work continuing until 1954. In 1954, the C Plant was switched to being the PUREX process pilot plant and was shut down in 1956. In 1962, C Plant was restarted as a pilot plant for the recovery of cesium and strontium from fission product waste. The C Plant was retired in 1967.

#### **2.4.8 108-B Tritium Extraction Facility**

The 108-B Building (known as P-10 Plant and also the Mint Works) located in the 100-B Area started in August 1944 to extract tritium [7]. The Li-Al (for a short period lithium fluoride) target elements were transferred to the 108-B facility after irradiation in one of the production reactors. Tritium extraction operations were performed intermittently between August 1949 and 1955. The 108-B tritium operation was terminated in 1955. The Li-Al target irradiation was continued with transportation to an

offsite facility for processing until Sep, 1964. A total of 10.6 kg of tritium was produced at Hanford. Internal exposure was related to tritium ( $^3\text{H}$ ). This whole-body exposure was added to whole-body dose summary (see ORAUT 2004 and ORAUT 2006b).

## **2.5 FUEL FABRICATION FACILITIES**

The Hanford Fuel Fabrication facilities described in subsequent sections were built and operated in the 300 Area from 1944 to 1988 [8]. These include three fuel fabrication facilities, 313 (Uranium Metal Fuels Fabrication), 314 (Uranium Metal Extrusion), and 333 (Fuel Cladding) Buildings, and two support facilities, 303 (Uranium Storage and Oxide Burner), and 306 (Reactor Fuel Manufacturing Pilot Plant). External exposures were related to betas and photons associated with uranium. Due to the pyrophoric nature of uranium turnings and chips, internal exposure was related primarily to inhalation of uranium. The years of operation and radionuclides are listed in Tables A-10 and A-11 respectively, in Attachment A.

### **2.5.1 313 Uranium Metal Fuels Fabrication Facility**

The aluminum-clad fuel for the first eight production reactors was produced in the 313 Building starting in March 1944. (Note: The Key dates document says December 1943.) Natural uranium billets or bars were heated to a red heat and shaped into long rods using an extrusion press (see 314 Building below). These were cut into shorter lengths called slugs using a turret lathe. After receiving a finish cut in another turret lathe, the slugs were degreased using nitric acid. The cleaned slugs were dipped in a succession of molten baths (i.e., triple-dip method) and pushed into an aluminum can. An aluminum cap was pushed into the can and the top edge of the cap was welded to the can. Bismuth fuel targets were fabricated in the 313 Building beginning in 1944. These were irradiated in the production reactors to produce  $^{210}\text{Po}$  (used as an initiator in the earliest atomic weapons). Lead-cadmium fuel rods, welded into non-bonded aluminum cans, were produced for use as "poison" elements for the production reactors. Lithium targets were manufactured for tritium production from 1949 to 1952 and again from 1965 to 1967. In the 1950s, production reactor fuel changed from natural uranium to low enriched uranium. In March 1954, a new simpler canning method involving a lead-dip process was initiated to replace the old method. All uranium scrap and waste from these processes were salvaged as uranium oxide and shipped off the Hanford Site. In 1955, the fuel production facilities were expanded to produce the fuel for the K Reactors. In January 1971, the manufacture of aluminum-clad fuel used in the first six reactors was terminated. After that time, only N Reactor fuel was manufactured (see Section 2.5.3 below).

### **2.5.2 314 Uranium Metal Extrusion Facility**

The 314 Building was known as the Press Building, Metallurgical Engineering Laboratory, and later as the Uranium Metal Extrusion Facility. Operation of the 314 Press Building commenced in July 1944 with a mission to process raw uranium billets into extruded rods that were suitable for fabrication into fuel elements. In early 1945, a 1,000-ton large extrusion press was installed in the 314 Building. After installation, the 313 and 314 Buildings assumed all of the fuel manufacturing responsibilities for Hanford. An additional mission, uranium scrap recovery, was started in 1945. An oxide burner was operated outside the building in 1946. A melt plant started operation in December 1947. Uranium scraps were mixed with  $\text{UF}_4$  (green salt) and calcium chips. Conversion to metal took place in a reduction furnace (Hanford Site Historical District no date). The high air contamination that occurred frequently involved a highly soluble class F material. The melt plant was shut down in 1954. The uranium billets were extruded into rods, outgassed, and straightened in the 314 Building. The extrusion process was terminated in 1948 when the fuel element process was changed to use rolled uranium rods. An oxide-burner was installed in the 314 Building in 1946. In 1950, a rolling mill was

installed in the 314 Building to fabricate Hanford fuel elements on the site. The building was deactivated in 1971.

### **2.5.3 333 Fuel Cladding Facility**

The N Reactor fuel was produced in the 333 Building starting in 1961. The N Reactor fuel elements used a tube-in-tube design consisting of slightly enriched uranium inner and outer cores and thin Zircaloy-2 cladding. The production process included cleaning of the uranium billets and Zirconium-2 cladding shells; billet assembly and preheating; extrusion; fuel element shaping and cleaning; and welding of the end cap. From 1965 to 1967, outer driver fuel elements were produced in support of tritium production at N Reactor. The Li/Al inner target element was manufactured in the 3722 Area Shop. The 333 Building was placed on standby in 1988 when the manufacture of N Reactor fuels ceased.

### **2.5.4 306 Reactor Fuel Manufacturing Pilot Plant**

Construction on the 306 Building was completed in 1956, and it began operation in May 1957 as a pilot plant for reactor fuel production. The 306 Building had a complete fuel element canning line with the exception of autoclaving. The co-extrusion process was developed in the 306-E Building in the early 1960s in support of the N Reactor fuel needs. This facility was shut down in 1984\*.

### **2.5.5 303 Facilities Fresh Metal Storage Facilities**

Ten buildings (303-A, B, C, D, E, F, G, J, K, and M) were built over a period of years from 1944 to 1983 to store fresh uranium, chemicals, uranium scraps and plutonium. Uranium was shipped to Hanford in the form of metal billets. The metal billets were moved to the 303 Fresh Metal Storage Buildings where they were inspected, entered into accountability records, and held for processing. Building 303-L is another building not mentioned above; it was a small building that was constructed in 1961 to burn uranium metal scraps to an oxide form that would be suitable for shipment to the Feed Materials Production Center for recovery. Burning was stopped in 1971 due to the use of unconventional burning vessels (two cement mixers lined with concrete) and poor ventilation. These two factors combined to produce airborne contamination readings that frequently exceeded the then-current Hanford Works (HW) maximum permissible concentration of  $2 \times 10^{-12}$   $\mu\text{Ci/mL}$  for unrestricted areas and  $6 \times 10^{-11}$   $\mu\text{Ci/mL}$  for restricted areas (see Gerber 1992). Building 303L was shut down in 1971 and the building was removed in 1976. In 1983, the new Oxide Burning Facility (303-M) was placed into operation at the same site. It operated from 1984 to 1987. In 1970\*, the 303-C Building was utilized by Pacific Northwest National Laboratory for the storage of plutonium and americium. A pressurization of one of the sealed metal storage cans resulted in the spread of plutonium contamination and the subsequent shutdown of the building until cleanup. It currently is being used for other purposes.

## **2.6 PLUTONIUM FINISHING FACILITIES**

Two plutonium finishing facilities, 231-Z (Plutonium Isolation Building) and 234-5Z (Plutonium Finishing Plant Complex) have operated at Hanford from 1945 to the present [9]. The latter is still involved in plutonium stabilization efforts as a part of the Hanford cleanup program. Both of these complexes are located in the 200-W Area. As noted in Section 2.6.3, the Plutonium Finishing Plant Complex consists of several buildings including 234-5Z that involves several processes [i.e., Rubber Glove Line, Remote Mechanical A Line, Remote Mechanical C Line, and Recovery of Uranium and Plutonium by Extraction (RECUPLEX)]; the 232-Z Incinerator; the 236-Z Plutonium Reclamation Facility; and the 242-Z Waste Storage Facility. External exposures were related to radiation fields,

primarily from plutonium low-energy X-rays and spontaneous fission neutrons. During the early years of plutonium finishing operations, essentially all photon radiation resulted from plutonium X-rays. Later, 60-keV gamma radiation from <sup>241</sup>Am contributed significantly to worker exposure. Neutron radiation was substantially elevated in part of the finishing operation where alpha radiation from plutonium produced neutrons as a result of the  $\alpha/\eta$  reaction with fluorine. Although relatively few Hanford personnel were involved in plutonium finishing, these facilities provided the majority of personnel exposures to neutron radiation. Internal exposures were related to contamination incidents involving americium and plutonium. These exposures occurred by inhalation, absorption and injection (i.e., wound sites). The years of operation and the radionuclides of concern are listed in Tables A-15 and A-16 respectively in Attachment A.

### 2.6.1 231-Z Plutonium Isolation Facility

The 231-Z, Plutonium Isolation Facility began the plutonium finishing process in January 1945 when the first plutonium nitrate solution was received. Adding hydrogen peroxide separated the plutonium from the nitrate solution purified plutonium. Until July 1949, the plutonium was dried and shipped off the Site for further refining. When the 234-5Z (see Table A-15) went into operation, in July 1949, the refined product was shipped off the Site for plutonium finishing. Chemical processing was continued in the 231-Z Building until 1956, when all steps were transferred to the 234-5Z Building. In 1956, the plutonium metallurgy developmental laboratory was moved from 234-5Z to 231-Z. The 231-Z Building continued to be used for metallurgical research on plutonium and alloys until 19UNK. Studies on the use of <sup>233</sup>U were also performed in this building.

### 2.6.2 234-5Z Plutonium Finishing Plant Complex

The 234-5Z Building was used starting in July 1949 for plutonium finishing operations. The Plutonium Finishing Plant (PFP) Complex consists of the 234-5Z Building including several production areas and several other buildings discussed in subsequent sections. The building is currently undergoing D & D.

#### 2.6.2.1 Rubber Glove Line

The Rubber Glove (RG) Line in the 234-5Z Building was used starting in July 1949 for processing plutonium nitrate. All of the tasks listed in the Table 2-1 with the exception of Task I were performed in the RG Line.

Table 2-1. Plutonium nitrate processing tasks [10].

Task	Name	Function
I	Purification, oxalate precipitation, wet chemistry, or feed production	Precipitate the plutonium-nitrate feed solution with oxalic acid and other agents;
II	Hydrofluorination or dry chemistry	Diffuse hydrogen fluoride gas through the precipitate;
III	Reduction	Combine the plutonium tetrafluoride with calcium; Fire at high temperature until fused into a metallic plutonium chunk called a button;
IV	Casting	Render plutonium buttons into pits;
V	Machining	Machine the pit to specified dimensions;
VI	Cleaning	Chemically clean the pit;
VII	Coating	Coat the pit for radiation safety; and
VIII	Final Inspection	Inspect the pit for correct specifications.

In December 1949, production was temporarily halted to make repairs to solve operational and mechanical problems. It was restarted early in 1950. The RG Line was placed on standby at the end of March 1953 with the exception of the coatings units that were shut down in May 1953. In 1955,

equipment from Tasks I and II was removed and buried. A majority of the remaining process equipment was removed from the RG Line in early 1957 in preparation for installation of the new Remote Mechanical C (RMC) Line.

#### 2.6.2.2 Remote Mechanical A Line

The Remote Mechanical A (RMA) Line was designed to reduce worker radiation exposure by automating the process described in the Table 2-1. In March 1952, the RMA Line began to process the plutonium (IV) oxalate that was prepared in 231-Z. By March 1953, the RMA Line began handling all of the plutonium work. In July 1954 a fire in the RMA Line stopped fabrication of pits for three weeks. The RMA Line was taken completely out of service in 1964. The weapon fabrication portion of the RMA Line was removed (see RMC Line below) in March 1966. In Sept. 1967, a glovebox in the RMA Line was reactivated in order to grind plutonium-aluminum scraps into turnings suitable for plutonium recovery. In 1968, Tasks I-III of the RMA Line were cleaned out and reactivated to participate in expanded programs for commercial (i.e., nondefense) nuclear development and experiments such as oxides for the Hanford Fast Flux Test Facility. In 1984, it was decided to keep the RMA Line in standby status. It was never operated again.

#### 2.6.2.3 Remote Mechanical C Line

The RMC Line began processing plutonium nitrate feed in October 1960. In 1962, a project was undertaken to install ten-inch thick water-filled shielding tanks to substantially reduce the neutron exposure to operators. Because of fire(s) in other facilities and the RECUPLEX criticality, other safety improvements including a new criticality alarm system, a new air sample counter and a new paging system were installed in 1963 and 1964. By 1964, the RMC Line was being used for the bulk of the metal processing and the throughput was increased substantially. As a result of a decision to concentrate weapon fabrication work at Rocky Flats Plant, the fabrication portion of the RMC Line was removed in March 1966. The line continued to operate on a mixed schedule for the next several years producing weapons-grade plutonium and fuel-grade plutonium and oxides. As a result of the explosion in the americium recovery process in the 242-Z facility, the RMC Line was shut down in 1976. After preparing to restart production of weapons-grade components, the RMC Line restarted in July 1985. The RMC Line was permanently shut down in May 1989.

#### 2.6.2.4 Recovery of Uranium and Plutonium by Extraction Facility

The RECUPLEX process facility began in July 1955; over the next few years, the facility was heavily used with increasing equipment failures and increasing radiation levels. In February 1960, RECUPLEX was temporarily shut down to permit an extensive cleanup of hoods and operating equipment. In April 1962, a criticality accident resulted in widespread contamination throughout the RECUPLEX room and in high external exposures to several workers. In May 1962, the Atomic Energy Commission decided to deactivate that section of the 234-5Z facility.

#### 2.6.2.5 232-Z Incinerator Facility

In January 1962, the 232-Z Incinerator began processing miscellaneous solid wastes to recover small quantities of plutonium. The process involved incineration of combustible materials, leaching noncombustible materials in nitric acid, and wet leaching of ash. The recovered plutonium was transferred to RECUPLEX and later the Plutonium Reclamation Facility. In 1973, the 232-Z Incinerator was shut down.

#### 2.6.2.6 236-Z Plutonium Reclamation Facility

The 236-Z Plutonium Reclamation Facility was placed into operation in May 1964 to recover plutonium from liquid waste generated in the plutonium finishing plant operations. Using a solution of tributyl phosphate diluted with carbon tetrachloride, metal nitrates and other wastes were stripped from a plutonium-bearing feed. Nitric acid-hydroxylamine solution was then used to separate the plutonium as a nitrate. The plutonium nitrate was then ready as a feed for the RMA and RMC Lines. In December 1975, 236-Z was shut down for maintenance upgrades and reviews of criticality safety specifications and procedures. In 1976, 236-Z operated for only a short time after restart until the explosion in 242-Z resulted in widespread, high levels of  $^{241}\text{Am}$  contamination in the work area. This accident resulted in the shutdown of the entire Plutonium Finishing Complex in April 1976.

#### 2.6.2.7 242-Z Waste Treatment Facility

The 242-Z Waste Treatment Facility began operation in 1963 to recover plutonium from aqueous waste streams from the PFP. An  $^{241}\text{Am}$  recovery process was installed in a glovebox in 242-Z and began operation in May 1965. The recovery process was converted from a batch to a continuous process in 1969. In April 1976, the 242-Z facility was shut down as a result of a strike. In August 1976, during restart of the americium recovery process, an explosion occurred in a cation ion exchange column containing approximately 100 g of  $^{241}\text{Am}$ . This resulted in substantial americium internal exposure. As a result, the 242-Z facility was permanently closed. Doors into the operating area were welded shut and the facility currently is waiting D&D efforts.

### 2.6.3 Plutonium Storage Facilities

Several plutonium storage facilities were constructed at the PFP (234-5Z) starting in 1949. These include 2736-Z, 2736-ZA, and 2736-ZB built in 1971, 1977, and 1982, respectively. There were 12 vault or vault-type rooms in the PFP. These vaults contained 93% of the Hanford Site's unirradiated plutonium items and 92% of the total Hanford unirradiated plutonium inventory in July 1994 at the time the Plutonium Vulnerability Study (DOE, 1994) was performed. External exposure in the vault rooms from low-energy photons and neutrons occurred during periodic inventory and inspection activities. Internal exposure was minimal because there were no routine activities that involved opening the storage containers. Internal exposure would have been a concern in the event of an incident that voided the containment afforded by the storage containers. Stabilization efforts were completed in August 2003.

## 2.7 RESEARCH, DEVELOPMENT, AND TESTING FACILITIES

The 21 major Research, Development, and Testing Facilities at Hanford were located in the 100, 200 and 300 Areas [11]. Construction of these started in 1944, with the last one completed in 1977. These facilities were built to support the development and testing of new processes, materials, and equipment. In some instances the facilities were used for several different purposes throughout their operating lives. Therefore, the potential exposures were dependent on the processes involved and the mission/process at any given time. The years of operation and the radionuclides of concern are listed in Tables A-17 and A-18 in Attachment A.

### 2.7.1 108-F Biology Facility

The 108-F Building was remodeled in 1949 to provide laboratory and office space for the Hanford Site Biology Program [12]. The facility was used to perform radiation effects studies on plants, animals, and fish in support of Hanford operations. Studies involved many radionuclides including  $^{90}\text{Sr}$ ,  $^{131}\text{I}$ ,

$^{238}\text{U}$ , and  $^{239}\text{Pu}$ . The building was expanded in 1953 and again in 1962 to provide additional space for biological experiments. The facility was closed in 1977 when the Biology Program moved to the 331 Building (see Section 2.7.16 below).

### **2.7.2 120 Critical Mass Laboratory Facility**

The Critical Mass Laboratory was originally operated in the 120 Building located near the 100-F Area starting in April 1950 [13]. This laboratory was used for nuclear physics research and development studies of plutonium solutions and solids to avoid the accidental occurrence of a criticality event in an operating facility. In November 1951, a substantial spread of contamination occurred as a result of an experiment performed with a plutonium solution. In December 1950, spontaneous ignition of rags soaked with nitric acid occurred during cleanup. While the metal building was not destroyed, the facility was permanently closed due to the extensive plutonium contamination. The site was subsequently decontaminated and decommissioned.

### **2.7.3 209-E Critical Mass Laboratory**

The 209-E Critical Mass Laboratory was placed into operation in July 1961 [14]. The laboratory, located in a room shielded by at least 3 ft of concrete, included a mixing room with a glovebox and mixing hood and a control room from which critical mass physics experiments were remotely conducted. Both  $^{239}\text{Pu}$  and  $^{240}\text{Pu}$  was used in the criticality studies. As a result, external exposures were minimized. Internal exposures were related to contamination incidents involving plutonium. This facility was shut down in 1986\* after a series of occurrences that involved criticality safety specifications.

### **2.7.4 222-B Laboratory**

The 222-B laboratory was opened in the 222-B Building in 1945 to perform process or research and development radiochemical operations in support of irradiated fuel-reprocessing facilities [15]. One of the main functions was to test the solution samples from the 221-B and 224-B Buildings at various steps in the separations process. External and internal exposures were associated with the FP and plutonium in the process samples. It was shut down in about 1975. This facility was converted to office space.

### **2.7.5 222-S Laboratory**

Construction of the 222-S laboratory was started in 1949. The laboratory contains laboratories and shielded cells that were used to provide analytical services in support of process control of REDOX, B-Plant, and 242-S and 242-A Evaporators [16]. It currently is used for analytical operations in support of waste management and environmental control processes. External exposures were related primarily to FP in process samples. Internal exposures would primarily be associated with samples associated with the separations plants process samples (e.g., FP and plutonium). In the early 1960s, some work was performed with  $^{147}\text{Pm}$ . Internal exposures were primarily related to contamination incidents.

### **2.7.6 222-T Laboratory**

The 222-T Laboratory was the first to operate commencing in 1944 in support of the separation process in 221-T and supporting work in 224-T [17]. External and internal exposure potential was similar to that in 222-B. It was shut down in 1980\*. Fire protection was shut off in 1986.

### **2.7.7 308 Plutonium Fuels Pilot Plant**

The Plutonium Fuels Pilot Plant (PFPP) was constructed in the 308 Building in 1960 to perform research and development on fuel elements used in the PRTR. In the mid-1960s, the PRTR fuel work was terminated. In the late 1960s, neptunium-aluminum alloy fuel target elements were produced for use in N Reactor for a  $^{238}\text{Pu}$  production run. A high bay area was added to the building in 1971. A  $^{147}\text{Pm}$  contamination incident occurred in the 308 Building in 1971. From 1977 to 1991, the facility was used for the production of FFTF fuel elements. The 308-A annex was added to the Plutonium Fabrication Pilot Plant in 1979 to accommodate additional plutonium fuels work. A 250-kW Training Research Isotopes, General Atomics (TRIGA) reactor was installed in the annex in the late 1970s to perform neutron radiography, a feature of the QA testing program. During its operation, the building experienced many incidents that involved the loss of control of radioactive materials, primarily plutonium. Most of these were contained within usually one laboratory and in adjacent corridors. Glovebox fires, explosions, and/or ruptures were the most frequent cause of contamination. Improperly sealed irradiated sample containers were another common cause. These incidents occasionally resulted in internal exposures. The 308 facilities were deactivated in 1990\*.

### **2.7.8 318 Radiological Calibration and Development Laboratory**

The 318 Building was originally built in 1967 to house the HTLTR (see Section 2.3.8). In the early 1980s, the reactor was removed and the heavily shielded 10-m<sup>3</sup> reactor cell was converted to a free-in-air calibration facility that contains a large  $^{252}\text{Cf}$  neutron source ( $10^9$  n/s) and a large  $^{137}\text{Cs}$  photon source (approximately 100 Ci) that were used for dosimeter calibration [18]. A shielded facility was built in the basement to house a high-level  $^{60}\text{Co}$  source (approximately 1 kCi) to create accident dose rate levels and three 300-kVp X-ray machines. The calibration laboratory commenced operation in 1983. Three major additions were constructed in 1985, 1987, and 1989. The first contained four source wells that held two  $^{137}\text{Cs}$ , one  $^{60}\text{Co}$ , and one  $^{252}\text{Cf}$  sources used for instrument calibration. The second addition housed instrument testing and repair laboratories and the last addition provided office facilities for the staff. As a result of the shielding, isolation, remote operations, and operating procedures, external exposures were minimized. Internal exposures were negligible. The facility is still in operation.

### **2.7.9 320 Low-Level Radiochemistry Facility**

The Low-Level Radiochemistry Laboratory was built in the 320 Building in 1966. The original missions were to house analytical chemistry services and provide plant support involving low-level and nonradioactive samples. The 320 Building currently provides a low-level radiochemistry facility in which very sensitive radiochemical analysis, sample preparation, and methods development can be performed. External and Internal exposures were minimal. The facility is still in operation.

### **2.7.10 321 Separation Facility**

The 321 Separation Facility (Cold Semi-Works) was built in 1944 with a mission to be used as a cold (i.e., nonirradiated material) pilot plant to test the bismuth phosphate chemical reprocessing methods and equipment and to study problems as the 221, 224, and 231 Buildings were being constructed. In late 1944, it was decided to add a laboratory for work with small amounts of solutions that contained several tenths of a curie to a curie of radioactive materials (Gerber 1993a; Hanford Site Historical District no date). Soon after startup, the 321 Building assumed a mission to demonstrate the effects of proposed process changes on decontamination factors in the 221, 224, and 231 Buildings, conduct isotope separations, and perform experiments on small irradiated samples. In 1949, 321 was used to develop the REDOX process. Tests using radioactive materials were discontinued after 1949. The

321 Building was used in 1953 to perform a cold test of the PUREX process. Pilot-scale tests of the U-Plant recovery process were conducted in 1955. Isotope campaigns were conducted in the 1960s using tracer levels of  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ ,  $^{144}\text{Ce}$ ,  $^{147}\text{Pm}$ , and  $^{237}\text{Np}$ . Primary contamination in the facility was due to thorium and uranium. External and Internal exposures were minimal. The building was deactivated in 1988.

### **2.7.11 324 Chemical and Materials Engineering Laboratory**

The Chemical and Materials Engineering Laboratory began operation in 1966 to provide research and development studies in support of the PRTR operations. It was used first as a fuel recycle pilot plant by housing chemical reprocessing and metallurgical examination capabilities used for PRTR fuel elements. It consisted of two groups of large shielded cells used for both radiochemical and metallurgical studies. The chemistry cells consisted of four cells connected to an air lock where studies of various processes for the solidification of high-level liquid waste were performed. It was used in conjunction with the 325-A hot cells to perform studies on solidification of high-level liquid waste (i.e., Nuclear Waste Vitrification Project) from processing irradiated fuel elements from commercial reactors). A special underground liquid waste pipe line connected the hot cells in 324 and 325-A. Most recently, it was used as a Waste Technology-Engineering Laboratory. Because most of the work was performed in hot cells, external and internal exposures were minimized. The 324 Building is currently undergoing D&D activities.

### **2.7.12 325 Radiochemistry Laboratory**

The 325 Building was completed in 1953 to permit multicurie level chemical development work in support of production and process improvement (Marceau 2002; Hanford Site Historical District no date). A high-level radiochemistry wing, 325-A, was placed into operation on the east side of the building in 1959 and 1960. It included three large hot cells for isotope research activities. This included separation and concentration of  $^{90}\text{Sr}$ ,  $^{90}\text{Y}$ ,  $^{131}\text{I}$ ,  $^{137}\text{Cs}$ ,  $^{144}\text{Ce}$ ,  $^{147}\text{Pm}$ ,  $^{210}\text{Po}$ ,  $^{238}\text{Pu}$ ,  $^{239}\text{Pu}$ , and  $^{244}\text{Cm}$  for special programs. The  $^{147}\text{Pm}$  was used in the manufacture of heat sources starting in 1966. The  $^{210}\text{Po}$  work started in June 1972 and was terminated in 1975\*. In 1990\*,  $^{90}\text{Y}$  was separated from  $^{90}\text{Sr}$  in multicurie quantities for medical use. These cells were also used in support of the studies on solidification of high-level radioactive waste (i.e., Nuclear Waste Vitrification Project) from processing irradiated fuel elements from commercial reactors. A special underground liquid waste pipe line connected the hot cells in 324 and 325-A. The Nuclear Waste Vitrification Project that was conducted in the 324 and 325 Buildings in the 1970s involved high "burnup" commercial fuel elements that were characterized by nominally 26%  $^{240}\text{Pu}$  (Carbaugh 2003). High-level radioanalytical hot cells were added on the west side in 19UNK. The building became known as the Radiochemistry/Cerium Recovery Building. Limiting access to high-level dose rate or contamination areas controlled external and internal exposures. Most exposures were related to maintenance performed in hot cells or accidents in laboratory areas where work was being performed with FP, plutonium, and other radionuclides. A major  $^{147}\text{Pm}$  contamination incident occurred in the late 1960s. The radiochemical laboratory work resulted in external exposure and any internal exposure resulted from contamination incidents. The 325 Building still is in use in support of cleanup efforts at Hanford.

### **2.7.13 326 Pile Physics Technology and Metallurgy Facility**

Operation of the 326 Building started in 1953 to continue exponential pile physics development work originally performed in the P-11 Facility and later in 189-D (Marceau 2002; Hanford Site Historical District no date). Po-Be and Ra-Be neutron sources with neutron emissions up to  $1 \times 10^8$  n/s were used to irradiate cobalt and copper test foils. The test foils exhibited radiation levels up to 10 rad/hr at 3 in. The facility was also used for metallurgical studies of reactor components and fuel elements to

evaluate characteristics and performance. Some of this work was transferred to 209-E in 1961. A High Energy Electron Microscope was installed in the basement in 1971 to perform materials studies. During microscope operations, there was a major spread of plutonium and irradiated steel (i.e., Fe) contamination. This and other contamination incidents resulted in some internal exposure. In 1983, the 326 Building became the "Chemical Science Building." This facility is still in operation.

#### **2.7.14 327 Radiometallurgy Laboratory Facility**

The 327 Radiometallurgy Laboratory was built in 1953(?) to replace the 111-B Test Building (Gerber 1993b; Marceau et al. 2002; Hanford Site Historical District no date). It was designed to provide post testing and other studies on irradiated materials, particularly fuel elements and fuel cladding materials from and for the production reactors. These facilities originally consisted of eight freestanding shielded cells and two water-filled storage pools. Several modifications were undertaken to provide a shielded loadout facility to handle high-level radioactive waste, a large shielded cell to perform special environmental radiometallurgy studies, and office space. In 1967, it was used for the experimental production of  $^{238}\text{Pu}$ . It was used to study irradiated PRTR, FFTF, General Electric Test Reactor (GETR), Experimental Breeder Reactor (EBR) II, and Material Test Reactor (MTR) fuel elements. In 1967, it was involved in a serious contamination event. The 327 Building was renamed the Post Irradiation Testing Laboratory in the 1980s. External and internal exposures were related to irradiated materials, and FP that were undergoing metallurgical studies. Work was also performed with  $^{233}\text{U}$  and  $^{238}\text{Pu}$ . The facility was deactivated in 1987.

#### **2.7.15 329 Biophysics Laboratory**

The biophysics laboratory was opened in 1952 to pioneer development of water chemistry, environmental monitoring, and bioassay analysis programs. Missions for the laboratory include the analyses of low-level (i.e., near-background) quantities of radioactive materials in air, vegetation, soil, wildlife, and river and well water samples. A neutron multiplier facility was built in 1974 as section D of the biophysics laboratory. It commenced operation in 1977 with a large  $^{252}\text{Cf}$  source. External and internal exposures were minimized. The building is still in operation.

#### **2.7.16 331 Life Sciences Laboratory Facility**

The Life Sciences Laboratory opened in the 331 Building in 1972 as a replacement to the 108-F complex. The facility was used to perform radiation effects studies on plants, animals, and fish in support of Hanford operations. Studies involved many radionuclides including  $^{90}\text{Sr}$ ,  $^{131}\text{I}$ ,  $^{238}\text{U}$ , and  $^{239}\text{Pu}$ . A hot cell that originally contained a 15-kCi  $^{60}\text{Co}$  source was used for special irradiation studies. External and internal exposures were at a minimum. The facility is still in operation.

#### **2.7.17 3706 Radiochemistry Laboratory**

The 3706 Building, the original radiochemistry laboratory, was placed in operation in early 1945 (Gerber, 1993c; Marceau et al. 2002; Hanford Site Historical District no date). This building was also known as the Technical Building. The original mission was to perform small-scale experiments with both low- and high-activity radioactive materials in support of production activities with the primary focus on improving the bismuth phosphate process. The QA/Quality Control activities associated with fuel element fabrication also were performed in the 3706 Building. Other missions were the metallurgical examination of irradiated fuel elements, fuel development for the 313 Building, examination of graphite from the experimental levels of the 100 Area piles, and special sample analyses from 231Z and 200 Area separation facilities. In 1947, it was used in the development of the REDOX process. Pioneering radiochemistry work in the development of the REDOX, PUREX, and

RECUPLEX processes was performed until 1953. Work involved many radionuclides including FP,  $^{14}\text{C}$ ,  $^{131}\text{I}$ ,  $^{235}\text{U}$ ,  $^{238}\text{U}$ , and  $^{239}\text{Pu}$ . External and internal exposures were related to these radionuclides. Thyroid checks were initiated in May 1947. In 1954, many of the laboratories were decontaminated and converted to offices. During the 1970s and 1980s, most of the remaining building was converted to offices that still were in use in the early 1990s.

### **2.7.18 3730 Gamma Irradiation Facility**

The 3730 Building was originally constructed in 1949 as a shop. In 1956, the work performed in the 3741 Building was transferred to this building. A 350-kCi Co-60 source was added to a pool in the 1960s for special irradiation studies. Irradiated samples measured from 25 to 50 rad/hr. Respiratory protection was required in the 1950s because of  $^{14}\text{C}$  and  $^{35}\text{S}$  airborne contamination. Several facility improvements were made during 1974 to 1981.

### **2.7.19 3732 Process Equipment Development Laboratory**

The 3732 Process Equipment Development Laboratory was constructed in 1949 as an engineering pilot plant for the triple-dip and lead-dip fuel canning processes (Gerber 1992). It is a one-story, metal frame structure on a concrete foundation, with a concrete floor and a corrugated metal roof. Overall dimensions are 28.5 ft by 48.16 ft. Powdered thorium oxide fuel targets for  $^{233}\text{U}$  production were fabricated in the 3732 Building from 1965 to 1967. The process of handling these powder targets spread powdered and particulate thorium contamination throughout the building. After the thorium oxide program switched to pelletized targets in the 3722 Building in 1968, these new fuel targets were canned in the 3732 Building through 1970. As a result, the 3732 Building contains standard fuel fabrication chemical wastes, as well as residual thorium oxide contamination in crevices and areas throughout and near the building. The facility is now empty.

### **2.7.20 3741 Graphite Hot Shop Facility**

The Graphite Hot Shop was constructed in 1944 to perform metallurgical studies on irradiated graphite samples. Po-Be and Ra-Be neutron sources were used in irradiation facilities in the basement to irradiate cobalt and copper foils. Internal exposures would have been primarily due to the large quantities of irradiated graphite (i.e.,  $^{14}\text{C}$ ) that were studied. The facility was torn down in 1956 and work was transferred to 3730 (Hanford Site Historical District no date).

### **2.7.21 3745 Radiological Calibrations and Standards Laboratory**

The Radiological Calibrations and Standards Laboratory opened in the 3745 Building in October 1944 [19]. The two-story wooden frame building contained a low scatter room in which dosimeters were calibrated using a  $^{226}\text{Ra}$  source and a 220-kVp X-ray machine. Other sources used included large  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  photon sources and  $^{252}\text{Cf}$ ,  $^{226}\text{Ra-Be}$ ,  $^{84}\text{Po-Be}$ ,  $^{238}\text{Pu-Be}$ ,  $^{239}\text{Pu-F}$ , and  $^{124}\text{Sb-Be}$  neutron sources. Instrument calibrations were performed in a different room that contained two vertical concrete-shielded wells in which the photon sources were housed and used. Instrument calibration sources included  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and  $^{226}\text{Ra}$  sources. A supporting facility, 3745B, was constructed of concrete blocks to house a 4-MeV Van de Graff positive ion accelerator. This was used starting in 1955 to perform fast neutron calibrations. A companion facility, 3745A, was built in 1950\* to house a 2-MeV negative ion Van de Graff accelerator. As a result of the shielding, isolation, remote operations, and operating procedures, external exposures were minimized. Internal exposures were negligible. The calibration operations were moved to the 318 Building in 1983. The building is still used for office space.

## **2.8 WASTE HANDLING FACILITIES**

### **2.8.1 High-Level Liquid Waste Tanks**

High-level radioactive liquid wastes from reprocessing facilities at Hanford were stored in underground single- and double-shell tanks starting in 1944 [20]. The high-level radioactive waste is transported through underground process lines to the storage tanks that are located in tank farms in 200-E and 200-W Areas. The storage tanks are of two types, single-shell and double-shell. Both types are cylinder-shaped concrete structures with carbon steel liners. The single-shell tank has a single liner and the double-shell tank has two liners with a space in between. Initially, the T and B Plants produced more than 10,000 gal of high-level radioactive waste for each ton of uranium processed. These wastes were transferred to the first 64 tanks constructed in 1944 and 1945. Thirty new single-shell tanks were constructed in 1947 and 1948. Additional single-shell tanks were constructed in 1950 and 1952 (30), in 1953 to 1955 (21), and in 1963 and 1964 (4). From 1968 to 1988, 28 double-shell tanks were constructed. Most of the single- and double-shell tanks are still in use. A new waste glassification facility is under construction to process the stored high-level liquid wastes. External exposure is due to high-energy beta and photon radiations from the FPs stored in the tanks. Under normal conditions shielding, distance, and time minimize personnel exposures. Most external exposures would be related to leaks of high-level wastes. Internal exposures to FPs were controlled through the use of respiratory protection.

### **2.8.2 216-Z-9 Trench Facility**

The 216-Z-9 Facility, known as the (Z-9) crib (i.e., enclosed trench), is located in the 200-W Area approximately 500 ft east of the Z Plant (i.e., PFP) exclusion area. The Z-9 trench was placed into operation in 1955 to serve the RECUPLEX Facility by receiving the acid waste stream of both aqueous and organic wastes as well as unwashed fabrication oil from the RMA Line from 1955 to 1962. The trench was an underground excavation within an active floor area of 30 by 60 ft, 21 ft beneath the top of the concrete slab cover. The excavation was covered by a 9 to 12-in.-thick reinforced concrete slab, 90 ft wide and 120 ft long at ground level. In 1965, because of concern that the waste plutonium posed a "potential criticality hazard," a decision was made to develop a soil mining and leaching operation to recover an estimated 45 kg of waste plutonium. An approximately 1,000-ft<sup>2</sup> containment structure was built underground to conduct the operation. It housed a soil packaging glovebox, personnel entry to the trench, and a personnel change room. The structure was located on the east side of the trench with part of the structure located over the top of the trench cover. The mining operator's cubicle, which contained the controls for operating the mining equipment, was in the west side of the trench cover through a reinforced opening in the trench cover. The mining operation commenced in August 1976 and was completed in July 1978. The principal internal exposure potential was related to <sup>239</sup>Pu contamination, most of which occurred in the soil packaging glovebox. Because the waste site was used only for plutonium, the external exposure potential during the mining operation was minimal. The facility currently is in a laid-away status.

### **2.8.3 241-Z Settling Tank**

The 241-Z Settling Tank, located within the fence of the PFP complex in the 200 West Area, was used from 1949 to 1973 to store large quantities of plutonium-bearing wastes. In 1974, 80,000 L of supernate were removed from the tank leaving an estimated 94-in.-deep layer of wet sludge containing a few tens of kilograms of plutonium. Internal and external exposures from this operation are minimal. The facility is currently awaiting D & D.

#### 2.8.4 242 Evaporator Facilities

The evaporator facilities (242-A, 242-B, 242-S, and 242-T) were constructed near each of the separation facilities to reduce and concentrate the volume of high-level wastes. The 242-T and 242-B Evaporators started processing high-level radioactive waste starting in 1951. Two new evaporator plants, 242-S and 242-A, commenced operation in 1973 and 1976, respectively. External exposure would be due to high-energy beta and photon radiations from the fission products stored in the tanks. Personnel exposures normally are controlled using shielding, distance, and time. Most external exposures would be related to leaks of high-level wastes. Internal exposures to FPs were controlled through the use of respiratory protection. The first three evaporator facilities were shut down in 19UNK. The 242-A is still in operation.

#### 2.8.5 Chemical Separations Exhaust Filtration Facilities

Gaseous waste is grouped into three headings: dissolver off-gases, process vessel vent systems, and exhaust ventilation air. Dissolver off-gases were contained the major portion of the radioactive iodine (primarily <sup>131</sup>I), as well as krypton and xenon isotopes. Dissolver off-gases also carried a high concentration of nitrogen oxides resulting from the reduction of nitric acid during the dissolution of the irradiated fuel elements. Table 2-2 lists the three exhaust filtration devices that were used starting in 1947 to reduce radioactive material releases from the B and T Separations Plants and later the REDOX Plant:

Table 2-2. Exhaust filtration facilities [21].

Filtration devices	Date installed
Caustic scrubbers	1947–1948
Sand filters and fiberglass filters	1947–1948 1954(REDOX)
Silver reactors	1950

These filtration devices accumulated substantive quantities of radioactive materials from the separations and plutonium concentrations. The caustic scrubbers were used to remove radiochemical vapors from the process vessels. Sand filters were installed in the 202-S, 221-B, 221-T, 291-B, 291-S, 291-T, 291-Z facilities. The filters were used in exhaust streams associated with the separations process to remove particulates and to reduce ruthenium emissions from the exhaust stream. Silver reactors were installed primarily to remove <sup>131</sup>I from the exhaust stream. Radionuclides of interest in the filtration devices included FP, <sup>103</sup>Ru, <sup>106</sup>Ru, <sup>131</sup>I, and <sup>239</sup>Pu. Internal and external exposures associated with these radionuclides would occur primarily during maintenance operations. These filtration devices became inactive as the separations facilities were shut down.

#### 2.8.6 340, 340-A and 340-B Liquid Waste Handling Buildings

The 340-facility complex was operated starting in 1954 to receive radioactive liquid wastes from various 300 Area laboratories via the radioactive liquid waste sewer line [22]. The complex accumulates the liquid wastes in storage tanks. After sample analyses and pH adjustment, the liquid wastes are shipped via a shielded railcar tank to the 200-E Area Tank Farms for treatment and disposal. The radionuclides of concern include <sup>60</sup>Co, <sup>90</sup>Sr, <sup>90</sup>Y, <sup>137</sup>Cs, <sup>147</sup>Pm, <sup>238</sup>Pu, <sup>239</sup>Pu, and <sup>144</sup>Ce. Access to the tank area was administratively controlled. The external exposures to the operators were related to the high-energy betas and photons. Internal exposures were unplanned and would be related to leaks or an accident. The facility is still in use.

## 2.9 ATTRIBUTIONS AND ANNOTATIONS

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

John (Jack) Selby served as the initial Subject Expert for this document. Mr. Selby was previously employed at Hanford and his work involved management, direction, or implementation of radiation protection and/or health physics program policies, procedures, or practices related to atomic weapons activities at the site. This revision has been overseen by a Document Owner, who is fully responsible for the content of this document, including all findings and conclusions. Mr. Selby continues to serve as a Site Expert for this document because he possesses or is aware of information relevant for reconstructing radiation doses experienced by claimants who worked at the site. In all cases where such information or prior studies or writings are included or relied on by the Document Owner, those materials are fully attributed to the source.

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**GLOSSARY****burnup**

Depletion of fissionable material (i.e.,  $^{235}\text{Pu}$ )

**mint**

Tritium

**pile**

Reactor

**pit**

A machined part of a nuclear weapon

**slugs**

Another name for fuel elements

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**A.1 REACTORS**

External exposures at the Production Reactors are primarily due to the presence of activation and fission products [23]. During operation, entry was restricted or prevented into areas where high direct dose rates from photons and neutrons could occur.

Internal exposures at the Production Reactors are related primarily to the inhalation or absorption of activation products and, to a lesser degree, fission products during refueling and maintenance operations. Studies in later years at N Reactor to characterize worker exposure indicated the primary internal exposure in the Production Reactors was due to <sup>60</sup>Co, a corrosion product. It was stated (Sula et al 1989), "In general, a major characteristic of these corrosion product radionuclides, regardless of origin, is the presence of several radionuclides within a matrix of oxidized metal with <sup>60</sup>Co the predominant radionuclide". Several radionuclides in the metal oxide corrosion product mixture include <sup>58</sup>Co, <sup>60</sup>Co, <sup>54</sup>Mn, and <sup>59</sup>Fe, with <sup>60</sup>Co being the predominant contributor to dose and activity. These radionuclides are all associated with elements found in steel and alloys used in reactor components. Other radionuclides might be present in trace amounts, but they generally are of minimal internal dosimetry significance.

There were seven small Research and Test reactors operated at Hanford starting in 1944 with only FFTF still in existence [24]. External and internal exposures at these reactors were low (i.e., minimal in most cases) and unique to the specific reactor. With the exception of routine tritium exposures when working in the containment vessel at PRTR, external and internal exposures are primarily associated with minor accidents.

External exposure at the PRTR was minimized as a result of the remote operation and the shielding. Maintenance operations resulted in external exposure from activation and fission products. A high extremity exposure occurred when a worker picked up an irradiated steel pin. Tritium (<sup>3</sup>H) oxide was the principal internal exposure contaminant during normal operation. This was added into the whole-body dose (see Internal and External Dosimetry Sections of this Site Profile). The reactor was shut down in 1969 after an accident resulted in contamination in the reactor. A sample of the contamination showed the major contaminant was <sup>95</sup>Zr/Nb. Other contaminants included <sup>60</sup>Co, <sup>103</sup>Ru, <sup>106</sup>Ru, <sup>106</sup>Rh, <sup>140</sup>Ba/La, <sup>141</sup>Ce, <sup>144</sup>Ce, and <sup>144</sup>Pr.

Table A-1. Production reactors years of operation [25].

Reactor								
B	C	D	Dr	F	H	KE	KW	N
9/1944– 2/1968	11/1952– 4/1969	12/1944– 6/1967	10/1950– 12/1964	2/1945– 6/1965	10/1949– 4/1965	2/1955– 1/1971	12/1954– 1970	12/1963– 1987

**A.2 FUEL REPROCESSING FACILITIES**

External exposures were primarily from high-energy betas and photons in the separations facilities associated with FP [26]. Internal exposures, primarily associated with contamination incidents, could be due to FP and/or plutonium. The following mix of radionuclides – <sup>238</sup>Pu, <sup>239</sup>Pu, <sup>240</sup>Pu, and <sup>241</sup>Pu – comprises most plutonium mixtures at Hanford. The Hanford plutonium mixtures as listed in Tables A-7, A-8, and A-9 were categorized by their weight percent of <sup>240</sup>Pu (Carbaugh 2003). When the production reactors were operating, the target mixture was ~ 6% <sup>240</sup>Pu (i.e., weapons grade).

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Table A-2. Radionuclides of concern for all production reactors.<sup>a</sup> (Marceau et al. 2002)

As-76	I-135	Sr-91
Ca-41	Mn-54	Sr-92
Co-58	Mn-56	U-238
Co-60	Na-24	Y-90
Cr-51	Nb-97	Y-92
Cu-64	Np-239	Y-93
Fe-59	P-32	Zn-65
Ga-72	Si-31	Zn-69
I-133		

a. The composition and relative abundance are not known. These radionuclides represent 98% of radioactive materials in effluents. It should be noted that several of these are short-lived activation products (e.g., <sup>31</sup>Si, <sup>76</sup>As, etc.) that would result in only limited, if any, exposure to workers.

Table A-3. Research and test reactors years of operation [27].

Reactor						
HTR	PCTR	TTR	PRTR	PRCF	HTLTR	FFTF
1943–1972	1954–1970	1954–1978	1960–1969	1962–1976	1968–1971	1980–1994

Table A-4. Radionuclides of concern for all research and test reactors. (Marceau et al. 2002)

Ru-103	U-235	S-35
Rh-106	Pu-238	Po-210
Ru-106	U-238	Ra-226
Ba-140/La	Pu-239	U-233
Ce-141	H-3	Np-237
Ce-144	Co-60	Pu-240
Pr-144	Zr-95/Nb	Cm-244
U-233	Cf-252	

A special study in the 1980s indicated frequent-intermittent releases of plutonium in the workplaces at levels below detectability for normal air sampling. This resulted in <10 mrem committed effective dose equivalent (Bihl, 1993; Lyon et al. 1988, 1989).

The new lung model for internal dosimetry uses absorption types. The new types are F, M, S for fast, moderate, and slow, respectively. Plutonium in nitrate form is M, which would apply to the separations plants up to the point when N cell was started at PUREX. Plutonium oxide is classed as type S. This would apply to material calcined at either N cell at PUREX. Type S at PUREX would apply only to N cell, not the PR Room. Contamination remaining in old gloveboxes, hood exhaust ducts, high-efficiency particulate air (HEPA) and sand filters and housings, etc., probably would be classed between M and S, but the default would be S. This is because plutonium slowly oxides.

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Plutonium at 233-S was type M until 1967 when the fire resulted in the facility shutdown. The plutonium would be Type S by the time D&D was started at 233-S in the 1980s. It should be assumed after 1990 that all plutonium at Hanford would be class S because of natural oxidation. Note: The default solubility classes should be used only when bioassay data are inconclusive.

The B Plant facilities were modified in 1968 to remove <sup>90</sup>Sr and <sup>137</sup>Cs from high-level wastes from the single- and double-shell waste tanks. The purified <sup>90</sup>Sr and <sup>137</sup>Cs solutions were transferred to the 225-B Waste Encapsulation Storage Facility (see Section 2.4.6). Internal exposures from the operation were minimal due to the remote operation. As a result of remote operation, external exposures to high-energy photons and beta particles that resulted from the processing of large quantities of strontium and cesium were minimized. The 108-B Facility was used for the extraction of tritium (<sup>3</sup>H) for several years. Internal exposure was related to tritium, which was added to whole-body exposure (see External and Internal Dosimetry Sections of this Site Profile).

Internal exposures at U and UO<sub>3</sub> plants were due to the large quantities of uranium processed. The contaminant could be found ranging from soluble uranyl nitrate and UO<sub>3</sub> to insoluble UO<sub>2</sub> and U<sub>3</sub>O<sub>8</sub>.

The inhalation class for Hanford uranium compounds, based on ICRP Publication 66 (ICRP 1994), is listed in Table A-14.

The years of operation and radionuclides of concern are listed in Tables A-5 and A-6.

Table A-5. Fuel reprocessing facilities years of operation [28].

Separation Facility								
B	T	REDOX	PUREX	U	UO <sub>3</sub>	225-B	C	Tritium
4/1945– 10/1952(a)	12/1944– present (b)	1/1952– 12/1967©	1/1956– 12/1992 (d)	3/1952– 1/1958	1/1952– 1993(e)	19UNK– present	1949*– 1967(f)	8/1949– 1955

- a. In 1968, B Plant started to remove Sr-90 and Cs-137 from high-level wastes.
- b. The T Plant discontinued reprocessing operation in March 1956 (\*) and was utilized as a Decontamination Facility; the 2706-T Annex was added in 1959.
- c. The 233-S facility located at REDOX started operation in 1957 and shut down in 1967.
- d. Closed in June 1972 and reopened in November 1983.
- e. Shut down in 1972 and opened in 1983 (there were 17 startups and shutdowns between 1984 and 1992)
- f. Started operations in 1952 (?) as REDOX Pilot Plant; 1954, started operations as PUREX Pilot Plant; 1962, started operation as Pilot Plant for recovery of cesium and strontium waste tanks

NOTE: date for d has not been resolved.

\* More than one date was found

UNK - No date found



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Am-241	0	2.19E-02	3.89E-02	5.22E-02	6.24E-02	7.03E-02	7.63E-02
Pu-239+240	7.98E-02	7.98E-02	7.98E-02	7.97E-02	7.97E-02	7.97E-02	7.97E-02
Pu-alpha	9.69E-02	9.62E-02	9.56E-02	9.49E-02	9.43E-02	9.37E-02	9.32E-02
Total alpha	9.69E-02	1.18E-01	1.35E-01	1.47E-01	1.57E-01	1.64E-01	1.69E-01
<b>Activity ratios</b>							
Pu-239+240: Am-241	NA	3.64	2.05	1.53	1.28	1.13	1.04
Pu-239+240: Pu-238	4.67	4.86	5.05	5.24	5.46	5.69	5.90
Pu-241: Pu-239+240	3.87	3.05	2.40	1.88	1.48	1.17	9.16
Pu alpha:Pu-239+240	1.21	1.21	1.20	1.19	1.18	1.18	1.17
Pu alpha: Pu-238	5.67	5.87	6.05	6.24	6.46	6.69	6.90
Pu alpha: Am-241	NA	4.39	2.46	1.82	1.51	1.33	1.22
Pu-241: Pu alpha	31.9	25.3	20.0	15.8	12.5	9.91	7.83

a. Time since separation of the <sup>241</sup>Am from the Pu mix.

Table A-9. Activity composition of Hanford reference commercial power fuel-grade plutonium mixture. (Carbaugh 2003)

<b>Mixture designation:</b>	<b>Fresh</b>	<b>5-year</b>	<b>10-year</b>	<b>15-year</b>	<b>20-year</b>	<b>25-year</b>	<b>30-year</b>
<b>Years of aging<sup>a</sup>:</b>	<b>0</b>	<b>5</b>	<b>10</b>	<b>15</b>	<b>20</b>	<b>25</b>	<b>30</b>
<b>Specific activity in mixture (Ci/g)</b>							
Pu-238	1.71E-01	1.64E-01	1.58E-01	1.52E-01	1.46E-01	1.40E-01	1.35E-01
Pu-239	3.41E-02	3.41E-02	3.41E-02	3.41E-02	3.41E-02	3.41E-02	3.41E-02
Pu-240	5.90E-02	5.89E-02	5.89E-02	5.89E-02	5.89E-02	5.88E-02	5.88E-02
Pu-241	1.34E+01	1.05E+01	8.28E+00	6.51E+00	5.12E+00	4.03E+00	3.17E+00
Pu-242	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04
Am-241	0	9.49E-02	1.69E-01	2.26E-01	2.79E-01	3.04E-01	3.31E-01
Pu-239+240	9.31E-02	9.31E-02	9.30E-02	9.30E-02	9.29E-02	9.29E-02	9.29E-02
Pu-alpha	2.65E-01	2.58E-01	2.52E-01	2.45E-01	2.39E-01	2.34E-01	2.28E-01
Total alpha	2.65E-01	3.53E-01	4.20E-01	4.71E-01	5.10E-01	5.38E-01	5.59E-01
<b>Activity Ratios</b>							
Pu-239+240: Am-241	NA	0.981	0.551	0.411	0.344	0.305	0.281
Pu-239+240: Pu-238	0.544	0.568	0.589	0.612	0.636	0.664	0.688
Pu-241: Pu-239+240	144	113	89.1	70.0	55.1	43.3	34.1
Pu alpha:Pu-239+240	2.85	2.77	2.71	2.63	2.57	2.52	2.45
Pu alpha: Pu-238	1.55	1.57	1.59	1.61	1.64	1.67	1.69
Pu alpha: Am-241	NA	2.72	1.49	1.08	0.857	0.770	0.689
Pu-241: Pu alpha	50.6	40.7	32.9	26.6	21.4	17.2	13.9

a. Time since separation of the <sup>241</sup>Am from the Pu mix.

**A.3 FUEL FABRICATION FACILITIES**

External exposures were related to betas and photons associated with uranium. Due to the pyrophoric nature of uranium turnings and chips, internal exposure was related primarily to inhalation of uranium. A pressurization of one of the sealed metal storage cans resulted in the spread of plutonium contamination and the subsequent shutdown of the building until cleanup. The years of operation and radionuclides of concern are listed in Tables A-10 and A-11 below. The radiological characteristics of Hanford uranium mixtures are listed in Table A-12 and the impurities in recycled Hanford uranium are listed in Table A-13. The inhalation class for Hanford uranium compounds is

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listed in Table A-14. Note: The default solubility classes should be used only when bioassay data are inconclusive [29].

Table A-10. Fuel fabrication facilities years of operation [30].

Fuel fabrication				
313	314	333	303 Facilities	306
3/1944–1/1971	7/1944–1971	1961–1988	1944–present	5/1957–1984

Table A-11. Radionuclides of concern for all fuel fabrication and storage facilities [31].

Am-241	Np-237	Pu-238	Pu-239	Th-232	U-235	U-238
--------	--------	--------	--------	--------	-------	-------

#### A.4 PLUTONIUM FINISHING FACILITIES

Although relatively few Hanford personnel were involved in plutonium finishing, these facilities provided the majority of personnel external exposures to neutron radiation. As production increased, 10-in.- thick water-filled walls were installed to reduce worker exposure to neutrons. Special lead-filled gloves were installed to reduce extremity exposure. Worker external exposure in the vault rooms was due to low-energy photons and neutrons that occurred during periodic inventory and inspection activities [32].

Table A-12. Radiological characteristics of Hanford uranium mixtures.  
(Carbaugh 2003)

Uranium mixture				
Weight percentage <sup>a,b</sup>	Natural (NU)	Depleted (DU)	Recycled (RU)	Commercial fuel (CF)
U-234	0.0057	0.0005	0.0082	0.0300
U-235	0.7204	0.2500	0.9700	2.9600
U-236	Negligible	Negligible	0.0680	Negligible
U-238	99.2739	99.7500	98.9500	97.0100
<b>Specific constituent activity in mixture (μCi/g, nCi/mg, or pCi/μg)<sup>c</sup></b>				
U-234	0.3563	0.0313	0.5125	1.8750
U-235	0.0156	0.0054	0.0210	0.0639
U-236	Negligible	Negligible	0.0440	Negligible
U-238	0.3336	0.3352	0.3325	0.3260
Total	0.7054	0.3718	0.9099	2.2649
<b>Specific constituent activity in mixture (dpm/μg)<sup>c</sup></b>				
U-234	0.7909	0.0694	1.1378	4.1625
U-235	0.0345	0.0120	0.0465	0.1419
U-236	Negligible	Negligible	0.0977	Negligible
U-238	0.7405	0.7441	0.7381	0.7236
Total	1.5659	0.8254	2.0200	5.0281
<b>Constituent fraction of total uranium activity in mixture</b>				
U-234	0.5051	0.0840	0.5632	0.8279
U-235	0.0221	0.0145	0.0230	0.0282
U-236	Negligible	Negligible	0.0484	Negligible
U-238	0.4729	0.9014	0.3654	0.1439
Total	1.0000	1.0000	1.0000	1.0000

a. NU, DU, and CF data from Rich et al, 1988.

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- b. RU data based on average of data presented by Sula, et al, 1991.
- c. Can be used to represent specific alpha activity in the mixture as well.

Internal exposures in the operating areas were related primarily to contamination incidents involving americium and plutonium because airflow patterns were designed to control the flow from areas of lower air contamination potential to higher. Maintenance and cleanup operations were conducted in protective clothing that included respiratory protection. Exposures occurred by inhalation, absorption, and injection (i.e., wound sites). Internal exposure in the vault areas was minimal because there were no routine activities that involved opening the storage containers. Internal exposure would have been a concern in the event of an incident that breached the containment [33].

Table A-13. Impurities in recycled uranium at Hanford. (Carbaugh 2003)

Constituent	Maximum allowed <sup>a</sup>	Observed range <sup>b</sup>	Reference level <sup>c</sup>
Plutonium	10 ppb U	<1–2 ppb U	0.4 nCi Pu-alpha/g U
Neptunium	Not established	0.04-0.16 ppm U	0.4 nCi Np-237/g U
Thorium	750 ppm U	8–10 ppm U	5 pCi Th-232/g U
Tc-99	Not established	3–4 ppm U	0.2 µCi Tc-99/g U
Ru-103,106	<20 µCi/lb U	<6 µCi/lb U	40 nCi Ru-106/g U
ZrNb-95	<10 µCi/lb U	<4 µCi/lb U	20 nCi ZrNb-95/g U
Other gamma emitters excluding Tc-99	<2 µCi/lb U	0.09 0.75 µCi/lb U	Negligible

- a. From UO<sub>3</sub> Plant operating specifications, OSD-U-185-0001 (Thompson 1986).
- b. From analysis of uranium lots 88-1, 88-2, 88-3 that were processed in 1988, and lots 93-01, 93-02, 93-03, 93-04, and 93-05, processed in 1993.
- c. A reference level is chosen for determining bioassay monitoring needs and for use as an initial assumption in evaluation of intakes. The use of the reference levels is expected to result in a slight overestimate of dose compared to levels actually observed in 1988.

Table A-14. Inhalation class for Hanford uranium compounds. (Carbaugh 2003)

ICRP 30 inhalation class from lung fluid studies	Compound and location	Recommended ICRP 66 lung absorption type <sup>d</sup>
80% D 20% W	Hanford UO <sub>3</sub> Plant smear sample dissolution study in 1984 <sup>a</sup> , (UO <sub>3</sub> powder)	F
10% D 90% Y	Hanford 303-M Building air sample dissolution study <sup>b</sup> (300 Area Uranium Fuel Production Facilities)	S
29% D 71% Y	Hanford 333 Building air sample dissolution study <sup>b</sup> (300 Area Uranium Fuel Production Facilities)	S
20% D 80% Y	Hanford 306-W Building Machine Shop air sample dissolution study <sup>b</sup>	S
	Uranyl nitrate at PUREX or UO <sub>3</sub> Plant	F
	UCl <sub>4</sub> or U carbonate (assumed form after discharge to the soil)	M <sup>c</sup>

- a. Sula, Bihl, and Carbaugh (1989).
- b. Fisher (1986).
- c. Cooke and Holt (1974).
- d. Note: The default solubility classes should be used only when bioassay data is inconclusive.

In February 1960, RECUPLEX was temporarily shut down to permit an extensive cleanup of hoods and operating equipment. A criticality accident that occurred in the RECUPLEX facility in April 1962

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resulted in high external radiation exposures and in widespread contamination throughout the RECUPLEX room [34].

The new lung model for internal dosimetry uses absorption types. The new types are F, M, S for fast, moderate, and slow, respectively. Plutonium in nitrate form is M, which would apply to the plutonium finishing plants where plutonium nitrate has been involved (e.g., RECUPLEX, 231-Z, etc.). Plutonium oxide that is classed as type S, would apply to material calcined at the RMC Line at PFP. Contamination remaining in old gloveboxes, hood exhaust ducts, HEPA and sand filters and housings, etc., probably would be classed between M and S, but the default would be S. This is because plutonium slowly oxides. It should be assumed after 1990 that all plutonium at Hanford would be class S because of natural oxidation. In a study performed in the early 1990s of the isotopic distribution of plutonium at PFP, it was stated there were approximately 3.7 million g of plutonium with the <sup>240</sup>Pu content ranging from 4% to >19% (Crowe and Szempruch 1994). Note: The default solubility classes should be used only when bioassay data is inclusive.

The years of operation and the radionuclides of concern are listed in Tables A-15 and A-16. The activity composition for Hanford reference plutonium mixtures is listed in Tables A-7, A-8, and A-9.

Table A-15. Plutonium finishing facilities years of operation [35].

Facility/process								
231-Z	232-Z	2345Z RG	2345Z RMA	2345Z RMC	2345Z RECUPLEX	2345Z Storage vault	236-Z	242-Z
1/1945– 19UNK(a)	1/1962– 1973	7/1949– 1957	3/1952– 1984(b)	10/1960– 1989(c)	7/1955– 1/1962	1949– present	5/1964– 4/1976(d)	1963– 1976(e)

- In 1956, the mission changed to plutonium metallurgy development: In 19UNK <sup>233</sup>U metallurgy studies were undertaken.
- In 1964, line shutdown: In 1967 a glovebox was reactivated; in 1968, Tasks I-III were cleaned out and reactivated; in 1984, it was decided to keep the RMA on standby.
- In 1962, 10-in.-thick water-filled shielding tanks were added to substantially reduce operator exposure to neutrons; several safety improvements made in 1963 and 1964; fabrication of pits removed from line in 1966. Shut down in 1976 as a result of explosion in 242-Z; the RMC Line restarted in 1985; shut down in 1989.
- In December 1975, it was shut down for upgrades; restarted in 1976; shut down in April 1976 as a result of explosion in 242-Z.
- In 1969, changed from batch to continuous process; in April 1976 shut down because of strike; in August 1976 restarted; shut down in August 1976 as a result of explosion in americium recovery area.

Table A-16. Radionuclides of concern for plutonium finishing facilities [36].

U-233	Np-237	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242	Am-241
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## A.5 RESEARCH AND DEVELOPMENT FACILITIES

The 21 major Research, Development, and Testing Facilities at Hanford were in the 100, 200, and 300 Areas. Construction of these started in 1944 with the last one completed in 1977. These facilities were built to support the development and testing of new processes, materials, and equipment. In some instances the facilities were used for several different purposes throughout their operating life. Therefore, the potential exposures are dependent on the processes involved and the mission/process at any given time. See Sections 2.7.1 through 2.7.21 for discussion on internal and external exposure potential at specific facilities. The years of operation and the radionuclides of concern are listed in Tables A-17 and A-18 below.

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Table A-17. 100 and 200 Area research and development facilities years of operation [37].

Facility/process					
108-F	120	209-E	222-B	222-S	222-T
1949–1977	4/1950–11/1951	7/1961–1986*	1945–1975	1949–present	1944–1986**

\*Only decade date found  
\*\*More than one date found

Table A-18. 300 Area research and development facilities years of operation [38].

Facility/process						
308	318	320	321	324	325	326
1960–1990 <sup>a</sup>	1983–present <sup>b</sup>	1966–present	1944–1988 <sup>c</sup>	1966–present	1953–present <sup>d</sup>	1953–present

Facility/process							
327	329	331	3706	3730	3732	3741	3745
1953–1987	1952–present	1972–present	1945– late1960s <sup>e</sup>	1949–1981	1949–1970	1944–1956	10/1944– 1983 <sup>f</sup>

- In mid-1960s, PRTR fuel work was terminated; neptunium-aluminum fuel elements produced in late 1960s; high bay area added in 1971; from 1977 to 1991, FFTF fuel elements were produced; the 308A annex was added in 1979; TRIGA reactor was installed in the late 1970s.
- The HTLTR commenced operation in the 318 Building in 1967; the reactor was shut down in 1971; the reactor was removed in the early 1980s; the calibration facility commenced operation in 1983; major additions were added in 1986, 1987, and 1989.
- The 321 separation building started in 1944; in late 1944, work with small amounts of irradiated materials to conduct separations experiments and to study decontamination factors; in 1949, a cold test of REDOX process was performed; a cold test of the PUREX process occurred in 1953.
- The 325-A hot cell wing was added in 1959\*; Pm-147 heat sources manufactured in 1966; Po-210 work started in June 1972 and ended in 1970\* for use with the demonstration of the Waste Vitrification Process for commercial wastes.
- Most of the radiation laboratories were removed in 1954; work with radioactive materials discontinued in late 1960s; building converted to offices in the 1970s and still in use in the early 1990s.
- The 3745-B annex that housed a 4-MV Positive Ion Accelerator started operation in 1955; the 3745-A annex that housed a 2-MV Negative Ion Accelerator started operation in 1950\*; the calibrations operations were transferred to the 318 Building in 1983; the building is being used as offices.

Table A-19. Radionuclides of concern for all 100, 200, and 300 Area research and development facilities [39].

C-14	Pm-147
Ce-144	Pu-238
Co-60	Pu-239
Cs-137	Ru-103
Cu-64	Ru-106
FP	Sr-90
I-131	U-238
U-235	Y-90

## A.6 WASTE FACILITIES

External exposure is related to high-energy beta and photon radiations from the fission products stored in the tanks. Under normal conditions shielding, distance, and time helped keep personnel external exposures at a low level. Leaks of high-level wastes that could result in unusual or

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unplanned external exposures were documented in incident or accident reports. In 1994, data were included in Boomer et al. (1994) on tank waste radionuclide inventory. The data from that report are included in Table A-22. Internal exposures to FP were controlled through the use of respiratory protection.

A mining operation to remove an estimated 45 kg of plutonium from the Z-9 trench was initiated in August 1976 and was completed in July 1978. The principal internal exposure potential was related to <sup>239</sup>Pu contamination, most of which occurred in the soil packaging glovebox. Because the waste site was used only for plutonium, the external exposure potential during the mining operation was minimal.

The years of operation and radionuclides of concern are listed in Tables A-20 and A-21 below.

Table A-20. Waste facilities years of operation [40].

Facility/process					
Waste tanks	Z-9 Trench Facility	241-Z	242 Evaporator Facilities	Exhaust Filtration Facilities	340 Waste Complex
1944–present	1955–1978	1949–1973	1951–present	1947–19UNK	1954–present

Table A-21. Radionuclides of concern for all waste facilities [41].

Ce-141	Pu-238
Ce-144	Pu-239
Co-60	Ru-103
Cs-137	Ru-106
FP	Sr-90
I-131	Y-90
Pm-147	

Table A-22. Tank waste radionuclide inventory [42].

Mega curies of radioactive specie	Liquid components		Solid components	
	Double-shell tanks	Single-shell tanks	Double-shell tanks	Single-shell tanks
Cs-137 and Ba-137	6.40 E+01	2.53 E+01	2.33 E+00	8.45 E+00
Sr-90 and Y-90	3.93 E+00	1.14 E+01	2.17 E+01	1.13 E+02
Tc-99	2.28 E-02	7.82 E-03	1.35 E-03	7.82 E-03
Am-241	1.45 E-02	4.70 E-03	7.97 E-02	4.23 E-02
Np-237	1.64 E-05	3.30 E-06	1.92 E-05	2.97 E-05
Pu	3.84 E-03	5.50 E-04	6.80 E-03	2.69 E-02
TRU	1.93 E-02	5.25 E-03	9.10 E-02	6.92 E-02