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**Weldon Spring Plant – Site Description**

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## PUBLICATION RECORD

| EFFECTIVE DATE | REVISION NUMBER | DESCRIPTION |
|---|---|---|
| 06/24/2005 | 00 | First approved issue. New technical basis document for the Weldon Spring Plant – Site Description. Incorporates formal internal and NIOSH review comments. Training is not required. Initiated by Robert Meyer. |
| 05/21/2013 | 01 | Revision to incorporate data that has been found since the initial draft was issued. Description of processed materials and throughputs were updated. No changes occurred as a result of formal internal review. Incorporates formal NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by David P. Harrison. |
| 03/24/2017 | 02 | Revision initiated to refer to Rev 02 of the Fernald internal dose technical basis document regarding recycled uranium contaminants and their mass concentrations. Includes editorial changes. No changes occurred as a result of formal internal review. Incorporates formal NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by David P. Harrison. |
| 09/12/2017 | 03 | Revision initiated to correct wording in Section 2.4.1 regarding the year recycled uranium work began at the Weldon Spring Plant. Includes editorial changes. Updated references in the text and in the Reference Section. No sections were deleted. No changes were needed as a result of formal internal review. Incorporates formal NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by David P. Harrison. |

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ac | acre |
| AEC | U.S. Atomic Energy Commission |
| AWE | Atomic Weapons Employer |
| BZA | breathing-zone air |
| CEDE | committed effective dose equivalent |
| CFR | Code of Federal Regulations |
| Ci | curie |
| cm | centimeter |
| CSS | Chemical Stabilization and Solidification (facility) |
| d | day |
| DOD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| DOL | U.S. Department of Labor |
| DU | depleted uranium |
| EDE | effective dose equivalent |
| EEOICPA | Energy Employees Occupational Illness Compensation Program Act of 2000 |
| EPA | U.S. Environmental Protection Agency |
| EU | enriched uranium |
| ft | foot |
| gal | gallon |
| HEPA | high-efficiency particulate air |
| hr | hour |
| in. | inch |
| kg | kilogram |
| L | liter |
| m | meter |
| MCW | Mallinckrodt Chemical Works |
| MeV | megaelectron-volt, 1 million electron-volts |
| mg | milligram |
| mi | mile |
| mR | milliroentgen |
| mrem | millirem |
| mrep | millirep |
| MT | metric ton |
| nCi | nanocuries |
| NIOSH | National Institute for Occupational Safety and Health |
| NLO | National Lead Company of Ohio |
| NPL | National Priorities List |
| ns | nanosecond |

| | |
|---|---|
| NU | natural uranium |
| ORAU | Oak Ridge Associated Universities |
| pCi | picocuries |
| RI/FS | remedial investigation/feasibility study |
| RU | recycled uranium |
| s | second |
| SEC | Special Exposure Cohort |
| SRDB Ref ID | Site Research Database Reference Identification (number) |
| SWTP | Site Water Treatment Plant |
| t | ton |
| TBD | technical basis document |
| TNT | thorium nitrate tetrahydrate |
| TSA | Temporary Storage Area |
| U.S.C. | United States Code |
| wk | week |
| WSP | Weldon Spring Plant |
| WSQ | Weldon Spring Quarry |
| WSRP | Weldon Spring Raffinate Pits |
| WSSRAP | Weldon Spring Site Remedial Action Project |
| yd | yard |
| yr | year |
| µs | microsecond |
| °F | degrees Fahrenheit |
| § | 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 historical background information and guidance to assist in the preparation of dose reconstructions at particular Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean nor should it be equated to an "AWE facility" or a "DOE facility." The terms AWE and DOE facility are defined in sections 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), respectively. An AWE facility means "a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling." 42 U.S.C. § 7384l(5). On the other hand, a DOE facility is defined 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 [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program);" and with regard to which DOE has or had a proprietary interest, or "entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services." 42 U.S.C. § 7384l(12). The Department of Energy (DOE) determines whether a site meets the statutory definition of an AWE facility and the Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Accordingly, a Part B claim for benefits must be based on an energy employee's eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility's designated time period and location (i.e., covered employee). After DOL determines that a claim meets the eligibility requirements under EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and the types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at a DOE facility includes individuals who are or were employed by DOE and its predecessor agencies, as well as their contractors and subcontractors at the facility. Unlike the abovementioned statutory provisions on DOE facility definitions that contain specific descriptions or exclusions on facility designation, the statutory provision governing types of exposure to be included in dose reconstructions for DOE covered employees only requires that such exposures be incurred in the performance of duty. As such, NIOSH broadly construes radiation exposures incurred in the performance of duty to include all radiation exposures received as a condition of employment at covered DOE facilities in its dose reconstructions for covered employees. For covered employees at DOE facilities, individual dose reconstructions may also include radiation exposures related to the Naval Nuclear Propulsion Program at DOE facilities, if applicable. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment at a DOE facility. Therefore these exposures are not included in dose reconstructions for covered employees (NIOSH 2010):

- Background radiation, including radiation from naturally occurring radon present in conventional structures
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

### 2.1.1 Purpose

The purpose of this technical basis document (TBD) is to provide historical information on facilities, processes, operations, and their associated nuclear materials of potential concern for the Weldon Spring Plant (WSP), Weldon Spring Quarry (WSQ), and the Weldon Spring Raffinate Pits (WSRP). Historically, the WSP has also been called the Weldon Spring Site, Weldon Spring Chemical Plant, and the Weldon Spring Feed Materials Plant. The WSP is also known as the Chemical Plant, Main Plant, or Main Site. For convenience, WSP is used throughout the remainder of this document where it is unnecessary to distinguish between the plant, the quarry, and the raffinate pits. This document provides background information for the subsequent TBDs in which further technical details are developed to support dose reconstruction. WSP operations played an important role in U.S. development of nuclear power and nuclear weapons. Operations focused on processing uranium and thorium from feed stocks to metal and other intermediate products for use at other facilities.

### 2.1.2 Scope

Section 2.2 provides the location and general history of WSP, and Sections 2.3 and 2.4 discuss site acquisition and development from 1954 to 1957 and site operations from 1957 to 1966. Section 2.5 covers 1967 to 1985 when the WSP was under the control of the U.S. Department of Defense (DOD), and Section 2.6 covers the DOE remediation period from 1985 to 2002. Section 2.7 discusses releases to the outdoor environment, and Section 2.8 discusses health protection at WSP during all periods. Section 2.9 provides supplemental information on job titles and locations during the operational period. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 2.10.

## 2.2 SITE LOCATION AND SUMMARY HISTORY

The main area of the WSP is a 220-ac site about 2 mi southwest of the community of Weldon Spring, Missouri, at the junction of Missouri State Route 94 and U.S. Highway 40/61 (Figure 2-1). The site contained 44 buildings and support structures along with two small ponds and the remnants of a railroad system (WSP) and four raffinate pits (WSRP). An 8.7-ac limestone quarry (WSQ), used in part to deposit radioactive wastes, is considered part of the WSP even though it is about 4 mi southwest of the plant. Figure 2-2 shows the layout of the WSP facilities.

In April 1941, the U.S. Department of the Army acquired 17,232 ac surrounding what is now the WSP as the site for an explosives production facility known as the Weldon Spring Ordnance Works. From November 1941 to January 1944, the Atlas Powder Company operated the Ordnance Works for the Army to produce trinitrotoluene and dinitrotoluene explosives. The Ordnance Works began operating again in 1945 but was closed and declared surplus in April 1946. By 1949, all but about 2,000 ac had been transferred to the State of Missouri and the University of Missouri.

There are four periods for WSP:

- Site acquisition and development, 1954 to 1957;
- Operational, 1957 to 1966;
- DOD control of the WSP, 1967 to 1985; and
- Remediation, 1985 to 2002.

WSP employment is covered under EEOICPA during only the operational and remediation periods, when the U.S. Atomic Energy Commission (AEC), U.S. Energy Research and Development Administration, and DOE had contractors and radioactive materials at the WSP. WSQ and WSRP employment is covered during those periods and during the DOD control period.

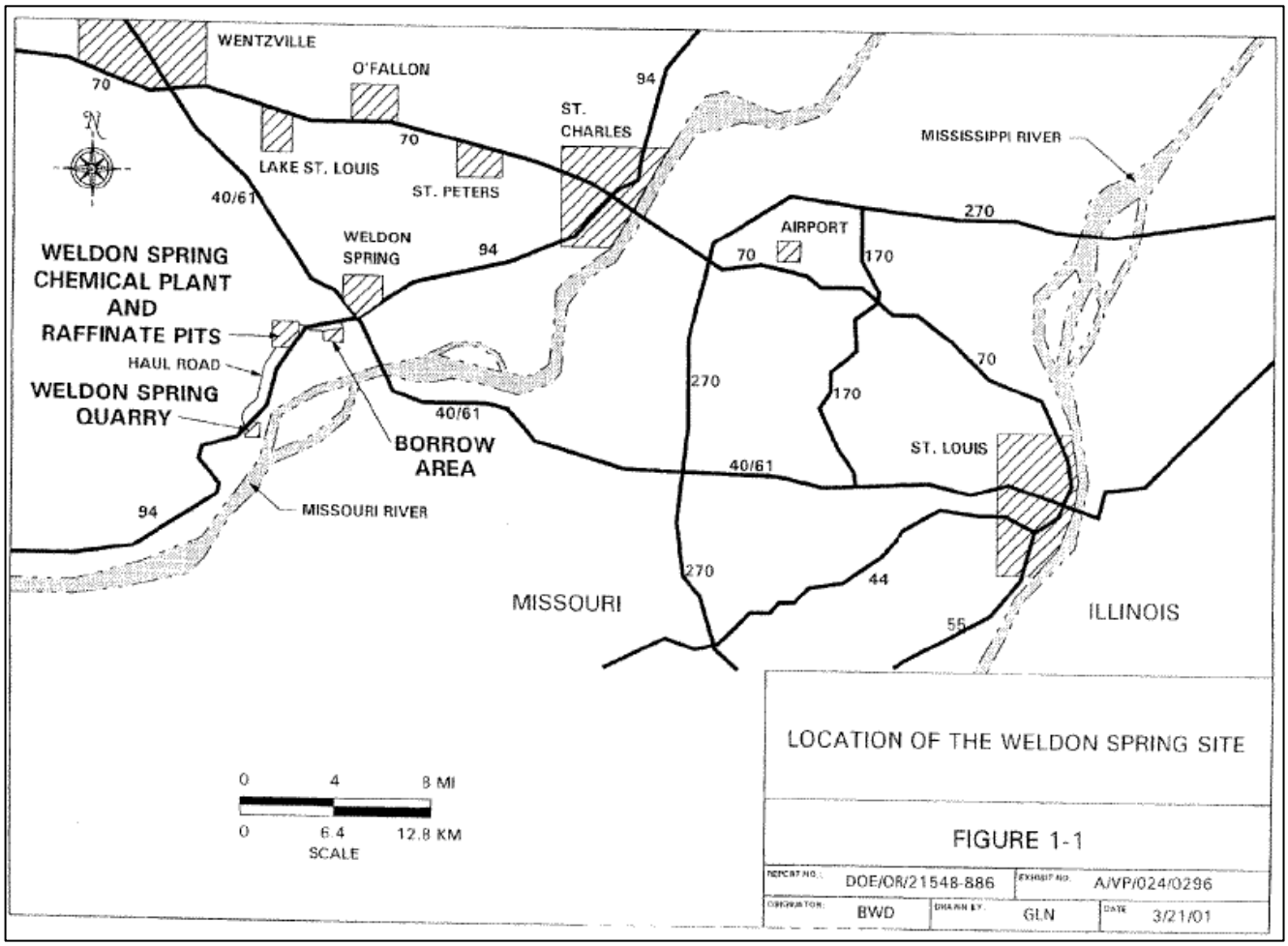


Figure 2-1. Locations of WSP facilities (DOE 2001a).

In 1956, approximately 220 ac of the former Weldon Spring Ordnance Works were transferred to AEC for construction and operation of a feed materials plant to process uranium and thorium ore concentrates, which operated from 1957 through 1966 (Army 1976). Construction was completed in February of 1957; initial operations began in June of 1957 (AEC 1958). Nuclear materials in the form of natural uranium (NU) concentrates were being stored at the site before the start of operations but, "since they were not processed, they did not engender operational losses" (Harris 1986). Therefore, it is reasonable to assume exposures before operational startup were negligible. Although the raffinate pits were physically part of the WSP, they are referred to separately in this document as the WSRP because they were managed separately from the WSP between the operational and remediation periods.

In 1958, a 9-ac quarry site was transferred to the AEC and is referred to as the WSQ in this document. Although the WSQ was not on the WSP site proper, it is covered within the scope of this TBD.

In August 1967, the WSP was returned to Army control for construction of an herbicide production facility (Army 1976), but AEC retained custody of WSQ and WSRP. Decontamination of the transferred WSP facilities was attempted between 1968 and 1970, but abandoned because of cost. The Army never completed or produced any herbicides during this period.

DOE regained responsibility for the WSP in 1985 and began site characterization and remediation in 1985. The quarry was placed on the U.S. Environmental Protection Agency (EPA) National Priorities

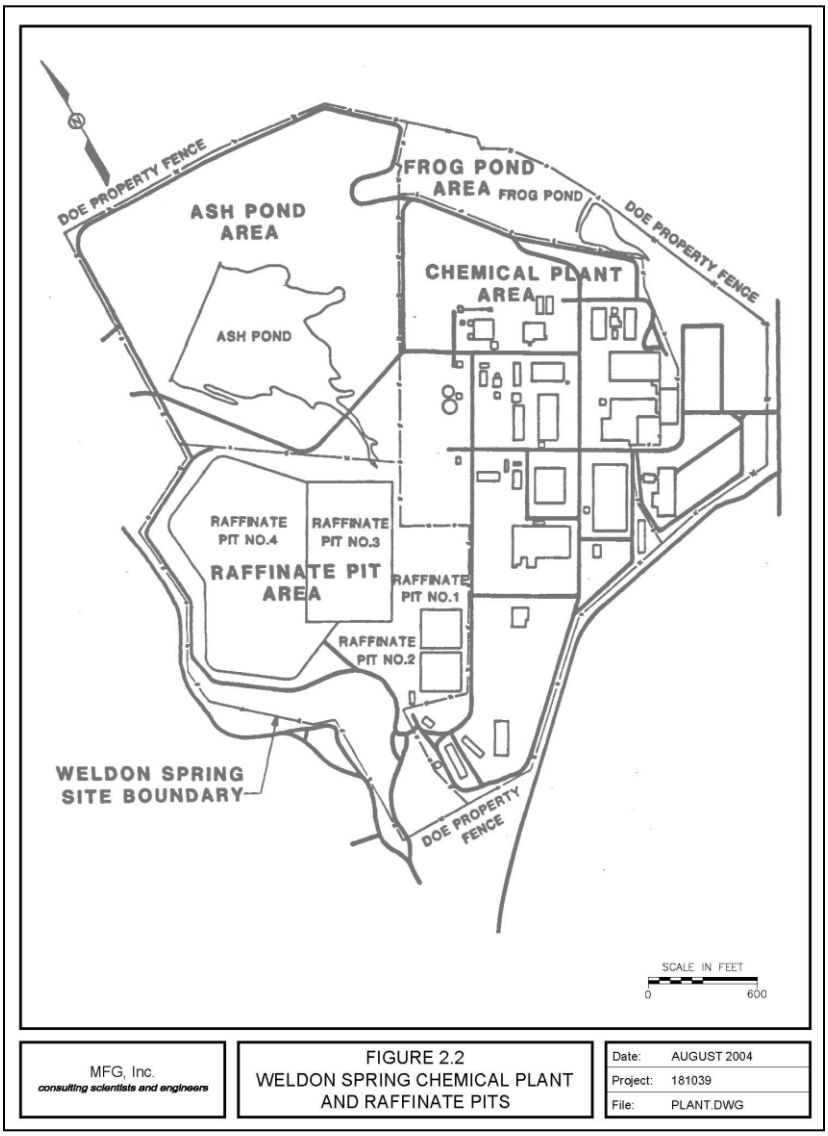


Figure 2-2. WSP and WSRP site layout (modified from Army 1976, p. 176).

List (NPL) in 1987, and the listing was expanded to include the WSP and associated waste storage areas in 1989.

The following sections provide more detailed descriptions of these activities. These descriptions are summarized from Army (1976) and Meshkov et al. (1986) unless otherwise noted.

## 2.3 SITE ACQUISITION AND DEVELOPMENT, 1954 TO 1957

In August 1956, Congress approved the transfer of 205 ac of the former Ordnance Works property from the Army to AEC. An additional 15 ac were later transferred to the AEC for expansion of waste storage capacity. The AEC began designing a feed materials plant in 1954 and constructed the plant now referred to as the WSP in 1956 and 1957 on this property for processing uranium and thorium feed stocks into metal and intermediate products. This facility replaced a more limited plant of similar operational capability in St. Louis (on Destrehan Street). The WSP facility was specifically designed to process uranium mill concentrates (yellowcake) from the United States and Canada. These materials were shipped to the WSP site for sampling to determine payment. Fractions of the total mill

concentrates were processed through chemical treatment operations. Other fractions, after sampling, were shipped to other DOE facilities for further processing.

## 2.4 OPERATIONAL PERIOD, 1957 TO 1966

### 2.4.1 Processed Materials

WSP was operated for AEC by the Uranium Division of Mallinckrodt Chemical Works (MCW) from 1957 to 1966 and processed materials from June 1957 to December 1966. Shutdown procedures were completed in 1967. DOE (2000a) estimated the employment at the site for the Uranium Division at about 600 employees, of whom about 300 would have handled radioactive materials.

In 1986, DOE prepared *Historical Nuclear Materials Balance Report for the Former AEC-Owned Weldon Spring Chemical Plant* (Harris 1986), which summarized the types and quantities of nuclear materials WSP received and processed. This report indicated that four types of nuclear materials were processed during the operational period of WSP: (1) NU, (2) depleted uranium (DU), (3) slightly enriched uranium (EU), and (4) natural thorium. The great majority of processed material was NU (approximately 98% of the total mass). An average of $1.2 \times 10^7$ kg ($1.4 \times 10^4$ t) of uranium-containing material was processed per year (Harris 1986). Total material balance closures (i.e., percent of material accounted for) for the 10 years of plant operations were 99.94% for NU, essentially 100% for DU, and 99.27% for EU. An average of $3.1 \times 10^5$ kg (350 t) of natural thorium was processed per year from 1964 through 1966, with an associated total material balance closure of 98.52%. Table 2-1 summarizes the total receipts by fiscal year of operation.

Table 2-1. Annual uranium and thorium mass receipts (kg) (Harris 1986).

| Fiscal year[a] | NU | DU | EU | Natural thorium |
|---|---|---|---|---|
| 1958[b] | 8,000,407 | 128 | 0.4 | 44 |
| 1959 | 12,898,013 | 11,255 | 0 | 0 |
| 1960 | 15,032,283 | 30,203 | 0 | 0 |
| 1961 | 15,546,776 | 94,260 | 0 | 0 |
| 1962 | 16,009,091 | 22,225 | 0 | 0 |
| 1963 | 18,873,351 | 0 | 94,695 | 0 |
| 1964 | 16,661,427 | 47 | 265,323 | 13,111 |
| 1965 | 11,445,290 | 2,769 | 441,977 | 313,699 |
| 1966 | 7,077,000 | 6,936 | 27,700 | 614,693 |
| 1967 | 472,339 | 0 | 12,890 | 0 |
| **Totals** | **122,015,977** | **167,823** | **842,585** | **941,347** |

a. Fiscal year begins on July 1 of the previous calendar year and ends on June 30 of the calendar year corresponding to the designated fiscal year.
b. Includes startup period in fiscal year 1957.

**Natural Uranium**

NU was received as continental ore concentrates (e.g., yellowcake) from uranium-milling facilities and was refined to extract the uranium, after which the uranium was converted to various compounds and metal forms and shipped off site. Processing of NU was a continuous operation during the life of the plant.

The primary uranium concentrates at WSP consisted of $^{234}U$, $^{235}U$, and $^{238}U$ in their natural abundances with very low concentrations of decay products. Historical documents report that WSP did not receive the high-quality pitchblende ores that were processed at the MCW Destrehan Street facility in St. Louis (Ingle 1991). Although some plant documents mention the receipt or processing of "ores," it appears that this term actually referred to ore concentrates (ORAUT 2009a, 2009b, 2009c).

Decay products and other impurities including natural thorium (e.g., $^{232}$Th and $^{228}$Th) were present in the uranium ore concentrates. These materials and their associated quantities were considered a minor hazard in comparison with the uranium itself. The *Weldon Spring Historical Dose Estimate* (Meshkov et al. 1986) estimates the offsite activities of $^{230}$Th and $^{226}$Ra in yellowcake to be 5% and 1% of $^{238}$U activity, respectively. However, specific isotopic characterization of raffinates at WSP indicates that the uranium mill processes that produced the yellowcake concentrates for both Fernald and WSP effectively removed the radium but were not effective in removing thorium, specifically $^{230}$Th. Measurements of the activity concentrations in Raffinate Pits 1, 2, and 3 can be used to determine the relationship between $^{230}$Th and other impurities during the initial uranium processing in Building 101 before any separations occurred, as discussed in ORAUT-TKBS-0028-5, *Weldon Spring Plant – Occupational Internal Dose* (ORAUT 2017b). The shorter lived decay products $^{210}$Pb and $^{210}$Po, for which no raffinate measurements were made, should be assumed present at the same activity as the $^{226}$Ra in raffinate pits. As indicated above, there is no suggestion in the historical records that WSP ever processed the high-activity pitchblende, which contained significant concentrations of radium. The ore concentrates were a relatively small source of radon because most of the radium in the ore was removed in the milling process, which occurred elsewhere. Radium is the parent of radon in the naturally occurring decay chain.

**Depleted Uranium**
Uranium depleted in $^{235}$U below its natural isotopic abundance ratio was received and processed on an intermittent basis as metal and various intermediate chemical forms. This form of uranium was used primarily in product development activities and flow-sheet improvements and was confined primarily to pilot plant activities.

**Enriched Uranium**
Uranium enriched to 1% or less $^{235}$U by weight was also received and processed on an intermittent basis. This type of uranium was typically in the form of scrap metal or residues. The uranium contents were recovered, processed to various chemical forms, and shipped off site. The coefficient of variation about the values assigned to all flows of EU was slightly greater than that for NU, primarily because of the heterogeneous nature of receipts.

**Natural Thorium**
Natural thorium was typically received in either nitrate or oxide form and processed on an intermittent batch basis in the refinery and oxide production and firing systems. Only a limited area of the WSP (refinery and pilot plants) processed the material. In addition, Dupree (1979) stated that approximately $3.6 \times 10^5$ kg (400 t) of "impure thorium nitrate and enriched uranium" were processed starting in 1965.

Thoron is the second progeny of $^{228}$Th and, a couple of weeks after the processing of thorium ores for thorium purification, can be considered to be in full equilibrium with the parent, $^{228}$Th. Thorium-228 is the third progeny of the long-lived $^{232}$Th and is generally in 40% to 65% equilibrium for the materials WSP processed. The degree of equilibrium is dependent on both the decay of $^{228}$Th (without replenishment from the 5.7-year half-life of $^{228}$Ra) after removal of the progeny and the time it takes the $^{228}$Ra to build into equilibrium with $^{232}$Th.

Thoron was present and a portion was released during the processing and storage of thorium at the WSP and the associated waste storage locations. The thoron, with its progeny, was a potential source of internal exposure in the thorium process buildings and at waste storage locations. Table 2-2 provides the half-life information for thoron and its progeny.

Table 2-2. Thoron and progeny (ORAUT 2017a).

| Isotope | Half life | Atoms/7.5 pCi | MeV/atom | PAEC 1[a] MeV per 7.5 pCi |
|---|---|---|---|---|
| Radon-220 | 56 s | 23 | 14.6 | 335 |
| Polonium-216 | 0.15 s | <1 | Included with Rn-220[b] | Included with Rn-220 |
| Lead-212 | 10.64 hr | 15,476 | 7.8 | 1.21E+5 |
| Bismuth-212 | 60.6 min | 1,469 | 7.8 | 0.12E+5 |
| Polonium-212 | 0.3 µs | Not applicable | Included with Bi-212[b] | Included with Bi-212 |
| Thallium-208 | 3 min | 73 | No alpha | 0 |
| **Total** | Not applicable | Not applicable | Not applicable | **1.33E+5** |

a. PAEC = potential alpha energy concentration.
b. The alpha energy is emitted by Po-216 and Bi-212. While Bi-212 directly emits an alpha only 36% of the time, the other 64% of the time it emits a beta and becomes Po-212, which then emits an alpha almost immediately (304 ns half-life). The average alpha energy released by a Bi-212 decay is then 7.8 MeV (6.07 MeV × 0.36 + 8.785 MeV × 0.64). Because Po-216 ultimately decays by two alphas (Po-216 and Bi-212), the alpha energy released per Po-216 atom is 14.6 MeV. Lead-212 and Bi-212 both decay with an effective alpha energy of 7.8 MeV.

**Recycled Uranium**

Some 1961 shipments that came from Fernald could have included some quantities of RU. In 1999, DOE initiated the complex-wide Recycled Uranium Mass Balance Project that identified WSP as a site that likely received RU in relatively small quantities beginning in 1961 (DOE 2000a). The significance of these receipts of RU is that this material contains trace amounts of residual transuranic elements including plutonium and neptunium, fission products such as technetium, and reactor-produced uranium isotopes such as $^{236}U$ (DOE 2000a). Site records do not include the level of detail necessary for an accurate estimate of the amount of recycled material WSP received and processed. It is known that the plant received shipments of uranium materials from other DOE sites that processed and shipped RU from fiscal years 1962 to 1967 (the period of RU shipment), but the amounts of RU versus NU are not known. Due to the lack of information about RU quantities, it is assumed that all uranium receipts beginning in 1961 were recycled (DOE 2000a) and contain RU contaminants. This assumption is based on the fact that Fernald received its first significant quantity of RU from Hanford in 1961 (ORAUT 2017a, p. 21), and because Weldon Spring Plant received most of its RU from Fernald (DOE 2000a, p. 121). The RU contaminants and their activity levels at the site are based on ORAUT-TKBS-0017-5, *Feed Materials Production Center – Occupational Internal Dose* (ORAUT 2017a) and stated in ORAUT-TKBS-0028-5, *Weldon Spring Plant – Occupational Internal Dose* (ORAUT 2017b).

### 2.4.2 Plant Processes and Operations

The main activity at WSP was to convert uranium concentrate to uranium trioxide ($UO_3$), uranium tetrafluoride ($UF_4$), and uranium metal. The received material was yellowcake (uranium concentrate). A wet solvent extraction method was used for $UF_4$ production. Before entering the refinery, the ore concentrate underwent a sampling and preparation process in the sampling plant.

#### 2.4.2.1 Uranium Concentrate Sampling

Building 101 was the sampling building. Ore concentrate arrived in drums of about 60% to 70% uranium. The drums were opened and sampled using one of two sampling methods – auger or mechanical – after which the drums were emptied into hoppers at the top of the building. From the hoppers, material was transferred to portable hoppers for transfer to the refinery (Figure 2-3). Yellowcake dust was collected in three large dust collectors, each with its own stack. Some yellowcake was repackaged in drums and shipped out; the rest was put into hoppers and moved to Building 103 for digestion. The dust collection system was vacuum cleaned from time to time, and the collected dust was reprocessed. Uranium dust was washed off the drums, equipment, and floors, and this dust was also reprocessed.

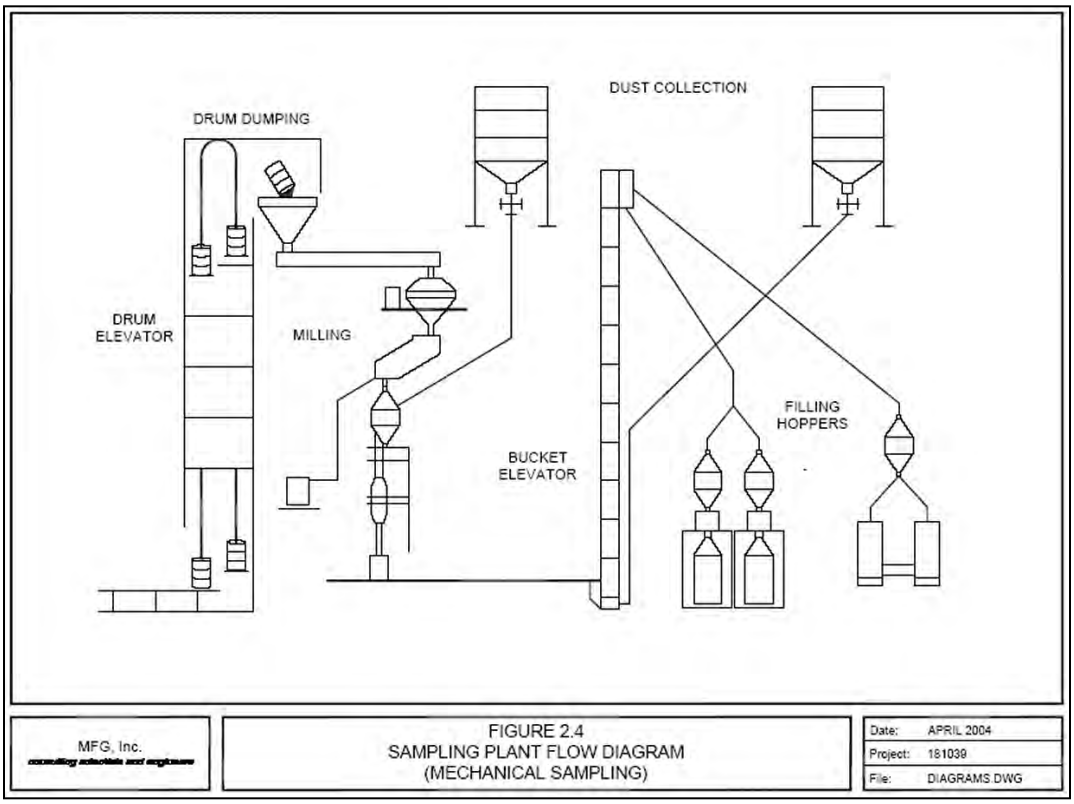


Figure 2-3. Sampling plant flow diagram (adapted from Army 1976).

### 2.4.2.2 Uranium Trioxide Production

The $UO_3$ (orange oxide) was produced, or refined, in three steps: digestion, purification by solvent extraction, and denitration (Figure 2-4). Building 103 was the first building of the refinery plant. Concentrate was brought in hoppers to the top of the building where there was one dust collector with one stack to collect yellowcake dust. The concentrate was heated and digested with nitric acid to produce a solution of uranyl nitrate. The digested material was passed to Building 105 in liquid form where pure uranyl nitrate solution was extracted and remained in liquid form. The highly purified uranyl nitrate solution was evaporated and pumped to gas-fired denitration pots in Building 103 where the remaining water was removed, producing pure $UO_3$. According to Meshkov et al. (1986), this was the dustiest part of the process. Impurities from the purification process were bled off in the raffinate, which was pumped to pits. This raffinate contained a conglomerate of radionuclides including thorium and radium in small concentrations.

The radon trapped in the ore concentrates was released during the acid digestion process in Building 103. The offgasses containing radon and nitrogen oxides from the digestion process were sent to the acid recovery plant (Building 108). This plant was the prime source of radon emission, which was estimated as being between 12 and 34 Ci/yr based on throughput (Meshkov et al. 1986, p. 48).

### 2.4.2.3 Uranium Tetrafluoride Production

The $UO_3$ was packaged into transfer hoppers and transferred from Building 103 to the top of Building 201, the green salt ($UF_4$) plant. Figure 2-5 shows the reduction and hydrofluorination process WSP used to produce $UF_4$. Hydrogen gas reduced $UO_3$ to uranium dioxide ($UO_2$).

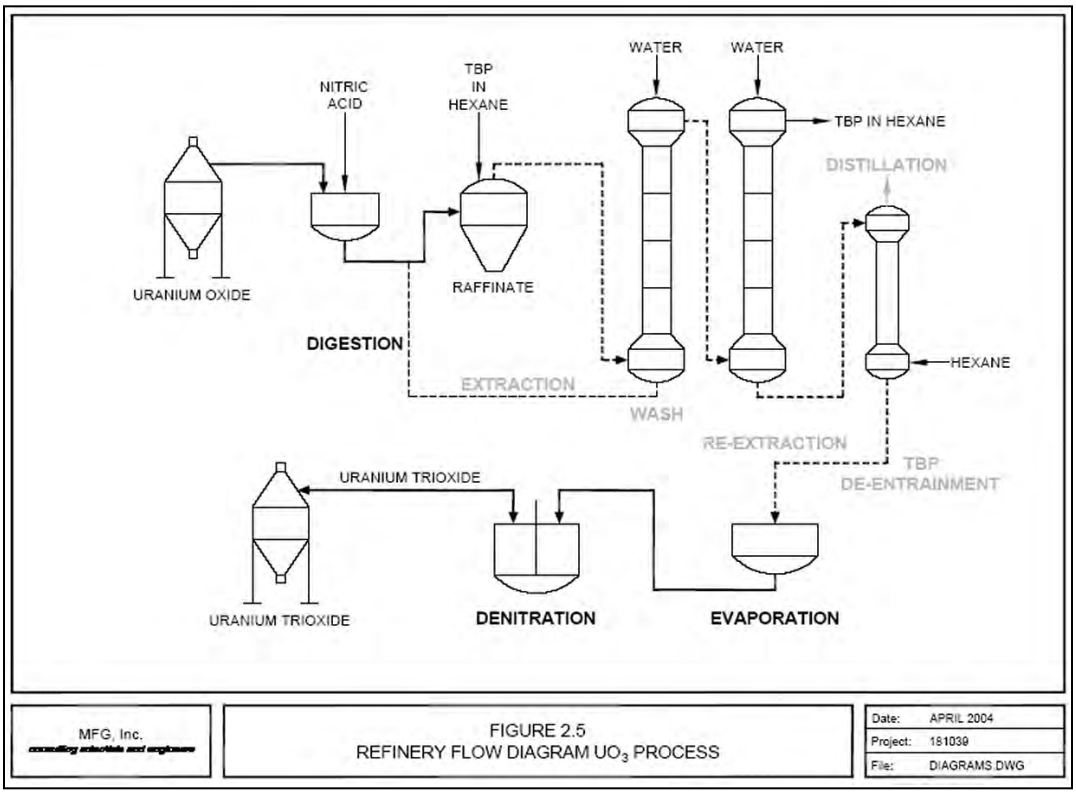


Figure 2-4. Digestion, purification, and denitration (adapted from Army 1976).

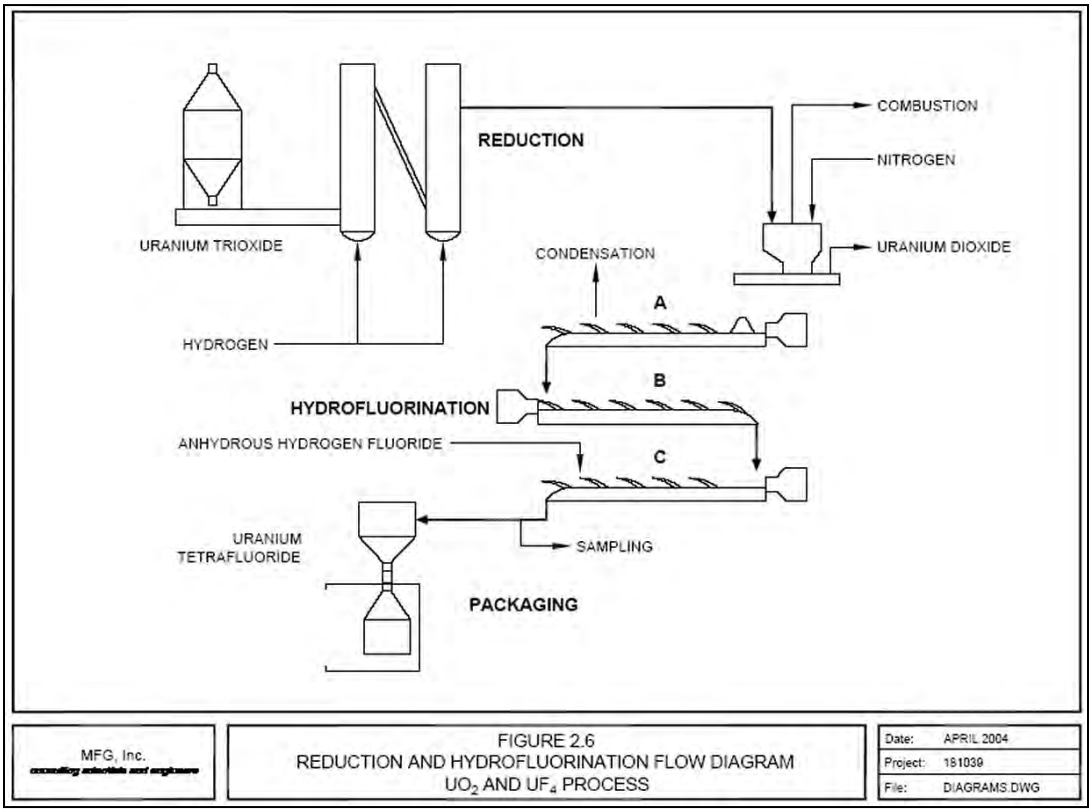


Figure 2-5. Reduction and hydrofluorination process (adapted from Army 1976).

The next step was hydrofluorination, in which $UO_2$ was transformed to $UF_4$ or green salt. Excess hydrogen fluoride (HF) gas from the process was filtered through carbon filters to recover uranium,

which was recycled to black oxide ($U_3O_8$). Discharge from the $UF_4$ reactor system was mechanically collected, crushed, and blended to obtain desired particle sizes. There were two additional dust collectors on the roof of Building 201 associated with the system to collect $UF_4$ dust, and there was a reverter in the building to convert $UF_4$ into $U_3O_8$.

#### 2.4.2.4 Uranium Tetrafluoride Conversion

$UF_4$ (green salt) was packaged in transfer hoppers and moved to Building 301, the metals plant. Magnesium was used to convert $UF_4$ to solid uranium metal in a multistep process. Figure 2-6 depicts this process. The reaction occurred in refractor-lined steel "bomb" shells, which were charged with a mixture of green salt and magnesium chips. Green salt and magnesium were mixed in a blender; the mixture was then placed in individual steel shells at the filling machine and sent to the furnaces for firing. In the furnace, the shell was heated to about 500°F and the charge was ignited electrically. Once ignited, the reaction proceeded spontaneously. Complete shells were moved to an outdoor cooling pad for about 3 days. The process generated green salt dust. $UF_4$ and magnesium fluoride (MgF), with 1% to 2% of residual uranium in various forms, were discharged from several dust collectors at the ground level on the south side of the building. A rotary kiln in Building 301 calcined uranium metal chips to recover the uranium from scrap and to convert them to $U_3O_8$. One standard dust collector was used for the dusty discharge, mostly $U_3O_8$, that was produced in this operation.

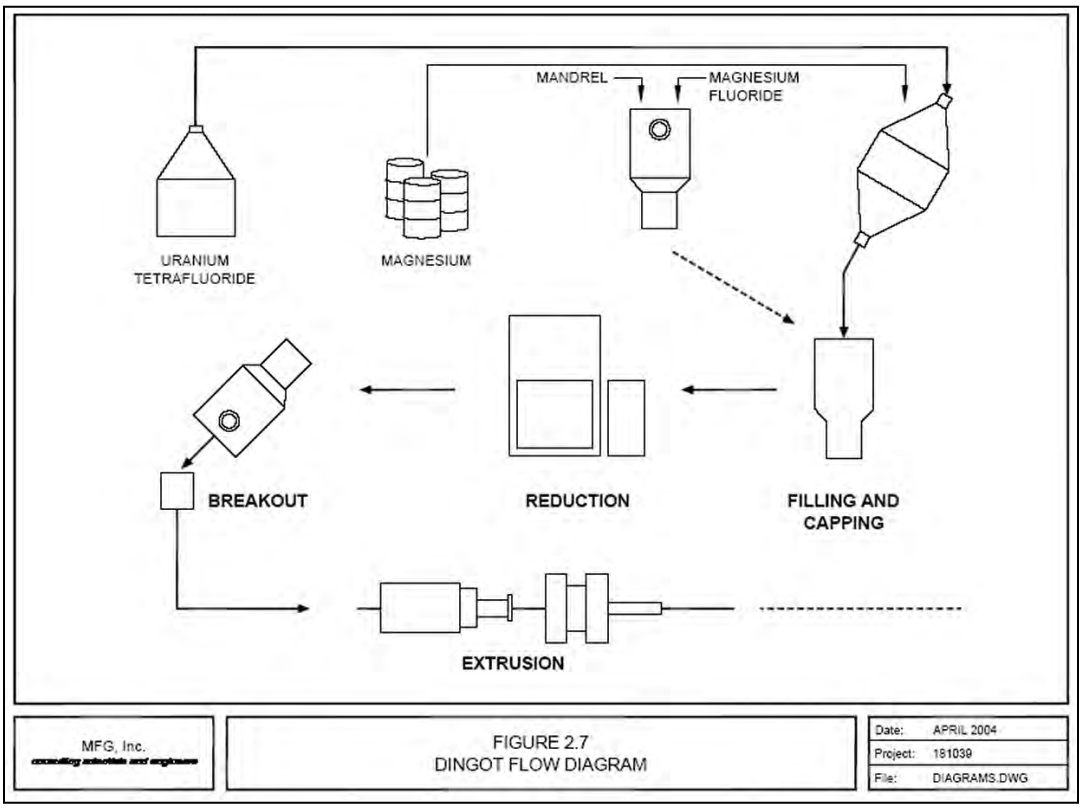


Figure 2-6. $UF_4$ conversion to uranium metal (adapted from Army 1976).

#### 2.4.2.5 Products Manufacturing

Uranium fuel cores were produced in Building 301. Uranium billets were extruded to rods to produce cores for use in reactors. The rods, approximately 22 ft long, were straightened, cut to lengths, heat-treated, degassed, and fed to a six-spindle automatic machine, which turned off a thin layer of material from the outside diameter and sectioned them into about 8.5-in. lengths. The rough cores were then treated at 950°F in a vacuum furnace to remove hydrogen gas from the metal. Degassed

cores were heat treated in molten salt at 1,350°F and quenched in water at 130°F to randomize the grain structure. Cores were further machined to remove the warp and oxide layer that resulted from heat treatment and degassing. Holes were drilled in the solid core, and it was reamed to final size. Good cores were inspected in an ultrasonic machine to ensure that the grain structure was neither too small nor too large. A dimensional inspection was performed to ensure that specifications were met. All acceptable cores were packaged in boxes and shipped by rail directly to reactor sites.

#### 2.4.2.6 Thorium Processing

Natural thorium was received in either nitrate or oxide form and processed on an intermittent basis in the refinery and oxide production and firing systems. In 1965 and 1966, first pure and then impure thorium oxide were processed initially on a pilot scale in Buildings 403 and 404 and later on a larger scale in Buildings 103, 105, and 301 (Harris 1986).

An average of $3.1 \times 10^5$ kg (350 t) of natural thorium was processed per year during 1964 through 1966, with an associated total material balance closure of 98.52%. MCW (1966) summarized operations with thorium as shown in Table 2-3. Thorium process wastes were deposited in Raffinate Pit 4. In the table, "TNT" abbreviates thorium nitrate tetrahydrate.

Table 2-3. Chronological summary of thorium operations.

| Operation title | Building | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|
| TNT crystal repackaging | 403 | Nov–Dec | May–Sep | None | None |
| TNT crystal repackaging | 301 | None | Oct–Dec | None | None |
| Denitration of TNT crystals & sol drying-hand unloading | 103 | Nov–Dec | May–Aug | None | None |
| Denitration of TNT crystals & sol drying-vacuum uploading | 103 | None | Sep–Dec | None | None |
| Denitration of TNT liquor & sol drying-vacuum uploading | 103 | None | None | Jan–Jul | None |
| Denitration by fluid bed-product packaged in drums | 403 | None | None | May–Jul | None |
| Denitration by fluid bed-liquor feed & sol product | 403 | None | None | Aug–Dec | Jan; Jun–Sep |
| Denitration of TNT liquor-scoop & pail transfer to sol tank | 103 | None | None | Oct–Nov | None |
| Sol drying-vacuum uploading | 103 | None | None | Aug–Dec | Jan; Jun–Sep |
| $ThO_2$ high firing-recast furnace | 301 | Nov–Dec | May–Sep | None | None |
| $ThO_2$ high firing-billet heaters | 301 | None | Oct–Dec | Jan–Dec | Jan; Jun–Sep |
| $ThO_2$ product packaging | 403 | Nov–Dec | May–Jul; Sep–Dec | Jan–Sep | None |
| $ThO_2$ product packaging | 103 | None | Aug | None | None |
| $ThO_2$ product packaging | 301 | None | None | Oct–Dec | Jan; Jun–Sep |
| Rotary kiln calcining of sump cake | 301 | None | None | None | Apr–Jul |
| Digest feed repackaging | 101 | None | None | None | Apr–Aug |
| Scrap digestion & raffinate disposal | 103 | None | None | None | May–Sep |
| Extraction | 105 | None | None | None | Jun–Sep |

#### 2.4.2.7 Analytical and Research Laboratories

The Analytical and Research Laboratories were housed in Building 407. The Analytical Laboratory had four sections. The Production Section had laboratories for process control, uranium accountability, sampling, and specifications testing. The Spectrographic Section measured impurities in raw materials and finished products. The Method Development Section provided analytical procedures for the laboratory. Equipment included infrared and ultraviolet spectrophotometers, vapor phase chromatograph, X-ray spectrometer, ultra-high-vacuum equipment, an isotope ratio mass spectrometer, and a time-of-flight mass spectrometer. The Special Analysis Section performed

analytical work for the research laboratory and pilot plants in addition to running production and uranium inventory samples.

The Research Laboratory consisted of three sections. The Dry Chemistry Section was concerned with problems in fluoride chemistry and with metallurgical studies. The Wet Chemistry Section worked on such studies as the digestion and extraction of raw material feeds, solvent quality, uranyl nitrate purity, and nitric acid recovery. The Instrumental Techniques Section used a wide variety of optical equipment: X-ray diffraction equipment for qualitative and quantitative analysis and electron and optical microscopes for particle-size distribution studies, identification of minerals, and studies of physical properties.

#### 2.4.2.8 Pilot Plants

Buildings 403 and 404 housed the WSP and Metallurgical Pilot Plants, respectively. Both had development facilities on a scale between those of the laboratory and the plant. After new processes and equipment were demonstrated on a small scale in the laboratory, they were investigated further in the pilot plants. Research was performed on the design, installation, and operation of an integrated fluid-bed system for producing uranium trioxide, uranium dioxide, and green salt. The WSP also studied a process for the simultaneous denitration of uranyl nitrate and reduction of $UO_3$. The Metallurgical Pilot Plant was equipped for large-scale development of the bomb-reduction step of the process.

#### 2.4.2.9 Raffinate Pits

The processing of uranium and thorium generated several chemical and radioactive waste streams, which were piped to the raffinate pits. The solids settled to the bottoms of the pits, and the supernatant liquids were decanted to the plant process sewer that drained off the site to the Missouri River. Of the amount of discards (i.e., material known to have been disposed of via plant stacks, sewers, and raffinate pits rather than shipped off the site), approximately 67% of the uranium and essentially all of the thorium went to the raffinate pits (Harris 1986).

Between 1958 and 1964, to contain process wastes from the plant, four raffinate pits were constructed in the southwest portion of the site for wastes from the plant (NLO 1977). Pits 1 and 2 were constructed in 1958 and were used for almost 2 years. The design volume of each of these two pits was 14,000 $m^3$ (500,000 $ft^3$) (NLO 1977).

Because of the high production rate, the first two raffinate pits filled rapidly, requiring the construction of the third and eventually the fourth. Pit 3 was constructed and put into operation in 1959, with a design volume of 127,000 $m^3$ ($4.5 \times 10^6$ $ft^3$). Pit 4 was constructed and put into operation in 1964, and its design volume was 340,000 $m^3$ ($1.2 \times 10^6$ $ft^3$) (NLO 1977, p. 20).

The uranium process wastes contained relatively low-level concentrations of uranium. The radionuclide of most concern in the raffinate pits was $^{230}Th$, due to its high activity concentration and its radiotoxicity. It is estimated that 152,382 kg of NU, 46 kg of DU, and 2,808 kg of EU were discharged to the raffinate pits (DOE 2000a, Table 2-23, p. 86).

Raffinate Pits 1, 2, and 3 received mostly uranium raffinates, and Pit 4 received both uranium and thorium raffinates. In the first three pits, $^{230}Th$ constituted greater than 80% of the total activity. An upper estimate of the $^{230}Th$ activity in the ore concentrates is 100% of the $^{234}U$ activity (its parent), or 50% of the total uranium activity (approximately 0.34 nCi/mg U). Some natural thorium (e.g., $^{232}Th$ and $^{228}Th$) was present in the uranium ore concentrates, which was also separated and sent to the raffinate pits.

#### 2.4.2.10 Weldon Spring Quarry

In 1958, AEC acquired the WSQ, which was previously part of the Army's Ordnance Works (DOE 1985). The WSQ was first used for storing radioactive waste in 1959, when an estimated 150 $m^3$ (5,400 $ft^3$) of drummed 3.8%-thorium residues were placed there. In 1966, approximately 13,500 $ft^3$ of drummed and bulk 3%-thorium residues were deposited in the WSQ.

Before 1963, the quarry only contained drummed thorium wastes that were likely submerged and not a significant source of radon. In 1963 and 1964, an estimated 38,000 $m^3$ of uranium- and radium-contaminated rubble, equipment, and soil were placed in the quarry after demolition of the Destrehan Street site, with a majority of this waste unsubmerged, which provided a potential source of radon exposure (MCW 1967, p. 16; Haroun et al. 1990, p. 20). Measurements in the quarry area in the late 1970s and early 1980s (before remediation) averaged 0.65 ± 0.41 pCi/L, which indicates the quarry was not a major source of radon (Meshkov et al. 1986, p. 101). As in the case of the raffinate pits, this value is limiting for the operational period.

### 2.4.3 Plant Operations and Radioactive Material of Concern Summary

Table 2-4 lists the WSP buildings, summarizes the activities that took place in them, and identifies the potential radionuclides of concern (MCW 1962, ca. 1964; Meshkov et al. 1986).

## 2.5 U.S. DEPARTMENT OF DEFENSE CONTROL PERIOD, 1967 TO 1985

In early 1966, AEC decided to close WSP at the end of the year, which resulted in a declining workforce as employees sought other employment. Decontamination of the buildings and equipment for unrestricted use were not part of the AEC shutdown directive. Under the shutdown procedures, hoppers and process lines were emptied and dust collectors and other points of material accumulation were cleaned out. Access ports were used to remove as much of the pure uranium compounds as possible from the production equipment. By the end of 1967, these shutdown activities were terminated and the facilities awaited turnover to the Army for use as an herbicide facility. The transfer of facilities to the Army began in March 1968.

At shutdown, only a few pounds of pure compounds were present in any one piece of equipment. The bulk of the remaining compounds was in building sumps and secondary pieces of process equipment and piping without routine access ports. For a short time after closure, some of the buildings were used for interim storage of drummed yellowcake from other mills, which was later shipped to various plants for refining and processing.

AEC transferred the WSP facility to the Army in 1967 (DOE 2003) for the purpose of using portions of the feed materials plant for the production of Agent Orange herbicide to meet needs in Southeast Asia. However, AEC maintained control of Building 434 (which had been used for the storage of ore concentrates), a 51-ac tract encompassing the four raffinate pits (WSRP), Building 438, and the WSQ.

The Army selected Buildings 103 and 105 for herbicide production, with blending and packaging to occur adjacent to Building 101. Construction of the herbicide facility began in December 1968 but was terminated when the project was canceled in early 1969. Cleanup and shutdown work was conducted on the site until June 1969. The Army began decontamination and equipment removal in Buildings 103 and 105 in March 1968. About 6,000 $yd^3$ of highly contaminated and unrecoverable material were hauled to the quarry 4 mi south on Highway 94. About 2,400 tons of contaminated scrap was shipped via rail and truck to a Knoxville, Tennessee, contractor. Another AEC contractor, National Lead Company of Ohio (NLO), received 20 railcars and one truckload of stainless-steel piping, valves, vessels, and spare parts. Approximately 135 barrels of uranium oxide were recovered from the buildings. A high-pressure hot-water solution containing an acidic wetting agent was used to

Table 2-4. Description of WSP buildings and operations.[a]

| Building | Description | Dates | Operations performed | Potential radionuclide exposures |
|---|---|---|---|---|
| 101 | Sampling Plant | June 1957–1966 | Preparation and sampling building designed to process approximately 75 ton/d of low-assay uranium ore concentrates. Housed equipment and facilities for drying, grinding, screening, blending, and sampling of ore concentrates and process residues. Incoming ore concentrates and residues were stored in drums on concrete pad. | NU dust,<br>Ra-226,<br>Th-230,<br>Po-210,<br>Pb-210,<br>Rn-222 and its short-lived progeny,<br>Th-232 and progeny (in 1966) |
| Area 102 A&B | Refinery Tank Farm | June 1957–1966 | Provided facilities for unloading, storing, and transferring liquid process material required in the refinery operation that were supplied or handled in tank-car and tank-truck quantities. | NU dust,<br>Ra-226,<br>Th-230,<br>Po-210,<br>Pb-210,<br>Rn-222 and its short-lived progeny,<br>Th-232 and progeny (in 1966) |
| 103 | Digestion and Denitration | 1957–1966 | Originally the nitrating, denitrating, and raffinate processing and storage area.<br>The northern digestion section received uranium ore concentrates that were digested and transferred as a slurry to Building 105 where the solvent was purified by extraction.<br>The middle denitration section received the purified uranium nitrate solution, which was denitrated to yield uranium nitrate solution, which was further denitrated to yield $UO_3$. During later years, thorium products were also processed in this building. | NU dust (as yellowcake and uranium trioxide),<br>Ra-226,<br>Th-230,<br>Po-210,<br>Pb-210,<br>Rn-222 and its short-lived progeny,<br>Th-232 and progeny (beginning November 1963) |
| 104 | Lime Storage | After 1956 | Facility for storing lime for acidity neutralization of raffinate solution. | NU dust (as yellowcake and uranium trioxide),<br>Ra-226,<br>Th-230,<br>Po-210,<br>Pb-210,<br>Rn-222 and its short-lived decay products,<br>Th-232 and decay products (beginning November 1963) |
| 105 | Extraction | Feb 1957–1966 | Purification building. Previously used for producing a highly purified uranyl nitrate hexahydrate (UNH) solution by means of extraction columns, process vessels, evaporators, and tributyl phosphate and hexane reaction tanks. | NU dust,<br>Ra-226,<br>Th-230,<br>Po-210,<br>Pb-210,<br>Rn-222 and its short-lived progeny,<br>Th-232 and progeny |

| Building | Description | Dates | Operations performed | Potential radionuclide exposures |
|---|---|---|---|---|
| 106 | Refinery Sewer Sampling | Unknown | Used as a sampling station for process waste streams. | Uranium dust,<br>Rn-222 and short-lived progeny |
| 108 | Nitric Acid Plant | 1957–1966 | Used for recovering and reconcentrating nitric acid and oxides of nitrogen. | Uranium dust or thorium (in 1966),<br>Rn-222 and short-lived progeny |
| 109, 110 | West Drum Storage, East Drum Storage | Unknown | Used to store drums containing ore concentrates and process residues. | Unknown |
| 201 | Green Salt Building | Feb 1958–1966 | Used for converting $UO_3$ to $UO_2$ and $UF_4$. | Uranium exposure as green salt dust or natural thorium (1965–1966) |
| 202 A&B | Green Salt Tank Farm | 1957–1966 | Used for tank car unloading and storage of hydrofluoric acid and ammonia. | Unknown |
| 301 | Metals Building | Apr 1958–1966 | Used for converting $UF_4$ to uranium metal. | Uranium as green salt dust and $U_3O_8$ or natural thorium (1965–1966),<br>Th-232 and decay products (beginning November 1963) |
| 302 | Magnesium Storage Building | 1957–1966 | Powdered magnesium handling building used for storage of magnesium. | U, Th, and their progeny |
| Pad 303 | Storage Pad | Unknown | Served as a material storage pad. | Unknown |
| 401 | Steam Plant | 1956–1966 | Steam-generating plant including coal conveyor and coal yard. | Unknown |
| 403 | Chemical Pilot Plant | 1957–unknown | Demonstration of pilot operations. | NU dust,<br>Ra-226,<br>Th-230,<br>Po-210,<br>Pb-210,<br>Rn-222 and its short-lived decay products,<br>Th-232 and decay products (starting November 1963) |
| 404 | Metallurgical Pilot Plant | 1957–unknown | Provided facilities for metal processing studies, ceramic work, and metal testing; housed Metallurgical Pilot Plant. | Uranium as green salt dust and $U_3O_8$ or natural thorium (1965–1966) |
| 405A & B | Pilot Plant Maintenance | 1957 | Building 405A was a small shop and storage building spare pilot plant equipment storage. The dust collectors and vacuum cleaning system for Buildings 403 and 404 were on Pad 405B. | Unknown |
| 406 | Warehouse | 1956 | Served as a warehouse and office area. | Unknown |

| Building | Description | Dates | Operations performed | Potential radionuclide exposures |
|---|---|---|---|---|
| 407 | Laboratory | 1957 | Used as an analytical chemistry laboratory. | NU dust,<br>Ra-226,<br>Th-230,<br>Po-210,<br>Pb-210,<br>Rn-222 and its short-lived decay products,<br>Th-232 and decay products (1965–1966) |
| 408 | Maintenance and Stores | 1956 | Contained numerous maintenance shops, office area, garage, receiving and shipping area, decontamination room, and a large storage area. | Unknown |
| 409 | Administration | 1957 | Contained offices for administrative staff. | Unknown |
| 410 | Services Building | 1957 | Contained the main gate, administrative offices, plant security office, health and safety office, kitchen, dining room, laundry facility for contaminated clothing, and clean and contaminated locker rooms with shower facilities. | Unknown |
| 412 | Electrical Substation | Unknown | Substation for electrical supply. | Unknown |
| 413 | Cooling Tower and Pump House | Unknown | Water-cooling tower and pump house. | Unknown |
| 414 | Scrap Classification and Equipment Storage | 1956 | Served as a salvage shop and equipment storage space. | Unknown |
| 415 | Process Incinerator | Unknown | Incinerator for process materials. | Unknown |
| 417 | Paint Shop | Unknown | Served as the paint shop. | Unknown |
| 426 | Water Tower | Unknown | Used for water storage (elevated water storage tank). | Unknown |
| 427 | Primary Sewage Treatment Plant | Unknown | Served as the primary sewage treatment plant for the site. | Unknown |
| 428 | Fuel Gas Plant | Unknown | Storage facility for fuel gas. | Unknown |
| 429 | Water Reserve Facilities | Unknown | Water storage (pump house and ground storage tank). Also noted to have been a propane gas storage facility. | Unknown |
| 430 | Ambulance Garage | Unknown | Used as an ambulance garage. | Unknown |
| 43I | Laboratory Sewer Sampler | Unknown | Used as a sampling station for process waste streams. | Unknown |
| 432 | Main Sewer Sampler | Unknown | Used as a sampling station for process waste streams. | Unknown |
| 433 | Garage | Unknown | Large equipment garage area. | Unknown |
| 434 | Storage | Unknown | Ore concentrate storage building. | Unknown |

| Building | Description | Dates | Operations performed | Potential radionuclide exposures |
|---|---|---|---|---|
| 435 | Storage | Unknown | Salvageable equipment storage. | Unknown |
| 436 | Storage | Unknown | Salvageable equipment storage. | Unknown |
| 437 | Records Retention Building | Unknown | Facility used for storage and retention of records. | Unknown |
| 438 | Storage | Unknown | Salvageable equipment storage. | Unknown |
| 439, 443 | Fire Training and Storage Building | Unknown | Facility used for fire training purposes and storage. | Unknown |
| 441 | Cylinder Storage | Unknown | Facility used for storage of compressed gas cylinders. | Unknown |

a. Adapted from Army (1976).

partially decontaminate Buildings 103 and 105. Portions of some concrete floors were removed and covered with tar and new concrete to mask radiological contamination. In June of 1969, the Kansas City District of the U.S. Army Corps of Engineers obtained custody of the 169-ac tract containing the WSP. Because the herbicide production program was cancelled in 1969, no major activities took place between 1969 and 1974.

DOE and its predecessors did not have contractors performing work on the 52-ac WSRP area or the 9-ac WSQ area until August of 1975, when it contracted with NLO to perform environmental monitoring in the pits and the quarry. In 1981, Bechtel National assumed management and maintenance responsibility for the pits and quarry. In 1985, custody of the chemical plant was transferred from the Army to DOE (DOE 2017).

## 2.6 REMEDIATION PERIOD, 1985 TO 2002

In 1985, DOE proposed designating control and decontamination of the chemical plant, raffinate pits, and quarry as a major project to be called the Weldon Spring Site Remedial Action Project (WSSRAP). In July 1986, a DOE project office was established on the site, and the project management contractor for the WSSRAP was a partnership of MK-Ferguson Company and Jacobs Engineering Group. The quarry was placed on the EPA NPL in July 1987. The chemical plant and raffinate pits were added to the NPL in March 1989.

The purpose of the WSSRAP was to eliminate potential hazards to the public and environment and to make surplus real property available for other uses to the extent possible. The scope of work included dismantling the 44 WSP buildings and structures and disposing of both radiologically and chemically contaminated structural materials and soils. The project also disposed of as much material as possible (including water, sludge, abandoned waste materials, and structural materials) from the raffinate pits, quarry, and nearby properties (DOE 2000b).

The *Record of Decision for the Management of the Bulk Wastes at the Weldon Spring Quarry* was finalized in March 1991 (EPA and DOE 1991). The quarry bulk wastes were excavated and placed in the Temporary Storage Area (TSA) at the WSP site based on an accelerated cleanup strategy involving limited characterization, a focused remedial investigation/feasibility study (RI/FS), and a limited baseline risk evaluation. Excavation of approximately 120,000 $yd^3$ of WSQ bulk wastes was complete in October 1995 (DOE 2003). Material at the TSA was eventually placed in the onsite engineered disposal facility referred to as the Disposal Cell. After bulk waste excavation, the selected remedy for residual contamination at the quarry site was to use long-term monitoring to verify that conditions at WSQ remain protective of human health and the environment.

Remedial investigations were conducted at the chemical plant and raffinate pits areas in 1988 and 1989 under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* RI/FS process. These investigations included characterization of groundwater, onsite soil contamination, radiological contaminants in the raffinate wastes, and contaminated sediment in offsite surface drainages, lakes, springs, and other surface water. The *Record of Decision for Remedial Actions at the Chemical Plant Area of the Weldon Spring Site* (DOE 1993a) identifies the selection of the final remediation and disposal method for the chemical plant and bulk wastes for the quarry (DOE 2003). Remediation activities included the removal of contaminated soil, demolition and removal of remaining concrete pads and foundations that supported the 44 structures and buildings, removal and treatment of the raffinate pit wastes, and disposal of site wastes in an onsite engineered disposal facility (DOE 2004a). Remediation via removal was complete in 2002, and DOE decided that remediation of the shallow groundwater aquifer under the former WSP would involve institutional controls and monitoring to achieve remediation objectives (DOE 2004a).

Several temporary staging areas and process structures were constructed or commissioned for the purpose of treating or storing excavated wastes and raffinate pit water during the remediation process. Two water treatment facilities were used: a Quarry Waste Treatment Plant and the Site Water Treatment Plant (SWTP). A TSA for the WSQ bulk wastes was an area designed and designated on the WSP to store excavated waste before placement in the Disposal Cell. A Chemical Stabilization and Solidification (CSS) facility operated to produce a grout for use in the engineered disposal facility. By mixing the contaminated raffinate pit sludges with fly ash and Portland cement, the plant provided a means for managing the contaminants as well as a material to fill voids and increase the structural stability of the facility. The full-scale CSS plant began operation in mid-1998. On November 13, 1998, the CSS plant completed processing sludge from Pit 3, treating approximately 122,000 $yd^3$ of sludge since April 1998 including more than 75 million gal of water with an average of 8% to 10% solids. The sludge was screened for oversized materials, then thickened with a polymer before it was blended with binder materials and transferred to the Disposal Cell. Approximately 188,000 $yd^3$ of grout were produced in the process. Demolition work on the SWTP was initiated on April 23, 1999, with activities complete in late June 1999. During 1999, Raffinate Pits 3 and 4, the Ash Pond Area, and the northern and southern portions of the TSA were remediated and their associated contaminants were placed in the Disposal Cell. Final site grading for the raffinate pits, Ash Pond, TSA, SWTP, Frog Pond, and material storage areas was performed in 2000. Construction of the Disposal Cell was completed in 2001, and nearly 1.5 million $yd^3$ of contaminated wastes had been placed in it (DOE 2004b; DOE 2002).

## 2.7 RELEASES TO THE OUTDOOR ENVIRONMENT

The following discussion is restricted to the periods for which the WSP has been listed as a "covered facility" according to the DOE Office of Environment, Health, Safety and Security list (DOE 2017), which are from 1955 to 1967 and from 1975 to 2002. Operations did not begin until 1957, so this discussion is limited to a beginning year of 1957. The site did not have AEC or DOE contractors performing work at WSP outside of these periods (DOE 2017). Table 2-5 summarizes the activities that released radionuclides to the WSP environment.

Table 2-5. History of radioactive effluent-generating activities (1957 to 2002).

| Date | Event |
|---|---|
| 1957–1966[a] | Operation of uranium feed materials plant.<br>Uranium concentrate converted to $UO_3$, $UF_4$, and uranium metal.<br>Some thorium processing.<br>Raffinate from the processing removed to raffinate pits.<br>14,500 MT of uranium materials received for processing and sampling per year from 1958 to 1964.<br>Some thorium processed from 1965 to 1966.<br>Uranium and thorium residues disposed of in the WSQ. |
| December 1966[a] | Plant closed, hopper and process lines emptied, dust collectors cleaned out. |
| 1975–1985 | Site remained essentially undisturbed. |
| 1985–2002 | Remediation involving excavation of contaminated soils and rubble. |

a. Expanded from Meshkov et al. (1986).

### 2.7.1 Airborne Emissions

According to Meshkov et al. (1986), air concentrations of uranium were measured during the WSP operational period along the plant site perimeter, around buildings on the site, and at the south edge of the quarry. Air concentrations of radon were measured from 1979 through 2001 around the chemical plant, pits, and quarry perimeters (Meshkov et al. 1986; Weidner and Boback 1982; Bechtel 1983a, 1983b, DOE 1984 to 1986a, 1987, 1988a, 1989 to 1992, 1993b to 1999, 2000c, 2001a, 2002). Air concentrations of particulates were measured during some of the postoperational years. This information suggests that air emissions were of potential concern not only during operational activities

when radionuclide-laden dust was created, but also from subsequent contamination of the surrounding terrain.

The total amount of uranium emitted to the atmosphere during the operational period (1957 to 1966) has been estimated from monitoring data (Meshkov et al. 1986) and a materials balance study (Harris 1986). Table 2-6 lists the buildings that produced most of the air discharges and summarizes the types of discharge and stack heights. Table 2-7 summarizes the reported atmospheric discharges from the materials balance study, which were engineering estimates derived from airflows and other process factors along with stack monitoring data. Based on these two methods, the amount of uranium activity emitted from the plant was estimated to range between approximately 1 and 5 Ci/yr. Release rates for uranium decay products ($^{230}$Th, $^{226}$Ra, and $^{210}$Pb) were also estimated by Meshkov et al. (1986) as a fixed percent of the (estimated) amount of released $^{238}$U. An estimate of radon release based on the amount of uranium processed during the period ranged from 12 to 34 Ci/yr.

Table 2-6. Location and height of stacks at the WSP (Meshkov et al. 1986, Table 3.2).

| Building number | Number of stacks | Discharge | Height of stack (m) |
|---|---|---|---|
| 101 | 2–3 | Yellowcake dust | 35 |
| 103 | 1 | Yellowcake dust | 23 |
| 103 | Several | $UO_3$ | Various |
| 201 | 6 | $UO_2$, $UF_4$, and $U_3O_8$ | 14–34 |
| 301 | Several | $UF_4$ and MgF with 1% uranium | 23 |
| 301 | 1 | $U_3O_8$ | Unknown |

Table 2-7. Estimated annual discharges to stacks (kg).[a]

| Fiscal year[b] | NU | DU | EU | Natural thorium |
|---|---|---|---|---|
| 1958 | No data | No data | No data | No data |
| 1959 | No data | No data | No data | No data |
| 1960 | 7,200 | No data | No data | No data |
| 1961 | 7,200 | 0 | 0 | 0 |
| 1962 | 7,200 | 0 | 0 | 0 |
| 1963 | 7,200 | 0 | 0 | 0 |
| 1964 | 7,483 | 0 | 0 | 0 |
| 1965 | 4,200 | 0 | 300 | 0 |
| 1966 | 4,158 | 0 | 0 | 0 |
| 1967 | 100 | 0 | 0 | 0 |
| **Total** | **44,741** | **0** | **300** | **0** |

a. From Table 7 in DOE (1986b).
b. Fiscal year begins on July 1 of the previous calendar year and ends on June 30 of the calendar year corresponding to the designated fiscal year.

Beginning in 1981, annual environmental monitoring reports have provided estimates of air concentrations of particulate radionuclides and of radon at the WSP and WSQ. These estimates reflect emissions during the latter part of the Army's custody (until 1985) and throughout remediation activities (until 2002). Because WSP remained in the environmental monitoring phase from 1975 to 1985, data from the period from 1981 to 1985 could be useful for estimating emissions from 1975 to 1980.

### 2.7.2 Waterborne Emissions

Waterborne emissions from WSP have been a result of discharge of solubilized radionuclides to surface water or groundwater. The four raffinate pits and the WSQ presented conditions where

contaminated sludge, soil, and rubble were covered or partially covered with standing water. During the operational period (1957 to 1966), the WSRP were a source of radionuclides that discharged to surface water. After WSP operations ended in 1966, a small but continuous discharge at the process sewer outfall occurred (Weidner and Boback 1982). During operations and in the years after plant closure, leaching of sediments in the pits and quarry provided a route of discharge to groundwater (Weidner and Boback 1982).

The four raffinate pits received neutralized residues and waste streams from the various processing steps at the WSP (Ficker 1981). The sludges in all the pits are essentially the same with the exception of those in Pit 4, because the latter was used predominantly during thorium processing. The pits were used as settling lagoons; the solids would settle out as a sludge, and the remaining supernatant would overflow to the plant process sewer. The solids were mostly acid insoluble compounds from the original ore material as well as hydroxides and precipitates that formed when the raffinates were neutralized with lime.

About 30% of the residues in Pits 1, 2, and 3 came from the uranium metal production step. Magnesium fluoride was produced as a scrap material during the reduction of $UF_4$ to uranium metal, and the slag contained about 5% uranium. This uranium was leached from the slag and then washed to remove the remaining soluble uranyl nitrate. The washed slag, almost uranium free, was pumped to the pits. In addition to residues from thorium processing, Pit 4 also contained drums and rubble dumped during plant closure (Ficker 1981).

During the operational period, the total amount of uranium discarded to the raffinate pits was measured and reported in the materials balance study (Harris 1986). Table 2-8 summarizes the recorded discharges to the raffinate pits.

Table 2-8. Estimated annual discharges to raffinate pits (kg).[a]

| Fiscal year[b] | NU | DU | EU | Natural thorium |
|---|---|---|---|---|
| 1958 | (c) | (c) | (c) | (c) |
| 1959 | (c) | (c) | (c) | (c) |
| 1960 | 46,193 | (c) | (c) | (c) |
| 1961 | 12,502 | 0 | 0 | 0 |
| 1962 | 8,831 | 46 | 0 | 0 |
| 1963 | 18,448 | 0 | 0 | 0 |
| 1964 | 35,243 | 0 | 0 | 2,469 |
| 1965 | 13,069 | 0 | 2,828 | 16,170 |
| 1966 | 18,067 | 0 | (20) | 26,809 |
| 1967 | 29 | 0 | 0 | 30,750 |
| **Total** | **152,382** | **46** | **2,808** | **76,198** |

a. From Table 7 in Harris (1986, p. 36).
b. Fiscal year begins on July 1 of the previous calendar year and ends on June 30 of the calendar year corresponding to the designated fiscal year.
c. Discharges to raffinate pits in AEC fiscal years 1958 and 1959 were held in inventory as "potentially recoverable." Beginning in fiscal year 1960, all previous and then current releases to the raffinate pits were treated as discharges and removed from the operating inventory as they occurred.

When the raffinate pits were in use, the supernatant solution from Pits 1 through 3 was decanted and fed to the plant storm sewer system via buried pipes (Weidner and Boback 1982). Sewage treatment effluent added to this flow, and the combined wastewater was discharged off the site into a natural streambed. The discharge point, called the process sewer outfall, was within a fenced right-of-way that enclosed the stream all the way to the Missouri River. Table 2-9 lists the estimates of discharges to the sewer from the materials balance study (Harris 1986). Supernatant from Pit 4 was never decanted, which is why Table 2-9 does not indicate thorium discharges to the sewer.

Table 2-9. Estimated annual discharges to sewer (kg).[a]

| Fiscal year[b] | NU | DU | EU | Natural thorium |
|---|---|---|---|---|
| 1958 | No data | No data | No data | No data |
| 1959 | No data | No data | No data | No data |
| 1960 | 3,472 | No data | No data | No data |
| 1961 | 6,461 | 0 | 0 | 0 |
| 1962 | 4,304 | 0 | 0 | 0 |
| 1963 | 6,374 | 0 | 0 | 0 |
| 1964 | 3,239 | 0 | 0 | 0 |
| 1965 | 1,254 | 0 | 979 | 0 |
| 1966 | 1,411 | 0 | 0 | 0 |
| 1967 | 205 | 0 | 0 | 0 |
| **Total** | **26,720** | **0** | **979** | **0** |

a. From Table 7 in Harris (1986).
b. Fiscal year begins on July 1 of the previous calendar year and ends on June 30 of the calendar year corresponding to the designated fiscal year.

While the majority of the thorium and uranium in the raffinate pits and quarry was insoluble, their progeny were likely to be more soluble. Therefore, both the WSRP and WSQ pose a potential source of groundwater contamination near the WSP site. Ongoing remediation involves active monitoring of the groundwater in this region.

### 2.7.3 Accidents

None of the documented accidents at the WSP site resulted in exceptionally high personnel exposure levels (such as a criticality event). Interviews with former WSP employees discussed several anecdotal radiological or contamination events, but none of the people interviewed reported that the events resulted in high exposures (ORAUT 2009a, 2009b, 2009d, 2009e, 2009f, 2009g).

The Health and Safety Division maintained annual logbooks of forms and memoranda for employees with high urinary uranium concentrations. Investigation reports were also included in the logs (for Action Level 2 exposures and above). Descriptions of the data forms in Table 2-10 are included to demonstrate MCW management of and response to high bioassay results (MCW 1960a, 1961a, 1962–1965). The Weldon Spring Urinary Uranium Program procedures for 1960 and 1963 provide additional information on the bioassay program and use of these forms (MCW 1960b, 1965).

As examples of the character of accidents, Dupree (1979) cites two accidental exposures of workers that occurred during plant operations and were described by Mason during a visit to ORAU in August 1979. In one instance, a worker overfilled a pot with molten uranyl nitrate solution, which spilled onto the floor. A full report of the incident was made (MCW 1961b). In the other case, a worker inhaled soluble uranium while trapped in a dust enclosure.

## 2.8 HEALTH PROTECTION PRACTICES

### 2.8.1 Operational Period, 1957 to 1966

According to a descriptive report of the MCW contributions between 1942 and 1967 (Fleishman-Hillard 1967), the design of the WSP "took advantage of the Company's and the AEC's accumulated wealth of experience concerning the handling of health and contamination problems encountered in uranium processing." The WSP layout was planned with the goal of minimizing the spread of contamination. Advanced dust-control systems were used, and onsite health facilities were provided. This 1967 document states, "...existing health programs were continued… at the new site, and a number of supplemental programs were initiated at the Weldon Spring plant."

Table 2-10. Forms for reporting high urinary uranium results.

| Form no. | Form title | Description |
|---|---|---|
| 7274 | High Exposure Incident Report | Includes the following information:<br>Employee name, department, job, type of exposure (film badge or urinary uranium with corresponding units), sample date, a description of the incident or occurrence, process or equipment to which the high exposure was attributed, and follow-up and remedial actions. |
| 7273 | Report of High Urinary Uranium Concentration<br><br>Report on Action Level Urinary Uranium Concentrations (Rev. 9-60) | Multiple employee names with their action level category (Action Level 1 to 4), and sample date.<br><br>Beginning in September 1960 the following information was preprinted on the form:<br>• Action Level 1 Monday 0.030 to 0.100 mg/L<br>• Action Level 1 Friday 0.060 to 0.100 mg/L<br>• Action Level 2 0.100 to 0.200 mg/L<br>• Action Level 3 0.200 to 0.300 mg/L<br>• Action Level 4 >0.300 mg/L |
| 7357 | Urinary Uranium Data for Week | Weekly summary of the Monday–Friday average urinary uranium concentrations by location, number of operators participating, percent of employees sampled with results less than the action level, and the names of the "peak men" (highest exposed employees). |
| 7463 | Urinary Uranium | Weekly summary of the Monday–Friday samples by cost center, concentration ranges, number of employees in each range, names of employees above the Monday or Friday limits (>0.030 or 0.060 mg/L, respectively), and the number of scheduled and reporting employees. |

Sources: MCW 1960a, 1960b, 1961a, 1962–1965.

The *Summary of Health Protection Practices* for the Uranium Division (MCW 1965) describes the policies and basic principles underlying the health protection program and includes information about survey meter checks, film-badging procedures, bioassay procedures, and restrictions on work assignments based on previous accumulated exposures. It is likely that this represents a revision of the 1955 program (Mason 1955), but it is not clear what or when specific changes were made over the intervening years.

Both the 1955 and 1965 documents rely on AEC standards of radiation exposure to the extent that health protection decisions were made about worker rotation based on a comparison of monitored personnel exposures with these standards for radiation workers (i.e., individuals in controlled areas). Table 2-11 summarizes the 1955 document's list of tolerated cumulative doses in use at MCW. In addition, the 1955 document states that the goal was to keep each individual cumulative exposure at no greater than one-half of the tolerance when averaged over 3 months. The methods claimed for controlling exposure consisted of shielding, semiremote operations, and worker rotation.

Table 2-11. Tolerated dose limits in 1955.

| Type of radiation | Tolerated dose limit[a] |
|---|---|
| Beta | 500 mrep/wk, whole body or part |
| Gamma | 300 mR/wk, whole body or part |
| Beta and gamma | 500 mrep/wk, whole body or part |
| Not specified | 1,500 mrep/wk hands and forearms |

a. The rep (from "roentgen-equivalent-physical") is an obsolete unit of absorbed dose for types of radiation other than X-rays and gamma rays; replaced by the gray.

Table 2-12 lists the WSP guides for prescribing restricted work so that AEC standards would not be exceeded (MCW 1965). Work restriction involved temporary relocation of the affected personnel from usual duties until the cumulative average was at an acceptable level.

Table 2-12. Guides for prescribing restricted work based on radiation exposure in 1965 (MCW 1965).

| Type of radiation or radioactive material | Dose limit |
|---|---|
| Gamma | 3 rem per 3 consecutive calendar months.<br>10 rem per 12 consecutive calendar months.<br>5 rem per 12 months averaged over employment beginning 1955. |
| Beta (skin of whole body, thyroid) | 10 rem beta + gamma to whole body per 3 consecutive months.<br>30 rem beta + gamma to whole body per 12 consecutive months. |
| Beta (hands, forearms, feet, ankles) | 25 rem beta + gamma to whole body per 3 consecutive months.<br>75 rem beta + gamma to whole body per 12 consecutive months. |
| Internal radioactive materials (when principal effect of the material is radiation dose to tissues) | 50% of the acceptable body burden specified in the recommendations of National Bureau of Standards Report 69 (NBS 1959).<br>Time-weighted exposure concentration averaged over any 4-wk period exceeds more than 5 times the quantity in Table 1 of AEC Appendix 0524. |
| Uranium | Average urine concentrations for 3 evenly spaced samples over a 72-hr period exceeds 0.15 mg/L and one sample exceeds 0.25 mg/L.<br>Time-weighted exposure air concentration averaged over 5 consecutive workdays exceeds 0.25 mg/$m^3$.<br>Concentration in exposure air averaged over a 1-hr exposure exceeds 2.0 mg/$m^3$ (a reduction factor of 5 is allowed for a well-fitted mechanical respirator, and a factor of 50 for positive pressure respirator).<br>Uptake by other than inhalation suspected or known, average urine concentrations for 3 evenly spaced samples over a 72-hr period exceeds 0.10 mg/L. |

#### 2.8.1.1 Badging

According to the Mason (1955) health protection program document, “each employee except office females wears [a] combination film badge-security badge.” The stated procedure was to exchange these badges biweekly “or more often as indicated.” Dosimeters were placed at selected points throughout process areas to serve as integrating area monitors, and routine meter surveys were used to detect hot spots and provide information for decisions about protective measures. Data from the meter surveys have not been found at this point.

#### 2.8.1.2 Radiological Exposure and Access Control

Workers at WSP had the potential for exposure to airborne radionuclides from uranium or thorium and to external radiation from the onsite radioactive materials. Film badges and bioassay were used to evaluate actual exposures throughout the operational history. Measures were taken to control potential exposures to below AEC standards. According to Mason (1955) these measures involved:

1. Instituting a work permit program (aimed primarily at protecting maintenance workers in hazardous areas), which involved establishing time limits and survey meter checks for areas with radioactive materials;

2. Conducting investigations and counseling to study causes for exposure trends or unusual individual exposures and to educate employees about protective measures;

3. Providing shielding, semiremote operations, and worker rotation to control exposure;

4. Providing work clothing from the skin out for personnel working in regulated areas (where radioactive materials were processed and handled), which could not be worn outside of these areas except under cover clothing;

5. Use of respirators as specified by the MCW Health Department; and

6. Instituting a job time-limit program for personnel who worked routinely in areas where the exposure rate was known to be above the AEC-based tolerance limits.

MCW (1965) is more general than Mason (1955), but it is reasonable to assume all of the above measures were still in place based on language in the 1965 report.

### 2.8.2 U.S. Department of Defense Control of Chemical Plant, 1967 to 1985

WSP was under control of the Army from 1967 until 1985; it is not a covered facility during those years. WSQ and WSRP remained under control of AEC and its successors, and they are covered facilities throughout this period. There were no contractors on those sites until 1975.

During the later years (1975 to 1985) of this period, contractors maintained the integrity of embankments of the pits, controlled vegetation, and conducted environmental sampling for assessment in relation to the maintenance role. Documentation of the health protection program in place for these workers has not been found. However, NLO (1977) states, “no personnel are employed or directly assigned to the Weldon Spring site,” and “NLO personnel perform sampling and engineering duties on assignment from the Feed Materials Production Center, Fernald, Cincinnati, Ohio.” Therefore, exposures to radionuclides at the WSP site were limited because the site was essentially undisturbed during this period and the external exposure rate and airborne concentrations of radioactivity were minimal in terms of potential short-term exposures to caretakers (NLO 1977).

### 2.8.3 Remediation Period, 1985 to 2002

During this period, the WSSRAP project management contractor implemented health protection practices in compliance with DOE guidelines and regulations on occupational radiation protection (DOE 1981, 1986b, 1988b). Because inhalation was recognized as the primary pathway of concern at the WSP site in relation to worker exposure during active remediation, the focus of the radiation protection program was to control dust emissions and prevent inhalation intakes (DOE 2001b). Intake by ingestion was considered possible, but less of a potential dose hazard than inhalation. Administrative controls were implemented to minimize ingestion hazards by limiting eating, drinking, and smoking in contamination areas; by using personal protective equipment such as coveralls, face shields, and gloves; and by meeting monitoring requirements.

Active remediation began in 1993 with the dismantlement of structures at the WSP and the removal of bulk wastes at the WSQ. Applicable DOE guidelines and regulations were specified in 10 CFR Part 835 at that time. Monitoring to assess internal exposure hazards to remediation workers included area monitoring for airborne radionuclides other than radon and thorium, area monitoring for radon and thorium, breathing-zone air (BZA) samplers, and bioassay. In work areas where long-lived airborne radioactivity concentrations were likely to exceed 2% of the DOE-established limit, BZA sampling was conducted on 25% of workers who spent more than 1 hr/d in the area. Bioassay requirements included baseline, routine, special, contamination incident, and exit urine samples analyzed for uranium for radiological workers who were likely to receive 100 or more mrem/yr committed effective dose equivalent (CEDE) and those who declared pregnancy and routinely entered controlled areas. The BZA-sampling results were used to determine bioassay participation.

According to the WSSRAP project management contractor (DOE 2000d), "external dose rates are very low at the WSP site. General area external beta dose equivalent rates are at background levels (i.e., 0.03-0.05 mrem/hr)," with external gamma dose equivalent rates ranging from background (about 60 mrem/yr) to about 113 mrem/yr for continuous exposure in general areas. These exposure rates were expected to remain constant for the duration of site remediation. The use of nuclear density gauges by remediation workers increased the gamma radiation fields near the equipment (3 mrem/hr at 30 cm from the source), so control measures were instituted in these special areas to limit worker exposure. Raffinate sludge could produce a contact gamma dose rate in the range of 1 to 3 mrem/hr (with shallow dose equivalent rates up to 10 mrem/hr). Therefore, most raffinate sludge treatment and disposal activities were performed remotely to limit exposure.

#### 2.8.3.1 Badging

According to the January 2000 *External Dosimetry Technical Basis Manual* (DOE 2000d), "WSSRAP has provided personnel dosimetry to radiological workers since October 1986," just after the establishment of the DOE office on the site. According to this manual, only one worker's monitoring results indicated an external effective dose equivalent (EDE) above 100 mrem/yr (the results for this worker were 170 mrem EDE in 1994). The highest measured shallow dose equivalent was 1,450 mrem (in 1994), and all measured extremity dose equivalents were less than this value. The DOE-regulated action level of 5,000 mrem annual shallow and extremity dose equivalent was never exceeded. As a result, the number of dosimeters issued to personnel was reduced by approximately 95% due to completion of many of the activities and because future WSSRAP activities were judged to be similar to previous activities. The issuance was reduced to include only declared pregnant workers who entered controlled areas and those radiological workers likely to receive 100 mrem EDE in 1 year from external sources or 5,000 mrem shallow dose equivalent to the skin or any extremity. The issuance decision was made by the Worker Protection Supervisor based on area radiation monitoring results and estimated exposure times.

#### 2.8.3.2 Radiological Exposure and Access Control

Access to WSP was limited to authorized personnel during the environmental monitoring period by a 7-ft chain-link cyclone fence topped with three strands of barbed wire. The site was completely enclosed by Army-owned areas, and security patrols were provided by the Army to hinder unauthorized access (NLO 1977).

During active remediation, measures were taken to control potential internal and external exposures according to DOE guidelines, many of which are noted above. Access to areas in which exposures could exceed regulatory limits was administratively controlled. The Worker Protection Supervisor (or designee) made decisions about access to areas based on area monitoring that evaluated external exposure rates as well as air concentrations of radionuclides including radon, thorium, and progeny (DOE 2000d, 2001b).

Workplace intake controls included:

- Area decontamination;
- Air-handling units equipped with high-efficiency particulate air (HEPA) filters;
- Dust suppression using water sprays;
- Dust elimination using surface wipe down, HEPA vacuuming, or both;
- Plastic dust barriers;
- Limiting work area access to essential personnel and equipment;
- Prohibiting eating, drinking, smoking, and chewing tobacco in the work area; and
- Training for hazard recognition before entry in controlled areas.

Respiratory protection was required when workplace control measures were not possible or sufficiently effective, and the need for such was generally assessed when annual intakes of radionuclides other than radon, thorium, and progeny were likely to result in dose equivalents exceeding 100 mrem CEDE, or when intakes of radon, thorium, and progeny were likely to result in dose equivalents above 500 mrem CEDE.

## 2.9 JOB TITLES AND LOCATIONS DURING OPERATIONAL PERIOD

Table 2-13 provides a correlation of the job titles and locations for the plant during the operational phase. This information is useful in identifying work locations of a worker if the job title is known. This information is from a document titled *History of MCW-Uranium Division (MAL-UD)* that accompanied a memorandum that describes a visit to Oak Ridge by Mont Mason (Dupree 1979), who was head of Health and Safety for MCW for a number of years.

Table 2-13. Partial list of job titles and locations during operational period.

| Job title | Job type | Job location or building[a] |
|---|---|---|
| 103 DX men | Porter | Refinery – Digestion and Denitration (103) |
| 105 DX men | Porter | Refinery – Extraction (105) |
| 201 DX men | Porter | Green Salt Plant (201) |
| 201 Production Office Porter | Porter | Green Salt Plant (201) |
| 301 DX men | Porter | Metals Building (301) |
| 408 Porter | Porter | Maintenance (408) |
| Accountability Lab | Technical | Analytical Laboratory (407) |
| Assistant Foreman | Supervisory | Stores (408) |
| Assistant Superintendent | Supervisory | Green Salt Plant (201) |
| Auxiliary Dissolving Operator | Operator | Refinery – Digestion and Denitration (103) |
| Blending Operator | Operator | Metals Building (301) – Conversion |
| Bomb Cooling Operator | Operator | Metals Building (301) – Conversion |
| Bomb Unloading Operator | Operator | Metals Building (301) – Conversion |
| Capping & Tamping Operator | Operator | Metals Building (301) – Conversion |
| Carpenter | Carpenter | Maintenance Department (408) |
| Casting Operator | Operator | Metallurgical Pilot Plant (404) |
| Ceramics Operator | Operator | Metallurgical Pilot Plant (404) |
| Clerical and Steno | Clerical | Stores (408) |
| Clerical and Steno | Clerical | Production Control office |
| Control | Technical | Analytical Laboratory (407?) |
| Decontamination Room DX | Porter | Various process buildings ? |
| Digester Operator | Operator | Refinery – Digestion and Denitration (103) |
| Dingot Chipping Operator | Operator | Metals Building (301) – Conversion |
| Dishwasher | Labor | Analytical Laboratory (407) |
| Draftsmen | Draftsmen | Engineering |
| Electrician | Electrician | Maintenance Department |
| Employee Benefits officer | Clerical | Industrial Relations |
| Engineer | Engineer | Maintenance Department (408) |
| Engineer | Engineer | Engineering |
| Extrusion Press Operator | Operator | Metals Building (301) – Fabrication and Extrusion |
| Feed Operator | Operator | Refinery – Digestion and Denitration (103) |
| Filling Operator | Operator | Metals Building (301) – Conversion |
| Fluoride Chemistry Technician | Technical | Research Laboratory |
| Foreman | Supervisory | Stores (408) |
| Foreman | Supervisory | Warehouse (406) |
| Foreman | Supervisory | Sampling Plant (101) |
| Foreman | Supervisory | Maintenance Department (408) |
| Foreman | Supervisory | Metallurgical Pilot Plant (404) |
| Foreman | Supervisory | Wet (Chemical?) Pilot Plant (403) |

| Job title | Job type | Job location or building[a] |
|---|---|---|
| Forge Press Operator | Operator | Metallurgical Pilot Plant (404) |
| Furnace and Saw Operator | Operator | Metallurgical Pilot Plant (404) |
| Furnace Operator | Operator | Green Salt Plant (201) |
| Furnace Operator | Operator | Metals Building (301) – Conversion |
| General Foreman | Supervisory | Refinery (103-105) |
| General Foreman | Supervisory | Green Salt Plant (201) |
| General Foreman | Supervisory | Metals Building (301) |
| General Foreman | Supervisory | Maintenance Department (408) |
| General Labor | Labor | Boiler House (401) |
| General Labor | Labor | Water Plant (429?) |
| General Office | Clerical | Health Department (410) |
| General Office | Clerical | Industrial Engineering |
| General Office | Clerical | Engineering |
| General Office | Clerical | Industrial Relations |
| General Office | Clerical | Safety and Fire |
| General Office | Clerical | Accounting |
| General Office | Clerical | Purchasing |
| General Office | Clerical | Administrative Services (409) |
| General Office | Clerical | Payroll (409?) |
| General Office | Clerical | Tabulating Office |
| General Office | Clerical | Research Laboratory (407?) |
| General Office | Clerical | Production Technical Department |
| Guard | Plant protection | Plant Wide |
| Guard Captain | Plant protection | Plant Wide |
| Guard Lieutenant | Plant protection | Plant Wide |
| HF Operator | Operator | Green Salt Plant (201) |
| Industrial Hygiene | Industrial Hygiene | Health Department (410) |
| Inspectors | Inspector | Safety and Fire |
| Jolter Operator | Operator | Metals Building (301) – Conversion |
| Laborer | Laborer | Maintenance Department (408) |
| Lathe Operator | Operator | Metals Building (301) – Fabrication and Extrusion |
| Lead Operator | Operator | Metallurgical Pilot Plant (404) |
| Lid Chipping Operator | Operator | Metals Building (301) – Conversion |
| Locker Room Porters | Porter | Services Building (410?) |
| Machine Maintenance | Laborer | Maintenance Department (408) |
| Magnesium Building Operator | Operator | Metals Building (301) – Conversion |
| Maintenance Clerks | Clerical | Maintenance Department (408) |
| Messenger | Messenger | Administrative Services |
| Metallurgical Technician | Technical | Research Laboratory |
| Methods Development | Technical | Analytical Laboratory |
| Misc. Digestion Operator | Operator | Refinery – Digestion and Denitration (103) |
| Motor and Equipment Tagger | Labor | Accounting (409?) |
| Nitric Acid Operator | Operator | Refinery – Digestion and Denitration (103) |
| NOK Operator | Operator | Refinery – Nitric Acid in Hexane (NAH) |
| Office and Steno | Clerical | Analytical Laboratory (407) |
| Oiler | Laborer | Maintenance Department (408) |
| Operator | Operator | Wet (Chemical?) Pilot Plant (403) |
| Operators | Operator | Sampling Plant (101) |
| Packaging Operator | Operator | Refinery – Digestion and Denitration (103) |
| Packaging Operator | Operator | Green Salt Plant (201) |
| Painter | Painter | Maintenance Department (408) |
| Pipe Maintenance | Laborer | Maintenance Department (408) |
| Plant Porter | Porter | Plant-wide |
| Pot Room Operator | Operator | Refinery – Digestion and Denitration (103) |
| Production Clerk | Clerical | Sampling Plant (101) |

| Job title | Job type | Job location or building[a] |
|---|---|---|
| Production Clerk | Clerical | Refinery (103-105) |
| Production Clerk | Clerical | Green Salt Plant (201) |
| Production Clerk | Clerical | Metals Building (301) |
| Production Machinist | Operator | Metallurgical Pilot Plant (404) |
| Production Operator | Operator | Metallurgical Pilot Plant (404) |
| Pulse Column Operator | Operator | Refinery (105/108)– Nitric Acid in Hexane (NAH) |
| Pumper Decanter Operator | Operator | Refinery (105/108)– Nitric Acid in Hexane (NAH) |
| Raffinate Operator | Operator | Refinery (103) – Digestion and Denitration |
| Recovery Operator | Operator | Refinery (103) – Digestion and Denitration |
| Residue Operator | Operator | Metallurgical Pilot Plant (404) |
| Rigger | Rigger | Maintenance Department (408) |
| Sampling plant DX men | Porter | Sample plant |
| Saw Operator | Operator | Metals Building (301) – Fabrication and Extrusion |
| Shift Assistant Foreman | Supervisory | Refinery |
| Shift Foreman | Supervisory | Refinery |
| Shift Foreman | Supervisory | Green Salt Plant – 201 |
| Shift Foreman | Supervisory | Metals Building (301) |
| Shift Foreman | Supervisory | Metallurgical Pilot Plant (404) |
| Shift Foreman | Supervisory | Wet (Chemical?) Pilot Plant (403) |
| Slag Building Operator | Operator | Metals Building (301) – Conversion |
| Special Analysis | Technical | Analytical Laboratory |
| Special Techniques Technician | Technical | Research Laboratory |
| Specification Testing | Technical | Analytical Laboratory |
| Spectrographic | Technical | Analytical Laboratory |
| Stenographer | Clerical | Maintenance Department (408) |
| Storekeeper | Stores | Stores (408) |
| Stripper Operator | Operator | Refinery (105/108) – Nitric Acid in Hexane (NAH) |
| Sump Operator | Operator | Metals Building (301) – Fabrication and Extrusion |
| Superintendent | Supervisory | Refinery (103-105) |
| Superintendent | Supervisory | Metals Building (301) |
| Superintendent | Supervisory | Maintenance Department (408) |
| Superintendent | Supervisory | Production Technical Department |
| Supervisor | Supervisory | Production Control office |
| Technical | Technical | Metallurgical Pilot Plant (404) |
| Technical | Technical | Wet (Chemical?) Pilot Plant (403) |
| Technical Services Staff | Technical | Production Technical Department–Sampling Plant (101) |
| Technical Services Staff | Technical | Production Technical Department–Refinery |
| Technical Services Staff | Technical | Production Technical Department–Green Salt Plant 201 |
| Technical Services Staff | Technical | Production Technical Department–Metals Building (301) |
| Tinner | Laborer | Maintenance Department (408) |
| Utility Operator | Operator | Green Salt Plant (201) |
| Vacuum Techniques Technician | Technical | Research Laboratory (407) |
| Warehouse Yard Operator | Operator | Sampling Plant (101) |
| Warehouse Yard Operator | Operator | Refinery (103-105) |
| Warehouse Yard Operator | Operator | Green Salt Plant – 201 |
| Warehouse Yard Operator | Operator | Metals Building (301) |
| Warehouse Yard Operator | Operator | Various |
| Welder | Welder | Maintenance Department (408) |
| Wet Chemistry Technician | Technical | Research Laboratory (407) |

a. A question mark denotes disagreement in the various documents that describe jobs or locations.

## 2.10 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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## GLOSSARY

**curie (Ci)**
Traditional unit of radioactivity equal to 37 billion ($3.7 \times 10^{10}$) becquerels, which is approximately equal to the activity of 1 gram of pure $^{226}Ra$.

**dose equivalent**
In units of rem or sievert, product of absorbed dose in tissue multiplied by a weighting factor and sometimes by other modifying factors to account for the potential for a biological effect from the absorbed dose

**dosimeter**
Device that measures the quantity of received radiation, usually a holder with radiation-absorbing filters and radiation-sensitive inserts packaged to provide a record of absorbed dose received by an individual.

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

**dosimetry system**
System for assessment of received radiation dose. This includes the fabrication, assignment, and processing of external dosimeters, and/or the collection and analysis of bioassay samples, and the interpretation and documentation of the results.

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

**extremities**
Portion of the arm from and including the elbow through the fingertips and the portion of the leg from and including the knee and patella through the toes.

**film**
(1) In the context of external dosimetry, radiation-sensitive photographic film in a light-tight wrapping. (2) X-ray film.

**gamma radiation**
Electromagnetic radiation (photons) of short wavelength and high energy (10 kiloelectron-volts to 9 megaelectron-volts) that originates in atomic nuclei and accompanies many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Gamma photons are identical to X-ray photons of high energy; the difference is that X-rays do not originate in the nucleus.

**gamma ray, particle, or photon**
See *gamma radiation*.

**hydrofluorination**
Chemical conversion to a form containing fluorine.

**isotope**
One of two or more atoms of a particular element that have the same number of protons (atomic number) but different numbers of neutrons in their nuclei (e.g., $^{234}U$, $^{235}U$, and $^{238}U$). Isotopes have very nearly the same chemical properties.

**neutron**

Basic nucleic particle that is electrically neutral with mass slightly greater than that of a proton. There are neutrons in the nuclei of every atom heavier than normal hydrogen.

**nuclide**

Stable or unstable isotope of any element. Nuclide relates to the atomic mass, which is the sum of the number of protons and neutrons in the nucleus of an atom. A radionuclide is an unstable nuclide.

**photon**

Quantum of electromagnetic energy generally regarded as a discrete particle having zero rest mass, no electric charge, and an indefinitely long lifetime. The entire range of electromagnetic radiation that extends in frequency from $10^{23}$ cycles per second (hertz) to 0 hertz.

**radiation**

Subatomic particles and electromagnetic rays (photons) with kinetic energy that interact with matter through various mechanisms that involve energy transfer.

**radioactivity**

Property possessed by some elements (e.g., uranium) or isotopes (e.g., $^{14}C$) of spontaneously emitting energetic particles (electrons or alpha particles) by the disintegration of their atomic nuclei.

**radionuclide**

Radioactive nuclide.

**raffinate**

Waste from uranium or thorium extraction as well as solids from the neutralization of this waste.

**rem**

Traditional unit of radiation dose equivalent that indicates the biological damage caused by radiation equivalent to that caused by 1 rad of high-penetration X-rays multiplied by a quality factor. The sievert is the International System unit; 1 rem equals 0.01 sievert. The word derives from roentgen equivalent in man; rem is also the plural.

**roentgen**

Unit of photon (gamma or X-ray) exposure for which the resultant ionization liberates a positive or negative charge equal to $2.58 \times 10^{-4}$ coulombs per kilogram (or 1 electrostatic unit of electricity per cubic centimeter) of dry air at 0 degrees Celsius and standard atmospheric pressure. An exposure of 1 roentgen is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher energy photons (generally greater than 100 kiloelectron-volts).

**shielding**

Material or obstruction that absorbs ionizing radiation and tends to protect personnel or materials from radiation.

**U.S. Atomic Energy Commission (AEC)**

Federal agency created in 1946 to assume the responsibilities of the Manhattan Engineer District (nuclear weapons) and to manage the development, use, and control of nuclear energy for military and civilian applications. The U.S. Energy Research and Development Administration and the U.S. Nuclear Regulatory Commission assumed separate duties from

the AEC in 1974. The U.S. Department of Energy succeeded the U.S. Energy Research and Development Administration in 1979.

**X-ray radiation**

Electromagnetic radiation (photons) produced by bombardment of atoms by accelerated particles. X-rays are produced by various mechanisms including bremsstrahlung and electron shell transitions within atoms (characteristic X-rays). Once formed, there is no difference between X-rays and gamma rays, but gamma photons originate inside the nucleus of an atom.