



**ORAU TEAM  
Dose Reconstruction  
Project for NIOSH**

Oak Ridge Associated Universities | Dade Moeller | MJW Technical Services

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**Weldon Spring Plant – Site Description**

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New       Total Rewrite       Revision       Page Change

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## TABLE OF CONTENTS

<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>
	Acronyms and Abbreviations .....	5
2.1	Introduction .....	7
	2.1.1 Purpose.....	8
	2.1.2 Scope.....	8
2.2	Site Location and Summary History .....	8
2.3	Site Acquisition and Development, 1954 to 1957 .....	11
2.4	Operational Period, 1957 to 1966.....	11
	2.4.1 Processed Materials .....	11
	2.4.2 Plant Processes and Operations .....	14
	2.4.2.1 Uranium Concentrate Sampling .....	14
	2.4.2.2 Uranium Trioxide Production.....	14
	2.4.2.3 Uranium Tetrafluoride Production.....	15
	2.4.2.4 Uranium Tetrafluoride Conversion.....	15
	2.4.2.5 Products Manufacturing .....	17
	2.4.2.6 Thorium Processing .....	17
	2.4.2.7 Analytical and Research Laboratories .....	18
	2.4.2.8 Pilot Plants.....	18
	2.4.2.9 Raffinate Pits.....	19
	2.4.2.10 Weldon Spring Quarry.....	19
	2.4.3 Plant Operations and Radioactive Material of Concern Summary.....	20
2.5	U.S. Department of Defense Control Period, 1967 to 1985 .....	20
2.6	Remediation Period, 1985 to 2002 .....	25
2.7	Releases to the Outdoor Environment.....	26
	2.7.1 Airborne Emissions.....	27
	2.7.2 Waterborne Emissions.....	28
	2.7.3 Accidents.....	29
2.8	Health Protection Practices .....	30
	2.8.1 Operational Period, 1957 to 1966 .....	30
	2.8.1.1 Badging.....	31
	2.8.1.2 Radiological Exposure and Access Control.....	32
	2.8.2 U.S. Department of Defense Control of Chemical Plant, 1967 to 1985 .....	32
	2.8.3 Remediation Period, 1985 to 2002 .....	32
	2.8.3.1 Badging.....	33
	2.8.3.2 Radiological Exposure and Access Control.....	34
2.9	Job Titles and Locations During Operational Period.....	34
2.10	Attributions and Annotations .....	37
	References .....	38

Glossary .....	43
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### LIST OF TABLES

<u>TABLE</u>	<u>TITLE</u>	<u>PAGE</u>
2-1	Annual uranium and thorium mass receipts .....	12
2-2	Thoron and progeny .....	13
2-3	Chronological summary of thorium operations .....	18
2-4	Description of WSP buildings and operations .....	21
2-5	History of radioactive effluent-generating activities .....	27
2-6	Location and height of stacks at the WSP .....	27
2-7	Estimated annual discharges to stacks .....	28
2-8	Estimated annual discharges to raffinate pits .....	29
2-9	Estimated annual discharges to sewer .....	29
2-10	Forms for reporting high urinary uranium results .....	30
2-11	Tolerated dose limits in 1955 .....	31
2-12	Guides for prescribing restricted work based on radiation exposure in 1965 .....	31
2-13	Partial list of job titles and locations during operational period .....	34

### LIST OF FIGURES

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
2-1	Locations of WSP facilities .....	9
2-2	WSP and WSRP site layout .....	10
2-3	Sampling plant flow diagram .....	14
2-4	Digestion, purification, and denitration .....	15
2-5	Reduction and hydrofluorination process .....	16
2-6	UF <sub>6</sub> conversion to uranium metal .....	17

**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
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
km	kilometer
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  
ppb parts per billion

RI/FS remedial investigation/feasibility study  
RU recycled uranium

s second

SRDB Ref ID Site Research Database Reference Identification (number)  
SWTP Site Water Treatment Plant

t ton  
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 7384I(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. § 7384I(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. § 7384I(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 Weldon Spring Plant 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, or 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 environmental monitoring period that began in 1967 and ended in 1985. Section 2.7 discusses site remediation that occurred after that from 1985 to 2002. Section 2.8 discusses releases to the outdoor environment, and Section 2.9 discusses health protection at WSP during all periods. Section 2.10 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 part of the WSP, although it is about 4 mi southwest of the plant. Figure 2-2 shows the layout of the WSP facilities.



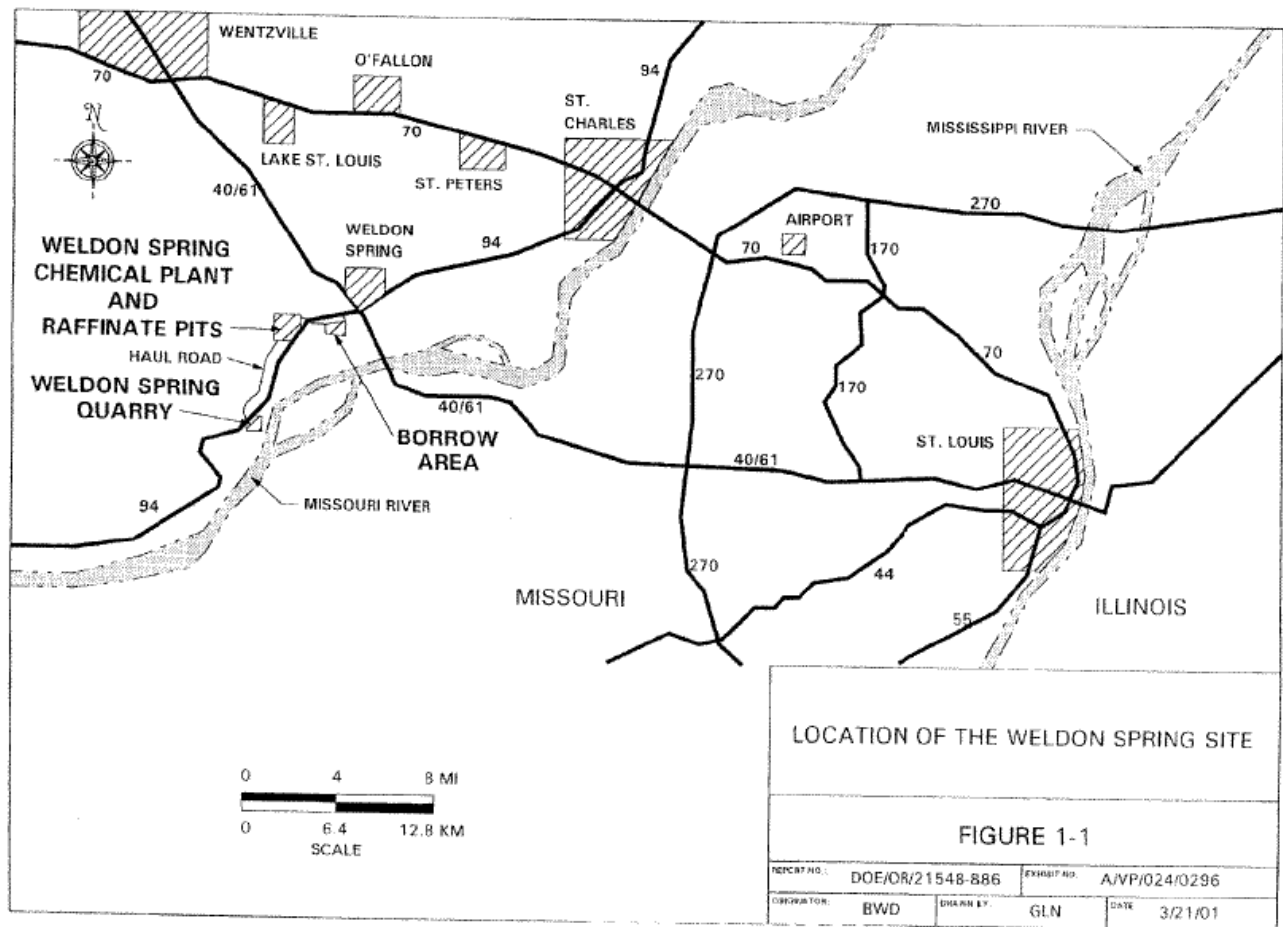


Figure 2-1. Locations of WSP facilities. (Source: MK-Ferguson, 2001a).

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 from 1975 to 1985 during the DOD control period.

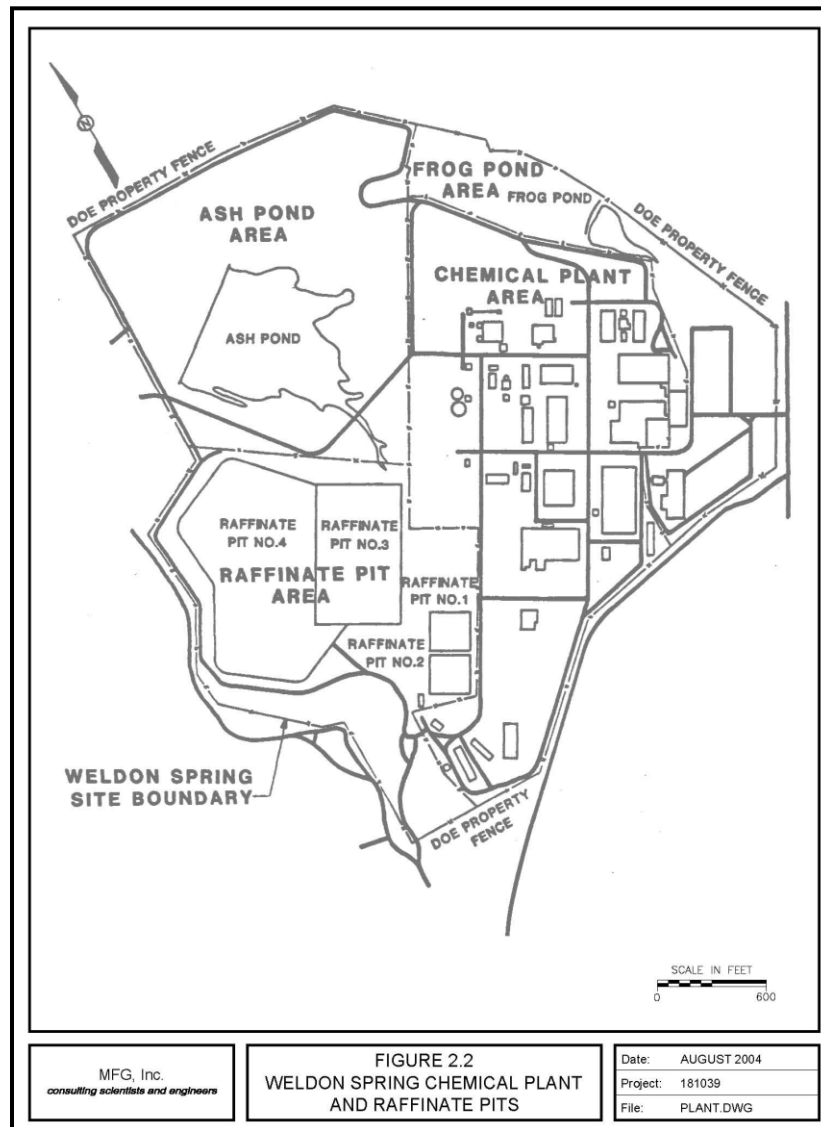


Figure 2-2. WSP and WSRP site layout (adapted from Army 1976).

In 1956, approximately 220 ac of the former Weldon Spring Ordnance Works were transferred to the U.S. Atomic Energy Commission (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; the date of initial operation was June of 1957 (MCW 1957). 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" (DOE 1986a). 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 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* (DOE 1986a), 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 (DOE 1986a). Total material balance closures (i.e., percent of material accounted for) for NU, DU, and EU for the 10 years of plant operations were 99.94%, essentially 100%, and 99.27%, respectively. 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.

#### **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.

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

Fiscal year <sup>a</sup>	NU	DU	EU	Natural thorium
1958 <sup>b</sup>	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
<b>Totals</b>	<b>122,015,977</b>	<b>167,823</b>	<b>842,585</b>	<b>941,347</b>

- 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.

The primary uranium concentrates at WSP consisted of <sup>234</sup>U, <sup>235</sup>U, and <sup>238</sup>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 2009c, 2009d, 2009g).

Decay products and other impurities including natural thorium (e.g., <sup>232</sup>Th and <sup>228</sup>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) is a historical study that estimates the offsite activities of <sup>230</sup>Th and <sup>226</sup>Ra in yellowcake to be 5% and 1% of <sup>238</sup>U activity, respectively. However, specific isotopic characterization of raffinate 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 <sup>230</sup>Th. Measurements of the activity concentrations in Raffinate Pits 1, 2, and 3 can be used to determine the relationship between <sup>230</sup>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 2017). The shorter lived decay products <sup>210</sup>Pb and <sup>210</sup>Po, for which no raffinate measurements were made, should be assumed present at the same activity as the <sup>226</sup>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 <sup>235</sup>U isotope 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, flow-sheet improvements, and confined primarily to pilot plant activities.

### Enriched Uranium

Uranium enriched to 1% or less <sup>235</sup>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) was exposed to 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  $^{228}\text{Th}$  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,  $^{228}\text{Th}$ . Thorium-228 is the third progeny of the long-lived  $^{232}\text{Th}$  and is generally in 40% to 65% equilibrium for materials processed at the WSP. The degree of equilibrium is dependent on both the decay of  $^{228}\text{Th}$  (without replenishment from the 5.7-year half-life of  $^{228}\text{Ra}$ ) after removal of the progeny and the time it takes the  $^{228}\text{Ra}$  to build into equilibrium with  $^{232}\text{Th}$ .

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 2016).

Isotope	Half life	Atoms/7.5 pCi	MeV/atom	PAEC 1 <sup>a</sup> MeV per 7.5 pCi
Radon-220	56 s	23	14.6	335
Polonium-216	0.15 s	<1	Included with Rn-220 <sup>b</sup>	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 $\mu\text{sec}$	Not applicable	Included with Bi-212 <sup>b</sup>	Included with Bi-212
Thallium-208	3 min	73	no alpha	0
<b>Total</b>	Not applicable	Not applicable	Not applicable	<b>1.33E+5</b>

a. 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 ( $6.07 \text{ MeV} \times 0.36 + 8.785 \text{ MeV} \times 0.64$ ). 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 post-1961 shipments that came from Fernald could have included some quantities of recycled uranium (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 of materials after 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  $^{236}\text{U}$  (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, the May 15, 2000, DOE report addressing WSP RU assumed that all uranium receipts after 1961 (71,413,060 kg) were recycled (DOE 2000a), which is a large overestimate of the actual quantity because the same document reports that the majority of material was NU. 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 2016) and stated within *Weldon Spring Plant – Occupational Internal Dose* (ORAUT 2017).

## 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 sampling – 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.

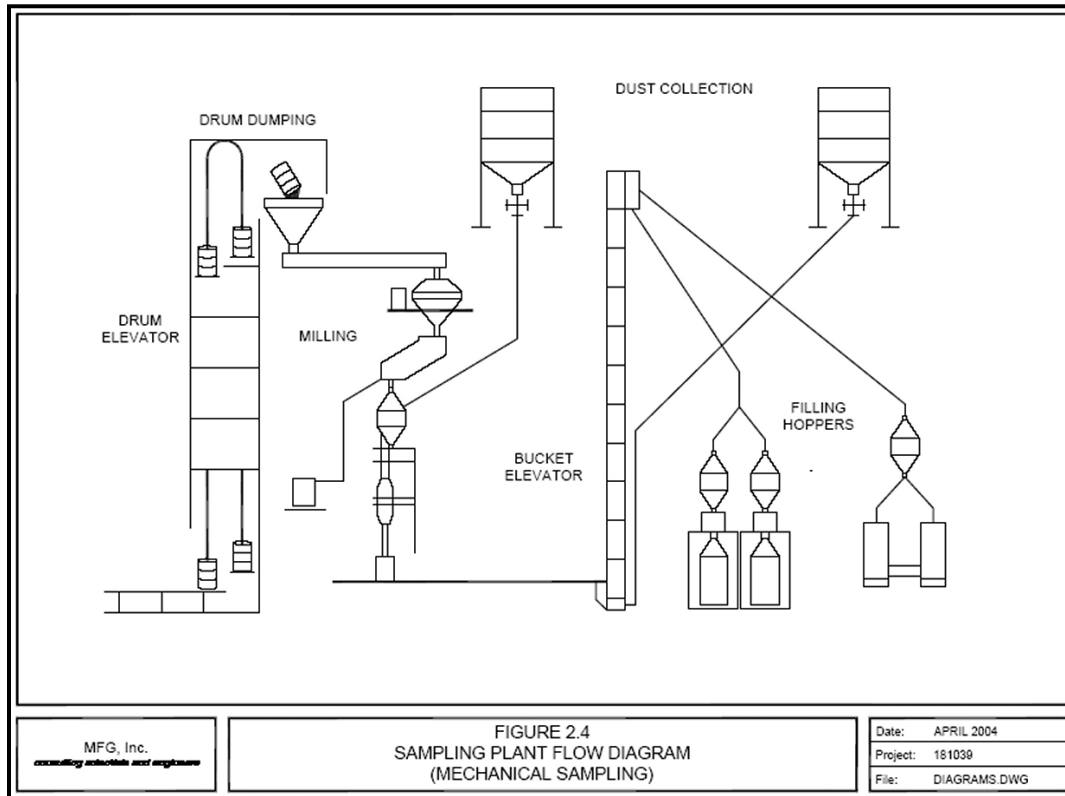


Figure 2-3. Sampling plant flow diagram (adapted from Army 1976).

### 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  $\text{UO}_3$ . 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.

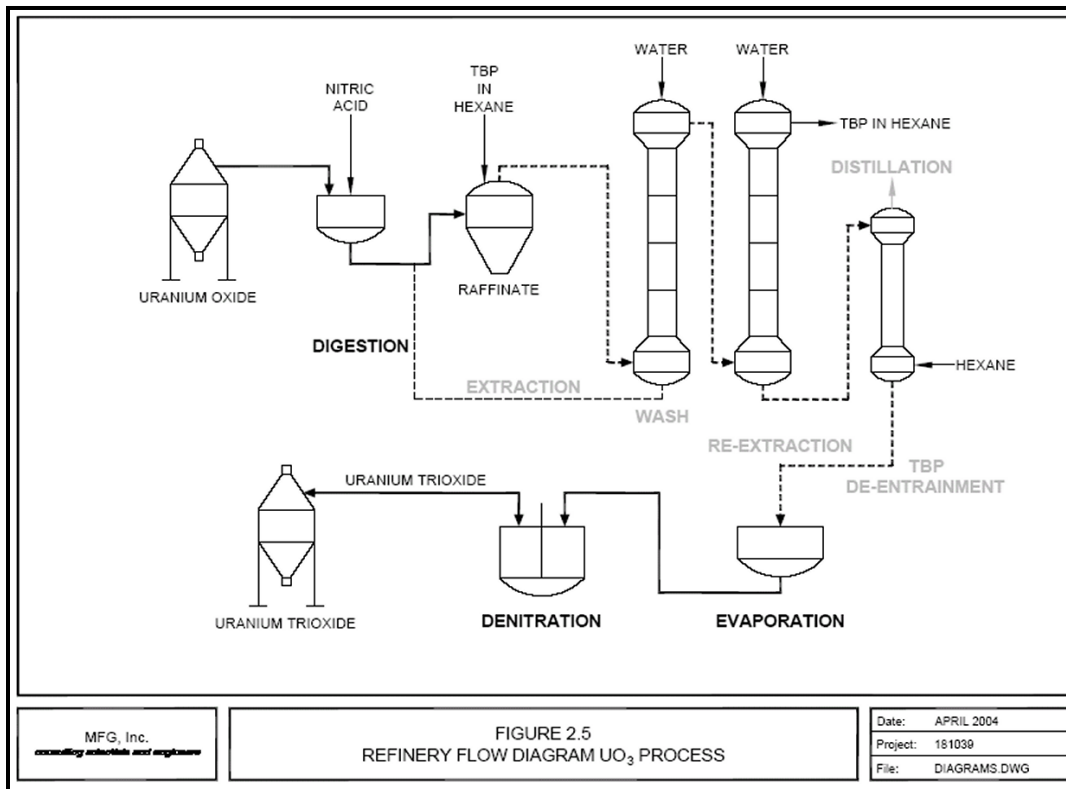


Figure 2-4. Digestion, purification, and denitration (adapted from Army 1976).

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 and 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  $\text{UO}_3$  was packaged into transfer hoppers and transferred from Building 103 to the top of Building 201, the green salt ( $\text{UF}_4$ ) plant. Figure 2-5 shows the reduction and hydrofluorination process used to produce  $\text{UF}_4$ . Hydrogen gas reduced  $\text{UO}_3$  to uranium dioxide ( $\text{UO}_2$ ).

The next step was hydrofluorination, in which  $\text{UO}_2$  was transformed to  $\text{UF}_4$  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 ( $\text{U}_3\text{O}_8$ ). Discharge from the  $\text{UF}_4$  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  $\text{UF}_4$  dust, and there was a reverter in the building to convert  $\text{UF}_4$  into  $\text{U}_3\text{O}_8$ .

### 2.4.2.4 Uranium Tetrafluoride Conversion

$\text{UF}_4$  (green salt) was packaged in transfer hoppers and moved to Building 301, the metals plant. Magnesium was used to convert  $\text{UF}_4$  to solid uranium metal in a multistep process. Figure 2-6 depicts

this process. The reaction occurred in refractory-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.

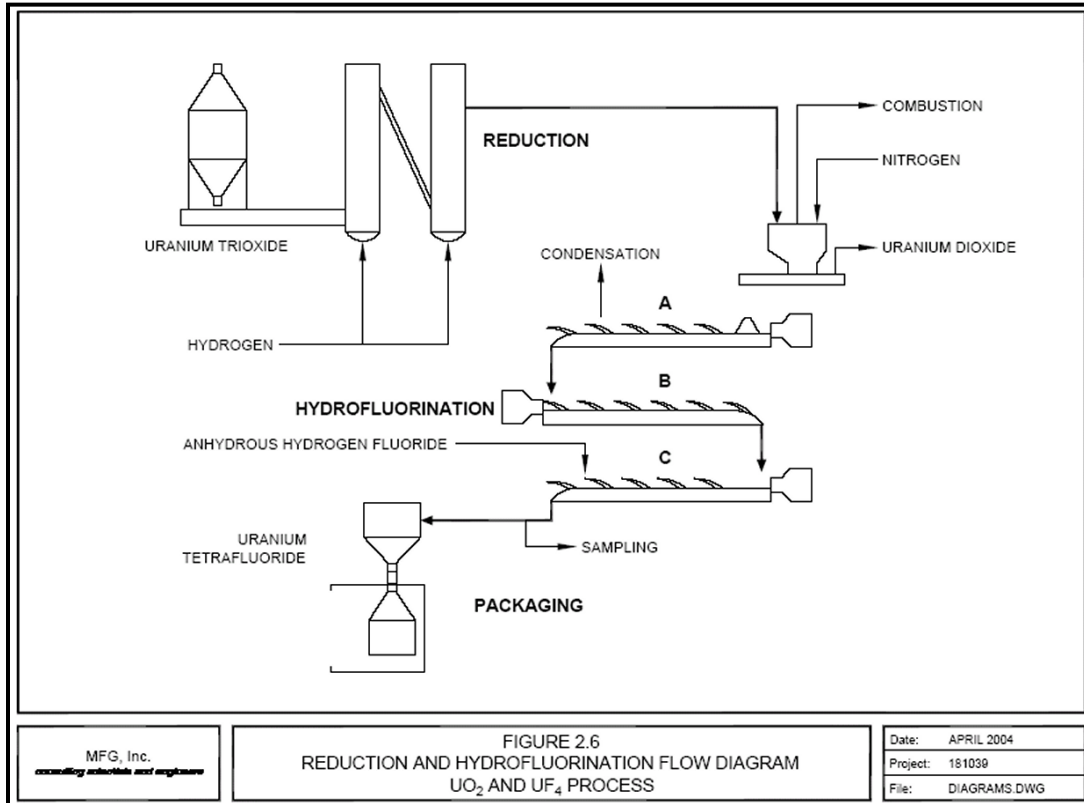


Figure 2-5. Reduction and hydrofluorination process (adapted from Army 1976).



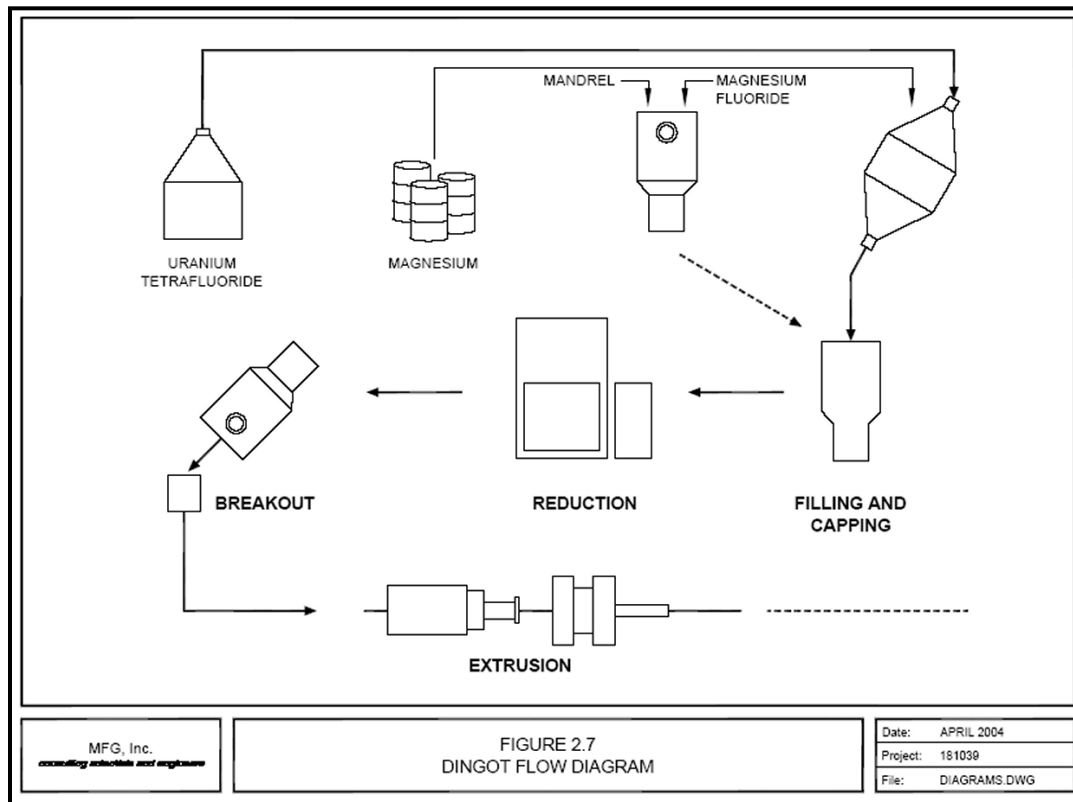


Figure 2-6.  $UF_4$  conversion to uranium metal (adapted from Army 1976).

### 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 (DOE 1986a).

An average of  $1.2 \times 10^7$  kg ( $1.4 \times 10^4$  t) of uranium containing material was processed per year (DOE 1986a). NU processing accounted for more than 97% of the nuclear materials throughput. Total material balance closures (i.e., percent of material accounted for) for NU, DU, and EU for the 10 years of plant operations were 99.94%, essentially 100%, and 99.27%, respectively. 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 (1958–1966) summarized operations with

thorium as shown in Table 2-3. Thorium process wastes were deposited in Raffinate Pit 4. In the table below, "TNT" abbreviates thorium nitrate tetrahydrate.

#### 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 in 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.

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
	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 <sub>2</sub> high firing-recast furnace	301	Nov–Dec	May–Sep	None	None
ThO <sub>2</sub> high firing-billet heaters	301	None	Oct–Dec	Jan–Dec	Jan; Jun–Sep
ThO <sub>2</sub> product packaging	403	Nov–Dec	May–Jul; Sep–Dec	Jan–Sep	None
	103	None	Aug	None	None
	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

#### 2.4.2.8 Pilot Plants

Buildings 403 and 404 housed the WSP and Metallurgical Pilot Plants, respectively. Both had development facilities on a scale intermediate between 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  $\text{UO}_3$ . 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 bottom 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 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 (DOE 1986a).

Between 1958 and 1964, to contain process wastes from the plant, four raffinate pits were constructed in the southwest portion of the site to contain process 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  $14,000 \text{ m}^3$  ( $500,000 \text{ ft}^3$ ) (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  $127,000 \text{ m}^3$  ( $4.5 \times 10^6 \text{ ft}^3$ ). Pit 4 was constructed and put into operation in 1964, and its design volume was  $340,000 \text{ m}^3$  ( $1.2 \times 10^6 \text{ ft}^3$ ) (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  $^{230}\text{Th}$ , 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 in 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,  $^{230}\text{Th}$  constituted greater than 80% of the total activity. An upper estimate of the  $^{230}\text{Th}$  activity in the ore concentrates is 100% of the  $^{234}\text{U}$  activity (its parent), or 50% of the total uranium activity (approximately 0.34 nCi/mg U). There was some natural thorium (e.g.,  $^{232}\text{Th}$  and  $^{228}\text{Th}$ ) 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 (Bechtel 1985). The WSQ was first used for storing radioactive waste in 1959, when an estimated  $150 \text{ m}^3$  ( $5,400 \text{ ft}^3$ ) of drummed 3.8%-thorium residues were placed there. In 1966, approximately  $13,500 \text{ ft}^3$  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  $38,000 \text{ m}^3$  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; DOE 1990, p. 20). Measurements in the quarry area in the late 1970s and early 1980s (before remediation) averaged  $0.65 \pm 0.41 \text{ pCi/L}$ , 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, 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.

Table 2-4. Description of WSP buildings and operations.<sup>a</sup>

Building	Description	Dates	Operations performed	Potential radionuclide exposures
101	Sampling Plant	June 1957–1966	Preparation and sampling building designed to process approximately 75 tons per day 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, Ra-226, Th-230, Po-210, Pb-210, Rn-222 and its short-lived progeny, 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 and were supplied or handled in tank-car and tank-truck quantities.	NU dust, Ra-226, Th-230, Po-210, Pb-210, Rn-222 and its short-lived progeny, Th-232 and progeny (in 1966)
103	Digestion and Denitration	1957–1966	Originally the nitrating, denitrating, and raffinate processing and storage area. The northern digestion section received uranium ore concentrates that were digestion and transferred as a slurry to Building 105 where the solvent was purified by extraction. 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 <sub>3</sub> . During later years, thorium products were also processed in this building.	NU dust (as yellowcake and uranium trioxide), Ra-226, Th-230, Po-210, Pb-210, Rn-222 and its short-lived progeny, 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), Ra-226, Th-230, Po-210, Pb-210, Rn-222 and its short-lived decay products, 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, Ra-226, Th-230, Po-210, Pb-210, Rn-222 and its short-lived progeny, 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, 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), 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 <sub>3</sub> to UO <sub>2</sub> and UF <sub>4</sub> .	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 <sub>4</sub> to uranium metal.	Uranium as green salt dust and U <sub>3</sub> O <sub>8</sub> or natural thorium (1965–1966), 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, Ra-226, Th-230, Po-210, Pb-210, Rn-222 and its short-lived decay products, 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 <sub>3</sub> O <sub>8</sub> 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, Ra-226, Th-230, Po-210, Pb-210, Rn-222 and its short-lived decay products, 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
431	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

<b>Building</b>	<b>Description</b>	<b>Dates</b>	<b>Operations performed</b>	<b>Potential radionuclide exposures</b>
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).



At shutdown, only a few pounds of pure compounds were present in any one piece of equipment with the bulk remaining in building sumps and in 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<sup>3</sup> 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 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 2012).

## **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* (ANL 1990) was signed in September 1990. 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 Investigations/Feasibility Study (RI/FS), and a limited

baseline risk evaluation. Excavation of approximately 120,000 yd<sup>3</sup> 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 long-term monitoring to verify that conditions at WSQ are 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, surface water and springs. The *Record of Decision for Remedial Actions at the Chemical Plant Area of the Weldon Spring Site* (DOE 1993) 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 pits 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<sup>3</sup> 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<sup>3</sup> 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 within 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<sup>3</sup> of contaminated wastes had been placed in it (DOE 2004 b; MK 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 Worker Advocacy list (DOE 2012), 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 2012). Table 2-5 summarizes the activities that released radionuclides to the WSP environment.

## 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 2000 around the chemical plant, pits, and quarry perimeters (Meshkov et al. 1986; Weidner and Boback 1982; Bechtel 1983a, 1983b, 1984, 1985, 1986; MK-Ferguson 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000a, 2001a). 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.

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

Date	Event
1957–1966 <sup>a</sup>	Operation of uranium feed materials plant. Uranium concentrate converted to UO <sub>3</sub> , UF <sub>4</sub> , and uranium metal. Some thorium processing. Raffinate from the processing removed to raffinate pits. 14,500 MT of uranium materials received for processing and sampling per year from 1958 to 1964. Some thorium processed from 1965 to 1966. Uranium and thorium residues disposed of in the WSQ.
December 1966 <sup>a</sup>	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).

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 (DOE 1986a). 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 (<sup>230</sup>Th, <sup>226</sup>Ra, and <sup>210</sup>Pb) were also estimated by Meshkov et al. (1986) as a fixed percent of the (estimated) amount of released <sup>238</sup>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 <sub>3</sub>	Various
201	6	UO <sub>2</sub> , UF <sub>4</sub> , and U <sub>3</sub> O <sub>8</sub>	14–34
301	Several	UF <sub>4</sub> and MgF with 1% uranium	23
301	1	U <sub>3</sub> O <sub>8</sub>	unknown

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.

Table 2-7. Estimated annual discharges to stacks (kg).<sup>a</sup>

Fiscal year <sup>b</sup>	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
<b>Total</b>	<b>44,741</b>	<b>0</b>	<b>300</b>	<b>0</b>

a. From Table 7 in DOE (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.

### 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 contained in 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<sub>4</sub> 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 contains 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 (DOE 1986a). Table 2-8 summarizes the recorded discharges to the raffinate pits.

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 (DOE 1986a). Supernatant from Pit 4 was never decanted, which is why Table 2-9 does not indicate thorium discharges to the sewer.

Table 2-8. Estimated annual discharges to raffinate pits (kg).<sup>a</sup>

Fiscal year <sup>b</sup>	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
<b>Total</b>	<b>152,382</b>	<b>46</b>	<b>2,808</b>	<b>76,198</b>

- From Table 7 in DOE (1986a, p. 36).
- 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.
- Discharges to raffinate pits in AEC Fiscal Years 1958 and 1959 were held in inventory as "potentially recoverable." Beginning in AEC 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.

Table 2-9. Estimated annual discharges to sewer (kg).<sup>a</sup>

Fiscal year <sup>b</sup>	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
<b>Total</b>	<b>26,720</b>	<b>0</b>	<b>979</b>	<b>0</b>

- From Table 7 in DOE (1986a).
- 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 is insoluble, their progeny are 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, 2009c, 2009d, 2009e, 2009f).

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 1960b, 1961b, 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 1960a, 1962).

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

Form no.	Form title	Description
7274	High Exposure Incident Report	Includes the following information: 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  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.  Beginning in September 1960 the following information was pre-printed on the form: <ul style="list-style-type: none"> <li>• Action Level 1 Monday 0.030 to 0.100 mg/L</li> <li>• Action Level 1 Friday 0.060 to 0.100 mg/L</li> <li>• Action Level 2 0.100 to 0.200 mg/L</li> <li>• Action Level 3 0.200 to 0.300 mg/L</li> <li>• Action Level 4 &gt;0.300 mg/L</li> </ul>
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, 1961b, 1962, 1962–1965.

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 1961a). 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 on-site 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.”

A 1965 revision of the *Summary of Health Protection Practices* for the Uranium Division is documented in MCW (1965). The policies and basic principles underlying the health protection program are described, and information is included 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 <sup>a</sup>
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. 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.

Type of radiation or radioactive material	Dose limit
Gamma	3 rem per 3 consecutive calendar months. 10 rem per 12 consecutive calendar months. 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. 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. 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). 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. Time-weighted exposure air concentration averaged over 5 consecutive workdays exceeds 0.25 mg/m <sup>3</sup> . Concentration in exposure air averaged over a 1-hr exposure exceeds 2.0 mg/m <sup>3</sup> (a reduction factor of 5 is allowed for a well-fitted mechanical respirator, and a factor of 50 for positive pressure respirator). 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, 1988). 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 (MK-Ferguson 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 (MK-Ferguson 2000b), "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**

The following information is from the WSSRAP contractor, MK-Ferguson Company and Jacobs Engineering Group.

According to the January 2000 *External Dosimetry Technical Basis Manual* (MK-Ferguson 2000b), "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 (MK-Ferguson 2000b, 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 the work locations of the claimants during their employment with WSP, if their job title is known. These were taken from an anonymous list that accompanied a memorandum (Dupree 1979) that describes a visit by Mont Mason to Oak Ridge. The notes were presumed to have been made by Mason, 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 <sup>a</sup>
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

<b>Job title</b>	<b>Job type</b>	<b>Job location or building<sup>a</sup></b>
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)
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)

<b>Job title</b>	<b>Job type</b>	<b>Job location or building<sup>a</sup></b>
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	Laborer	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)
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)

Job title	Job type	Job location or building <sup>a</sup>
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  $^{226}\text{Ra}$ .

### 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.,  $^{234}\text{U}$ ,  $^{235}\text{U}$ , and  $^{238}\text{U}$ ). 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.,  $^{14}\text{C}$ ) 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 R 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.