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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
11/19/2003	00	Technical Basis Document for the Y-12 National Security Complex – Site Description. First approved issue. Initiated by William E. Murray.
09/09/2004	00 PC-1	Deletes unused reference on page 22. First approved page change revision. Initiated by William E. Murray.
01/19/2005	01	Revises document to incorporate changes from NIOSH Office of General Counsel (OGC), to include a glossary and additional acronyms, to delete two unused references and add one new reference, to update the contents, and to make editorial changes. Approved issue of Revision 01. Initiated by William E. Murray.
10/11/2005	01 PC-1	Page change initiated to incorporate the definition of U.S.C. on page 5 and details for the definition of a DOE facility on pages 6 and 7. No sections were deleted. First approved page change revision of Revision 01. Retraining is not required. Initiated by William E. Murray. Approval: Signature on File 10/06/2005 William E. Murray, Document Owner Signature on File 10/04/2005 Judson L. Kenoyer, Task 3 Manager Signature on File 10/04/2005 Richard E. Toohey, Project Director Signature on File 10/11/2005 James W. Neton, Associate Director for Science
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11/08/2007	02	Approved revision initiated to add Attributions and Annotations section and additional references in response to review. The previous Section A-3, Y-12 Facilities, was eliminated. No further changes occurred as a result of formal internal review. Incorporates formal NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Task Manager. Initiated by William E. Murray.

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

ACE	U.S. Army Corps of Engineers
AEC	U.S. Atomic Energy Commission
CEDE	committed effective dose equivalent
Ci	curie
COLEX	column exchange
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ELEX	electrical exchange
EU	enriched uranium
ft	foot or feet
gal	gallon
HEU	highly enriched uranium
ICRP	International Commission on Radiological Protection
in	inch
keV	kiloelectronvolt, 1 keV = 1,000 electronvolts
kg	kilogram
LEU	low enriched uranium
LLW	low-level waste
mCi	millicurie
MED	Manhattan Engineer District
MeV	megaelectronvolt, 1 MeV = 1 million electronvolts
mg	milligram
mi	mile
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NU	natural or normal uranium
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
POC	probability of causation
RCRA	Resource Conservation and Recovery Act
RU	recycled uranium
RWP	radiological work permit

SNM	special nuclear material
SRDB Ref ID	Site Research Database Reference Identification (number)
SRS	Savannah River Site
TBD	Technical Basis Document
TEC	Tennessee Eastman Corporation
TRU	transuranic
UNH	uranyl nitrate hexahydrate
U.S.C.	United States Code
WETF	West End Treatment Facility
wt %	weight percent
y	year
§	section or sections

2.1 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions for particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry monitoring results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived:

- Radiation from naturally occurring radon present in conventional structures
- Radiation from diagnostic X-rays received in the treatment of work-related injuries

[1] The U.S. Department of Labor is ultimately responsible under the EEOICPA for determining the POC.

2.1.1 Purpose

The purpose of this Technical Basis Document (TBD) is to describe the activities, facilities, and radiation sources at the Y-12 National Security Complex (formerly the Y-12 Plant) over its operating history. The TBD provides the historical technical information on plant operations and facilities that is needed to reconstruct doses for both monitored and unmonitored workers. *Y-12* was a code name for the plant during the Manhattan Project and has been in use since that time. This TBD is part of the overall Y-12 Site Profile, which describes Complex facilities and processes, historical information, and environmental data in relation to dose reconstruction for Y-12 workers. It contains technical information to assist in the reconstruction radiation doses from these activities for both monitored and unmonitored workers.

2.1.2 Scope

This document provides an historical overview of the activities and processes that have occurred in the buildings and facilities on the Y-12 site, the treatment and storage of radioactive wastes, the onsite radionuclides and their solubility and radiation sources, and the accidents that have affected large groups of workers or large areas of the site.

Y-12 is in the eastern section of the Oak Ridge Reservation (ORR) near Oak Ridge, Tennessee. The Complex occupies approximately 811 acres (0.67 mi wide and 3.2 mi long) and consists of approximately 531 buildings that cover more than 7.5 million ft^2. Construction of Y-12 as part of the Manhattan Project began in late 1942 and was completed in 1943.

The information in this TBD is based on reports and other sources of information that are not classified. In some cases, classified documents have been redacted to allow their release and use as unclassified information. We are fully aware that more information is available that may be of use in reconstructing worker doses. Due to classification restrictions, such information can not be included in this document. Even though the classified information is not included in the TBD, it will be taken into account by the dose reconstructor in estimating dose incurred at the facility.

2.1.3 The Missions of the Y-12 Plant

Y-12 has played an important role in the development of the U.S. nuclear weapons program. The first mission of Y-12 was to separate the fissionable isotope of uranium, ^{235}U, for use in nuclear weapons. The second was manufacturing of nuclear weapons parts during the Cold War, and today the mission focuses on support of U.S. nuclear defense policies. At its peak, Y-12 employed approximately 22,000 workers.

First Era, Uranium Isotope Separation, 1942 to 1947
The Y-12 Plant, which was conceived in 1942 by the Manhattan Engineer District (MED) of the U.S. Army Corps of Engineers (ACE), was constructed by Stone and Webster Construction Company at a cost of about $427 million. Before completion, the operating contractor, the Tennessee Eastman Company (TEC) of Kingsport, Tennessee, moved its people in to start operations. The Calutron Pilot Plant and training facility (Building 9731) was the first building to begin operations, in the fall of 1943. (calutron is from *California University Cyclotron*).

Despite technical problems, this first-of-a-kind electromagnetic isotope separation (calutron) plant succeeded in its mission. In a little over 2 years, the uranium fuel was separated for the Hiroshima nuclear weapon. The gaseous diffusion process at the Oak Ridge Gaseous Diffusion Plant (ORGDP)

was the MED's backup for enriching uranium. Because this process was workable and much less costly, Y-12 was shutdown in December 1946 and employment was cut drastically.

Second Era, Cold War Nuclear Weapons Components Manufacturing, 1947 to 1992
Y-12 eventually became one of twelve production facilities with a unique role. Its new mission was to produce the key components of nuclear weapons and test the devices necessary for expansion of the nuclear weapons stockpile, and for the safekeeping of the nation's highly enriched uranium (HEU) stockpile. Many support tasks were given to Y-12, notably the production of the enriched lithium that was urgently needed for the thermonuclear program in the 1950s and 1960s. Y-12 succeeded in carrying out these challenging missions to develop state-of-the-art technologies necessary to new weapons designs over a period of almost 50 years.

Third Era, Multiple New Missions, 1992 to present
The nation's stockpile of nuclear weapons was reduced by 90% during this time. The number of operational buildings was reduced, and Y-12 manufacturing technology was transferred to industry, where that was allowed. Ongoing missions include:

- Storing HEU for DOE
- Disassembling weapons or components to study aging and other effects
- Producing a small number of nuclear weapons parts and assemblies
- Decontamination and decommissioning (D&D) of unused buildings
- Conducting major efforts in environmental and waste management

By the end of 1992, 50 research and development agreements were negotiated between Y-12 and governmental and commercial entities. Informally termed "Work for Others," challenging problems were successfully solved for other Federal agencies.

2.2 OPERATING CONTRACTORS

The TEC was the original Y-12 contractor under agreement with the U.S. ACE. On January 1, 1947, in accordance with the Atomic Energy Act of 1946, all activities were turned over to the U.S. Atomic Energy Commission (AEC). During the same year, the MED was disbanded and TEC was replaced by Carbide and Carbon Chemicals Corporation as the Y-12 site contractor. The following is a list of the site's prime contractors throughout Y-12 history.

Operating Contractor[a]	Period[a]
Tennessee Eastman Corporation	1943 to 1947
Carbide and Carbon Chemicals Corporation	1947 to 1950
Carbide and Carbon Chemicals, Division of Union Carbide and Carbon Corporation	1951 to 1956
Union Carbide Nuclear Company, Division of Union Carbide and Chemicals Corporation	1957 to 1963
Union Carbide Corporation, Nuclear Division	1963 to 1984
Martin Marietta Energy Systems, Incorporated	1984 to 1994
Lockheed Martin Energy Systems	1994 to 1998
BWXT Y-12	1998 to present

a. ChemRisk 1993, p. 174.

2.3 SITE ACTIVITIES

From inception, Y-12 was specifically designed to enrich uranium via an electromagnetic separation process. The actual device used for enrichment, the calutron, used a massive magnetic field to

separate isotopes of uranium based on slight differences in mass. Two stages of separation and enrichment were required. The first and larger stage, designated *alpha*, produced slightly enriched feed material for the second stage, known as the *beta* stage. The alpha and beta chemical operations were required to produce feed material for the calutrons, to recover valuable waste and byproducts, and to produce the final material for use in a nuclear weapon.

Early operations at Y-12 were narrowly focused. The primary hazards at the facility were uranium-bearing chemicals including, but not limited to the following: (ChemRisk 1993, p. 222; ChemRisk 1999, pp. 172-185; BWXT 2003a, p.11):

- Uranium dioxide (UO_2),
- Uranium trioxide (UO_3),
- Uranium tetroxide (UO_4),
- Triuranium octoxide [also uranium oxide] (U_3O_8)
- Uranium tetrafluoride (UF_4)
- Uranium hexafluoride (UF_6),
- Uranium tetrachloride (UCl_4),
- Ammonium diuranate [$(NH_4)_2U_2O_7$],
- Uranyl nitrate [$UO_2(NO_3)_2$],
- Uranyl nitrate hexahydrate (UNH) [$UO_2(NO_3)_2 \times 6H_2O$],
- Uranyl fluoride [UO_2F_2],
- Uranium metal
- Uranium aluminum (U-Al)

In addition, bulk quantities of industrial chemicals [e.g., carbon tetrachloride (CCl_4), hydrogen peroxide (H_2O_2), dibutyl carbitol ($C_{12}H_{26}O_3$), nitric acid (HNO_3), and hydrochloric acid (HCl)] were used or produced at the plant. Because Y-12 was basically a heavy industry site, many other common industrial materials such as asbestos, solvents, acids, alkalis, and oils were used and available for potential worker exposure.

Electromagnetic operations at Y-12 continued for a number of years after 1947. However, these activities were chiefly directed toward research on new radionuclides for medical or other uses.

Over the following years, Y-12 became a highly sophisticated nuclear weapons component manufacturing facility and development engineering organization. The Complex receives, stores, and protects uranium and lithium materials and parts; dismantles nuclear weapons components; and serves as a government repository for enriched uranium (EU). In addition, Y-12 has many treatment, storage, and disposal facilities for hazardous and radioactive materials. Table 2-1 (BWXT 2003a, pp. 30-31) shows the radionuclides of concern at Y-12. Some building numbers and their corresponding radionuclides are not available at this time.

Table 2-1. Radionuclides of concern.[a]

Radionuclide	Type of emission	Radioactive half life (y)	Radionuclide	Type of emission	Radioactive half life (y)
^{99}Tc	Beta	2.13×10^{5}	^{236}U	Alpha	2.34×10^{7}
^{228}Th	Alpha	1.91×10^{0}	^{238}U	Alpha	4.47×10^{9}
^{230}Th	Alpha	7.54×10^{4}	^{237}Np	Alpha	2.14×10^{6}
^{232}Th	Alpha	1.45×10^{10}	^{238}Pu	Alpha	8.64×10^{1}
^{234}U	Alpha	2.47×10^{5}	^{239}Pu	Alpha	2.4×10^{4}
^{235}U	Alpha, some gamma	7.4×10^{8}	^{241}Am	Alpha	4.32×10^{2}

a. Adapted from BWXT 2003b, pp. 30–31.

2.4 SITE PROCESSES

Over the years, the mission of Y-12 has evolved from separating uranium isotopes to encompass a multitude of new missions. Manufacturers conduct their own research using unique machinery available at Y-12 as well as expertise throughout the ORR. In addition, Y-12 provides landlord services for DOE as well as other types of management, such as the Transportation and Safeguards Division and the Oak Ridge National Laboratory (ORNL). Other responsibilities include environmental restoration and waste management; putting facilities into a safe, legally compliant condition for shutdown; and providing protection of government property. Tables 2-2 and 2-3 provide a chronology by building of Y-12 operations and key uranium operations, respectively, from the beginning to the present.

2.4.1 Electromagnetic Enrichment, 1943 to 1947

Uranium was enriched for use in atomic weapons by processing large amounts of UCl_4 in calutrons (ChemRisk 1999, p. 172). These operations were housed in the alpha buildings (Buildings 9201-1, 9201-2, 9201-3, 9201-4, and 9201-5) and beta buildings (Buildings 9204-1, 9204-2, 9204-3, and 9204-4) that contained the first and second stages, respectively, of the enrichment processes.

2.4.2 Feed Preparation for Enrichment, 1943 to 1947

Feed preparation involved conversion of large quantities of uranium oxides (including UO_2, UO_3, and U_3O_8) into UCl_4 – the feed material for the calutrons (ChemRisk 1999, p. 174). Most operations occurred in Buildings 9202, 9203, 9206, and 9212.

2.4.3 Uranium Reclamation and Salvage, 1944 to 1951

An elaborate system of mechanical and chemical processes was used to recover and reclaim residual uranium feed and product material found on equipment and scrap material associated with the calutron operations or on material shipped from the AEC's Weldon Spring (Missouri) Plant that had ^{235}U content worth recovering. (It is important to point out that, in many early reports, this is referred to as recycling uranium and the product is referred to as recycled uranium (RU). The uranium reclaimed in these operations contains only the original feed material introduced into the calutrons and does not contain the added radioactive contaminants associated with the RU from reactor plutonium production targets and fuel elements.) These operations included mechanical scraping and brushing, nitric acid washing, and distillation and reclamation of solid uranium compounds adhering to surfaces. Uranium-contaminated materials included condensates, scrubber solutions, raffinates, destructive distillates, oils, and miscellaneous residues. These facilities handled mostly natural uranium (NU) and depleted uranium (DU). These operations occurred primarily in Buildings 9202, 9203, and 9206.

Salvage operations involved EU recovery from all non-product components or byproducts of the operations. Uranium was reclaimed from materials that are not considered to be production equipment, such as liquid and solid waste materials from maintenance and cleanup activities (e.g., mop water, laundry washes, and floor drain residues). Other salvage operations included mechanical scraping and brushing, nitric acid washing, and distillations and reclamation of solid uranium compounds. Some uranium was recovered for future use, while that in wash fluids was discharged to East Fork Poplar Creek (ChemRisk 1999, p. 178). Combustible materials such as wood, rags, sponges, filter paper, and carbon solids were burned in muffle furnaces and incinerators to recover the uranium. Scraps and materials that could not be decontaminated were buried within the ORR

Table 2-2. Chronology by building of operations (ChemRisk 1999, p. 171; Oliver 2003, 2007).

Building	1943–1948	1949–1951	1952–1963	1964–1995	1996–2007
9201-1	Tracks 1 and 2, α – I calutrons (uranium enrichment).	Uranium enrichment operations.	Uranium reclamation and salvage operations.	Fusion energy research operations.	General manufacturing for tooling, including work for others. Almost all clean work.
9201-2	Tracks 3 and 4, α - I calutrons (uranium enrichment).	Uranium enrichment operations.	COLEX lithium/ mercury enrichment.	Research and development operations.	ORNL facility.
9201-3	Track 5, α - I calutrons (uranium enrichment).	Uranium enrichment operations.	Uranium reclamation and salvage.	Fusion energy research operations.	Currently used for office space.
9201-4	Tracks 6 and 7, α - II calutrons (uranium enrichment).	Uranium enrichment operations.	COLEX lithium/ mercury enrichment.	Engineering and administrative facilities.	Awaiting D&D.
9201-5	Tracks 8 and 9, α - II calutrons (uranium enrichment).	Uranium enrichment operations.	COLEX lithium/ mercury enrichment.	NU/DU press, rolling, and machining operations.	NU/DU press, rolling, and machining operations; building evacuated (2007); surveillances occur; storage; awaiting D&D.
9202	α and chemical preparation and reclamation operations.	Uranium product reclamation operations.	Uranium process development and improvement.	Uranium process development and improvement operations.	Technology development.
9203	^{235}U analysis and initial uranium product processing	Uranium product reclamation operations.	Reclamation and salvage operations.	Y-12 production development and research operations.	Technology development.
9204-1	Tracks 1 and 2, ß calutrons (uranium enrichment).	Uranium enrichment operations.	Stable isotope separation operations.	Fusion energy research operations.	ORNL facility; however, BWXT Y-12 occupies office space.
9204-2	Tracks 3 and 4, ß calutrons (uranium enrichment).	Uranium enrichment operations.	Special material operations.	Special material operations.	Special material operations.
9204-2E	--	--	--	Uranium assembly operations.	Uranium assembly operations.
9204-3	Tracks 5 and 6, ß calutrons (uranium enrichment).	Uranium enrichment operations.	Stable isotope (*e.g.*, copper) separation.	Stable isotope (*e.g.,* copper) separation.	ORNL facility.
9204-4	Tracks 7 and 8, ß calutrons (uranium enrichment).	Uranium enrichment operations.	ELEX lithium/mercury pilot-scale.	NU/DU press and rolling.	Material storage operations.
9206	ß chemical reclamation and product processing.	Uranium product reclamation and salvage operations.	Uranium chemical processing and metal production.	Uranium chemical processing and metal production.	No longer a Material Access Area. Currently undergoing deactivation. D&D initiated.
9207	Uranium reclamation and salvage.	Uranium reclamation, salvage operations.	Maintenance and reclamation and salvage.	ORNL biological research.	ORNL facility (vacated in 2005); awaiting D&D.
9211	Uranium reclamation and salvage.	Uranium salvage and product reclamation operations.	Uranium salvage and product reclamation.	ORNL biological research.	ORNL biological research operations; (vacated in 2005); awaiting D&D.
9212	ß product processing.	Uranium conversion and reclamation operations.	UF_6 conversion, chemical and weapons production operations.	Chemical and weapons production.	Chemical operations and weapons production.
9215	--	--	EU machining and metal finishing operations.	EU machining and metal finishing operations.	EU machining, metal finishing; DU H-1 foundry.
9998	--	NU H-1 foundry.	DU H-1 foundry.	DU H-1 foundry.	DU processing operations.

Table 2-3. Key uranium operations (ChemRisk 1999, pp. 172-185).

Key uranium operations	Buildings involved	Dates of operation
Electromagnetic Enrichment: Y-12 processed about 50,000 kg of UCl_4 in calutrons in both alpha and beta enrichment buildings. To obtain a desired enrichment, UCl_4 was processed through many calutrons and reclaimed and reprocessed frequently. Alpha operations enriched from 10 to 20% ^{235}U. Beta operations further enriched partially-enriched, reclaimed alpha material up to 98% ^{235}U. EU compounds were recovered and converted to uranium oxide for shipment or reclaimed for further alpha or beta enrichment. DU was removed from process equipment and disposed of through building vents and storm sewer drains.	**Alpha Buildings 9201-1,2,3,4,5** **Beta Buildings 9204-1,2,3,4**	1943–1947
Feed Preparation and Product Processing: Volatile UCl_4 was the chemical form of uranium fed into the alpha and beta calutrons. UCl_4 was produced using two chemical conversions involving UO_3 and CCl_4. The first method was liquid phase chlorination in which uranium and CCl_4 were heated under pressure and formed UCl_4 crystals. The second method was vapor phase chlorination in which CCl_4 was gradually added to UO_3 and heated inside a chemical reactor bowl for about eight hours and then purged with nitrogen to exhaust phosgene vapors from the system. From both methods, UCl_4 crystals were collected and placed in charge bottles which were loaded into calutrons for enrichment.	**9202, 9203, 9206, 9212** 9202 and 9203 housed alpha uranium feed preparations and product recovery operations. They also handled EU, DU, and NU. 9206 was used to recover beta product with higher enrichment levels (>50%). Highly enriched material was converted to UCl_4 for further enrichment. 9212 received ~ 4,700 kg of UF_6 with an average ^{235}U content of 30% between 1945 and 1947.	1943–1947
Uranium Recovery and Reclamation: Y-12 stopped enriching uranium after WWII. Operations now centered on reclaiming residual uranium found on equipment and scrap material. These operations included mechanical scraping and brushing, nitric acid washing, and distillation and reclamation of solid uranium compounds adhering to surfaces. Uranium-contaminated materials included condensates, scrubber solutions, raffinates, destructive distillates, oils, and miscellaneous residues. These facilities handled mostly NU and DU.	**9202, 9203, 9206, 9212** 9202, 9203 received DU, slightly EU, and NU. 9206 was the main uranium reclamation facility and housed sanding, grinding, chemistry, and incinerator operations.	1944–1951 1950s–1990s
Uranium Salvage: Salvage operations reclaimed uranium from materials that are not considered to be production equipment, such as liquid and solid waste materials from maintenance/ cleanup activities such as mop water, laundry washes, and floor drain residues. Combustible materials such as wood, rags, sponges, filter paper, and carbon solids were burned in muffle furnaces and incinerators to recover uranium. Other salvage operations included mechanical scraping and brushing, nitric acid washing, and distillations and reclamation of solid uranium compounds.	**9206, 9207, 9211** 9206 housed salvage operations and process operations were similar to 9207 and 9211. 9207 and 9211 processed incinerated solid waste and reclaimed NU and slightly EU.	1947–1951
Uranium Preparation and Reclamation: Y-12 began a continuous growth of uranium weapons component manufacturing operations handling a variety of uranium compounds and enrichment. EU prepared for reduction to metal involved conversion of UF_6 to UF_4 purification of uranyl nitrate solutions, precipitation for uranium reclamation, and then reduction to uranium metal.	**9202, 9206, 9211, 9212** 9212 housed the largest chemical operations for EU purification, reclamation and chemical conversion, as well as NU and DU machining operations.	1952–1995
Uranium Forming/Machining: Y-12 had operations capable of casting, rolling, and machining uranium metal. These operations handled EU, DU, and NU. Uranium was pressed, rolled, shaped, and machined into finished weapons components.	**9201-5, 9204-4, 9215, 9998** 9201-5, 9204-4 housed DU. 9215 housed EU. 9998 contained H-1 foundry operations that included DU reclamation and parts manufacturing.	1952–1995
Uranium Component Assembly: Machined components were sent through finishing operations that included drilling, welding, brazing, polishing and final specification checks. Bldg. 9202 was primarily used for early pilot scale operations that involved design and implementation of fabrications and assembly processes and final inspection procedures. Assembly operations generally were not associated with significant releases of uranium compounds. Any measurable amounts of uranium were recovered and reclaimed and were reintroduced into the production stream. Uranium was routinely recovered and reclaimed from articles such as rags, paper towels, oils and liquid waste products. Process exhaust stacks were equipped with HEPA filtrations and periodically inspected for buildup of uranium.	**9202, 9204-2, 9204-2E** 9204-2, 9204-2E housed uranium assembly operations.	1952–1995

(ChemRisk 1993, p. 243-245). These operations occurred primarily in Buildings 9206, 9207, and 9211.

In these operations, no radioactive contaminants were added that were different from the original uranium feed materials.

2.4.4 Uranium Preparation and Recycling for Weapons Components, 1949 to 1995

Uranium for weapons production was first processed in recovery, purification, and conversion operations. From about 1949 to 1964, Y-12 received cylinders of highly-enriched (93.5%) UF_6 as feed material for nuclear weapons parts manufacturing. Once purified and converted to metallic form, the uranium was transferred to processing operations for forming and shaping the metal into weapons part configurations. After 1964, the majority of EU processed at Y-12 was reclaimed from nuclear weapons stockpiles (Owings 1995, pp. 22-23).

Uranium recycle and purification processes began in 1953 and continue through today. These operations occurred primarily in Buildings 9202, 9206, and 9212. RU contains transuranic (TRU) material (e.g. plutonium and neptunium-237), fission products, (e.g. technetium-99), and reactor-generated uranium products (e.g. ^{236}U) (BWXT Y-12 2000, p. 21). Thus, the processing and re-enrichment of RU might present an increased potential hazard for occupational and environmental exposure that is greater than is normally associated with the processing of unirradiated uranium. The RU streams encompassed a variety of material forms including UNH, molten UNH, UO_2, UO_3, UF_4, uranium metal, uranium alloys, and a variety of associated wastes (BWXT Y-12 2000, p. 34). Y-12 was involved with highly-enriched RU processing operations at five different locations. Chemical processing of highly enriched RU occurred in the 9212 complex until the early 1970s and later in Building 9206 (BWXT Y-12 2000, p. 34). The EU product was stored in Building 9720-5. The S-3 ponds served as impoundments for process wastewater until the mid-1980s (BWXT Y-12 2000, p. 36). After the ponds were closed, the RU process wastewater was treated by a variety of methods at the West End Treatment Facility (WETF).

2.4.5 Uranium Forming and Machining for Weapons Components, 1949 to 1995

Formed uranium metal parts were machined into finished weapons parts and then transferred to Y-12 assembly operations. Numerous buildings were needed to support these diverse operations, and the buildings were frequently modified to meet changes in production needs. These operations occurred primarily in Buildings 9201-5, 9204-4, 9215, and 9998.

DU operations for the production of weapons components have existed at Y-12 since the early 1950s. DU is a form of uranium that consists of over 99.28% ^{238}U and less than 0.72% ^{235}U by mass. The DU and DU alloy operations typically included melting and casting, forging and rolling into plates, forming or extruding into shapes, and final heat treating to obtain the desired properties. The depleted forms were then machined into the final design specifications for weapons components. Buildings 9998, 9215, 9201-5, and 9204-4 housed the majority of the Y-12 DU processing operations. Particle or dust collectors, such as cyclones and bag houses, were used in most of the processes to capture the larger particles. Airborne losses from the foundry and other operations were relatively large from 1948 to 1956. When production levels increased, additional filters were installed sometime in 1955. Potentially large uranium losses might have occurred in 1954 and July 1956 because a minimal amount of dust was collected or filtered in comparison to the amount of uranium collected after the new filtering equipment was operating efficiently. The losses during 1956 from stack monitoring were estimated to be about 0.1 kg of DU per day. Continuous monitors were installed on the exhaust stacks in the mid-1950s (ChemRisk 1993, p.225).

2.4.6 Weapons Components Assembly, 1952 to 1995

Weapons parts were assembled into finished products, inspected and tested against design criteria, and then shipped off the site. The majority of these operations were housed in Buildings 9204-2 and 9204-2E. Table 2-3 shows the key uranium operations over time at Y-12.

2.4.7 Stockpile Stewardship and Management, 1996 to 2007

DOE is responsible for maintaining the safety and reliability of the nation's nuclear weapons. Y-12 supports DOE in that mission by providing resources to address safety, programmatic, and operational considerations. This includes maintaining skills and physical assets critical to weapons production and technology.

2.5 FACILITIES

Building 9731: The first building to become operational was the Calutron Pilot Plant in Building 9731 in the fall of 1943. This building, also known as XAX/XBX, contained two each of the alpha and beta calutrons. This facility was also used as a training facility. During the first 4 months of operation, only 4% of the uranium in the source (called *charge bottles*) actually ended up in the receivers, while the remaining 96% either remained in the source, coated the electrodes, missed the receiver slits, or was splattered all over the liner. All side streams were collected to recover EU. A major concern was the growing amount of uranium of partial enrichment in product streams that needed to be reclaimed, purified, and further enriched (Wilcox 2001, p.15).

9212 Complex: The 9212 Complex includes Buildings 9212, 9809, 9812, 9818, 9815, and 9980. More than 100 operations or processes have been performed in this Complex. The largest, Building 9212, originally had four wings, A, B, C, and D, and its primary activity was uranium recovery and reclamation. This complex originally recovered and reclaimed HEU from the calutrons (BWXT Y-12 2000, p. 30). After WW II, Building 9212 was expanded to accommodate the increased production of uranium from the ORGDP and to provide the capability to recover and reclaim uranium from waste materials. In 1948, new structures were built between the four wings. In 1951, the E Wing was added to facilitate the casting and machining of uranium components. The UF_6 conversion facility in the D Wing was shutdown in 1964, essentially stopping the introduction of new HEU metal in the weapons stockpile (BWXT Y-12 2000, p. 30).

The 9212 Complex currently performs four primary functions (BWXT Y-12 2000, p. 31):

- Casting of HEU metal
- Accountability of HEU from plant activities
- Recovery and reclamation of HEU in a form suitable for storage
- Serving as the U.S. source of all HEU used in test, research, or propulsion reactors and for isotope production

The 9212 Complex also supports the International Atomic Energy Agency in sampling surplus EU, packaging HEU for offsite shipment, and producing specialized uranium compounds and metal for research reactor fuel.

Building 9202: Building 9202 became operational late in 1943. This is a bulk treatment facility that was designed to process UO_3 to UO_2 to UCl_5 to UCl_4 – the feed material for the alpha calutron sources.

Building 9203: Building 9203 became operational in November 1943. In this building, UCl_4 was made from UO_2 for the alpha calutron feed (charge bottles). Other activities included washing alpha collector pockets to reclaim the product, developing two different beta chemical reclamation processes (i.e., precipitation and electrochemical processes, later extraction processes), analytical chemistry laboratories, and mass spectrometry and fission counting labs to determine enrichment levels (assays).

Alpha Buildings and Beta Buildings: Over the course of one (1) year starting in 1943, Y-12 put into operation eight of nine electromagnetic enrichment process buildings, including five first-stage enrichment operations called *alpha* buildings (9201-1, 9201-2, 9201-3, 9201-4, 9201-5) and three second-stage enrichment operations called *beta* buildings (9204-1, 9204-2, 9204-3). A fourth beta building, 9204-4, was operating by November 1945. As part of the war effort, Y-12 processed roughly 50,000 kg of UCl_4 in the alpha and beta calutron buildings (ChemRisk 1999, p. 172). The calutrons were arranged in large groups called *racetracks*, typically with 96 calutrons per alpha track and 36 calutrons per beta track (1,248 calutrons total). Each building typically housed two tracks. To obtain a desired enrichment, UCl_4 was processed through many calutrons and reclaimed and reprocessed frequently. Alpha operations enriched uranium from 10% to 20% ^{235}U. Beta operations further enriched the reclaimed alpha material up to 98% ^{235}U (Owings 1995, p. 18). EU compounds were reclaimed and converted to an oxide form for shipment to Los Alamos, or reclaimed for further alpha or beta enrichment. The DU was removed from process equipment and disposed of through building vents and storm sewer drains (ChemRisk 1999, p. 172).

9206 Complex: Building 9206, centrally located at Y-12, has been used extensively for the chemical processing of uranium. Related structures that house supporting or process services and/or equipment, are Buildings 9768, 9720-17, 9409-17, 9510-2, and 9767-2 and the east and west tank farm pits.

Building 9206 has carried out several EU processes and activities (BWXT Y-12 2000, p. 32):

- Chemical reclamation, charge preparation, HEU recovery, and product processing for the electromagnetic process (1945 to 1946)
- Recovery of EU from programs at Y-12 and many other sites (1947 to 1994)
- Production of uranium compounds for other sites (1949 to 1972)
- Conversion of UF_6 to UF_4 to uranium metal for weapons (1954 to 1964)
- Casting and machining of HEU metal for weapons (1955 to 1965)
- Recovery of HEU from the Savannah River Site (SRS) solutions and other scrap for return to SRS as uranium metal (1972 to 1989)
- Conversion of excess HEU metal to oxide feed for the Portsmouth Gaseous Diffusion Plant (1980 to 1985)
- Storage of in-process materials (1950 to present)

The following non-EU processes and activities at Building 9206 include (BWXT Y-12 2000, p. 32):

- Reclaiming DU chips (1951 to late 1950s)
- Production of uranium compounds for other sites (1949 to 1972)
- Canning of normal assay uranium slugs for nuclear reactor use (1950 to 1952)
- Storage of in-process materials (1950 to present)

Building 9720-5: Building 9720-5 is used as a warehouse for short- and long-term storage of strategic materials. Built in 1944, it has been renovated several times. This building serves as a shipping and receiving facility for Special Nuclear Material (SNM) and the primary storage facility for interim and prolonged low-maintenance storage of HEU (BWXT Y-12 2000, p. 33).

Building 9215: Building 9215 was used to manufacture parts from DU and EU. The uranium was pressed, rolled, shaped, and machined into finished weapons components.

Building 9995: Building 9995 is used as an analytical laboratory to assay nuclear components. The activities allowed Y-12 to move into the forefront of the nuclear weapons complex in the analytical chemistry field during the years after 1952.

2.6 WASTE TREATMENT AND DISPOSAL OPERATIONS

The S-3 Ponds: Between 1951 and 1984, four seepage pits known as the S-3 ponds were used to dispose of over 2.7 million gal of a variety of liquid wastes including concentrated acids, caustic solutions, mop waters, and byproducts from the uranium recovery processes including uranium and other heavy metals. These unlined pits were designed to allow liquid either to evaporate or percolate into the ground (BWXT Y-12 2000, p. 110). Various metal impurities and radionuclides that were stripped from HEU during the solvent extraction steps in Buildings 9212 and 9206 (approximately 10% to 30% of RU, plutonium, neptunium, and technetium) were discharged with the dilute nitric acid and other process-derived acid wastewater to the S-3 ponds before the mid-1980s (BWXT Y-12 2000, p. 33).

The S-3 Ponds served as impoundments for process wastewater until the mid-1980s. The four earthen basins had no direct discharge to any local creek or river tributary. After the ponds were closed, RU process wastewater was treated by a variety of methods at the WETF, and New Hope Pond served as a surface-water impoundment that captured entrained solids from rainwater and secondary wastewaters.

Clean-up and closure of the ponds began in 1984. The site has been covered with gravel and clay, paved, lined, and it is now a parking lot. Sludge removed from the pond sediments is stored in aboveground tanks. The S-3 ponds were finally closed in 1989 in accordance with the Resource Conservation and Recovery Act (RCRA). Before capping the ponds, sludge samples were taken from each pond to ascertain the airborne (internal) exposure potential for workers who would place the cap materials. Based on the first evaluation, no special precautions were needed for this work, other than the normal requirements for handling DU. However, the second evaluation included the effects from thorium and strontium and concluded the material should be treated as a mixture of 45 wt% ^{238}U. The primary reason for the increased exposure potential was the inclusion of ^{230}Th and ^{228}Th. These two radionuclides contributed about 90% of the exposure potential (BWXT Y-12 2000, p. 110-111).

WETF, Building 9616-7: Beginning in the mid-1980s, after closure of the S-3 ponds, the WETF was constructed to treat mixed low-level waste (LLW) and LLW-contaminated wastewater from Y-12 production and other ORR processes. Nitrate wastewater that was contaminated with EU was mixed

with much larger quantities of wastewater that was contaminated with DU. The EU component was diluted to less than normal assay uranium (BWXT Y-12 2000, pp. 33-34). Wastewaters are discharged into East Fork Poplar Creek, under a National Pollutant Discharge Elimination System permit. In 1997, sludge from the WETF was analyzed for radionuclides. Elevated levels of ^{228}Th, ^{230}Th, and ^{237}Np were found (BWXT Y-12 2000, p. 113). Sampling is now conducted on an ongoing basis. Both the tanks as well as incoming tankers are sampled periodically.

New Hope Pond: New Hope Pond was constructed and placed in operation in the 1950s to provide a retention basin on East Fork Poplar Creek at the east end of Y-12. The pond facilitated mixing of water and offered a sampling point for rainwater runoff, once-through cooling water, steam plant boiler blow-down, and secondary production process wastewaters. The pond also functioned to remove any suspended contamination from rainwater, miscellaneous releases from various tank farms and storage yards, and inadvertent releases from process buildings.

In 1973, New Hope Pond was dredged, and the resultant sludge was transferred to a basin on Chestnut Ridge. In 1983, samples were taken to determine if the sediment that had accumulated in the pond was hazardous. It was concluded that the data from the leach test showed no hazardous material by the RCRA definition (BWXT Y-12 2000, p. 113).

2.7 CRITICALITY ACCIDENT

On June 16, 1958, there was an accidental, prompt–critical neutron chain reaction in a solution system at Y-12. The accident occurred in the C-1 Wing of Building 9212, in a 55-gal stainless-steel drum. The cause of the accident was a super-critical quantity of highly enriched uranyl nitrate solution that accumulated in the drum due to a leaky valve (Wilcox 2001, p. 34).

The accident occurred in a process phase that was a temporary arrangement that used portions of a new and an old installation. Both installations were necessary to maintain production during an interim phase of remodeling a process. This temporary arrangement split the responsibility for the operation among three different supervisors in three separate areas. This contributed to the cause of the accident by complicating communications and control. The incident occurred during the draining of material, thought to be water, from a safe geometry (5-in. storage pipes) into an unsafe geometrical drum. During this incident, approximately 1.0×10^{18} fissions occurred (ORAUT 2006, p. 10).

Eight employees were in the vicinity of the drum. Based on their reported proximity and on the activation of the indium foil strip in their badges, these eight employees received the highest radiation doses of any who might have been exposed. One of the eight was within 3 to 6 ft of the drum. The other seven were from 15 to 50 ft away. Special, post-hoc methods were used to determine the neutron and gamma exposures of the involved employees.

As employees left the plant for the day, their badges were collected and taken to the secondary control center to obtain activity readings on the indium foil. A list was compiled of the 31 employees with potentially significant neutron doses. (The doses received by these employees have been calculated for use in dose reconstruction [ORAUT 2006, p. 17]). These employees were routed through the medical test routine (UCNC 1958, pp. 10, 44).

2.8 RADIONUCLIDES AND RADIATION SOURCES

The three main exposure fields at Y-12 are from process and other radioactive materials, radiation-generating equipment (X-rays and accelerators), and criticality or nuclear accidents. The most

common process materials are EU (^{235}U) and DU (^{238}U). Both radionuclides are primarily alpha emitters but ^{235}U does emit 0.185 MeV gamma rays (BWXT Y-12 2001b, p. 11).

2.8.1 Uranium

Uranium is a naturally-occurring radioactive element that is used for nuclear reactor fuel and in nuclear weapons components. The two principal natural isotopes are ^{235}U (0.72%) and ^{238}U (99.28%). NU also includes a trace amount of ^{234}U progeny by mass (0.0055%) (DOE 2000, p. 21).

DU is a by-product of the enrichment process and it is depleted in both the ^{235}U and ^{234}U isotopes. Typical DU isotopic abundances are 99.80 % ^{238}U, 0.20% ^{235}U, and 0007% ^{234}U (DOE 2000, p. 21). However, DU is commonly referred to as D38 at Y-12. The D38 refers to the nominal assay of the DU which was usually 0.0038% ^{235}U (Owings 1995, p. 44).

EU is uranium that has been processed to raise the concentration of ^{235}U above the natural abundance of 0.72%. The first known records for EU are from the calutron era when the product had been produced by the electromagnetic process at Y-12. NU was enriched in the ^{235}U isotope in a two stage process. The alpha calutrons produced EU that contained from 10% to 20% ^{235}U. This material was the feed material for the second stage enrichment by the beta calutrons that increased the ^{235}U isotopic abundance up to 98% of the final product. After 1947, the low enriched (<20% ^{235}U) uranium (LEU) was produced by the diffusion plants (Owings 1995, pp. 16, 18).

The degree of internal hazard from uranium exposure depends on its chemical and physical form and its enrichment. In past enrichment processes, ^{234}U and ^{235}U could not be separated because of the small difference in their mass. Thus, ^{234}U was enriched along with ^{235}U. Because ^{234}U is a small fraction of the weight of NU, it contributes as much as one-half of its total radioactivity (ChemRisk 1999, p. 23). Thus, ^{234}U becomes the major internal radiation source (ORAUT 2005, p. 4). Most of the external dose from DU results from ^{234}Th and ^{234}Pa progeny (BWXT 2001b, p. 11).

2.8.2 Recycled Uranium

RU is defined as any uranium that has been irradiated in a reactor. As a result, RU contains TRU material, fission products, and reactor-generated uranium products. The primary buildings and facilities that handled RU were Buildings 9212 and 9206, the WETF, and the S-3 ponds. In addition, RU is stored in Building 9720-5.

2.8.3 X-Ray and Electron-Generating Equipment

The X-ray and electron-generating equipment that has been used at Y-12 includes linear electron beams, electron beam welders, scanning electron microscopes, X-ray photoelectron spectrometers, secondary ion mass spectrometers, enclosed beam diffraction equipment, and medical diagnostic X-ray equipment. The emitted energy range is from 15 keV to 9 MeV (BWXT Y-12 2001b, p. 11).

2.8.4 Radionuclide and Neutron Sources

The most common radionuclide source facilities are segmented gamma scanners with ^{169}Yb (emits a 63.1-keV gamma ray), a ^{60}Co well source (1.33- and 1.17-MeV gamma rays) for calibration of radiation monitoring equipment, and ^{252}Cf spontaneous fission neutron sources (average neutron energy is 2 MeV) for nondestructive testing and material inventories (BWXT Y-12 2001b, p. 11).

Three gamma-ray sources, 4.55 mg ^{226}Ra, 23.0 mg ^{226}Ra, and 250 mCi ^{60}Co, are used in the calibration of personnel meters and low-range radiation instruments. A 9-Ci ^{60}Co source is used in the calibration of high-range survey meters. A large 15-Ci ^{60}Co gamma source is used in the Radiographic Laboratory (CCCC 1951, p. 10). The types of sources and locations are in Table 2-4.

Table 2-4. Known sealed radiation sources.
(CCCC 1951, p. 10)

Sources	Buildings
Ra-Be, Po-Be	9203
Ra, Co, Ta, Po-Be	9983
Po-Be, Ra-226	9737, 9201-2, 9204-3
Ra-226	9212
Ra-226, Co	9212
Ra-226	9206,9706-2

2.8.5 Special Nuclear Material

There has been a wide variety of SNM, source material, and other nuclear materials at Y-12. The various materials include HEU (>20% ^{235}U), LEU (< 20% ^{235}U), DU, NU, thorium, enriched lithium (40%, 60%, and 95% ^{6}Li), ^{2}H, plutonium, and ^{233}U (Owings 1995, p.7).

Since the weapons material flow was initiated, pure metal has been shipped and received as 100% uranium. The SNM metal that was generated in the early days of weapons production at Y-12 was not as pure as later products. The primary impurity was carbon.

2.8.6 Transuranic Elements

The primary sources of TRU materials ($^{238, 239, 240}$Pu and ^{237}Np] were RU from SRS and the Idaho Chemical Processing Plant (BWXT Y-12 2000, p. 179). The Rocky Flats Plant returned HEU parts that had potential TRU contamination, and special development projects (BWXT Y-12 2000, p. 71-72). Y-12 proactively evaluated RU receipts from its inception against a specification that would maintain uranium as the dominant dose hazard. Dose estimates did not indicate a significant TRU problem (BWXT Y-12 2000, p. 147). In comparison to the current regulatory monitoring criteria, it would not warrant the initiation of special bioassay sampling beyond that necessary for uranium. Recent workplace sampling confirmed that the historical specification ensured that uranium was the dominant radiological hazard, even against current regulatory requirements (BWXT Y-12 2000, p. 147). The exception was waste streams, as evidenced by sludge samples from the WETF. The other radionuclides present were ^{99}Tc, ^{237}Np, $^{238, 239, 240}$Pu, and ^{241}Am (BWXT Y-12 2000, p. 113).

2.8.7 Thorium

The first record of thorium at Y-12 is from January 1947 (Owings 1995, p. 63). At that time, the inventory was used in research and development studies, primarily by ORNL personnel at Y-12. It was not until fiscal year 1952 that thorium activity increased significantly. Shipments and receipts were primarily between Y-12 and ORNL (Owings 1995, p. 63).

Processing of thorium at Y-12 began in the early 1960s (BWXT Y-12 2001a, p. 11). The thorium metal in pellet form was pressed into electrodes and two arc meltings were made. The metal from these melts was pressed and/or rolled, formed, and machined. Metal scraps and chips were salvaged and also pressed into electrodes for the arc-melting process.

The following activities by facility occurred as part of the process (BWXT Y-12 2001a, pp. 11-12):

- Pellet/scrap preparation, arc melting, crop and trim machining, and sawing (Building 9205-1)
- Mold press sintering, ingot forging, canning and annealing after first cold roll, and final inspection/assembly (Building 9204-4)
- Ingots canned before first cold roll (Building 9201-1)
- Cold and hot rolling (Building 9215)
- Cleaning and final plating (Building 9206)
- Machining activities (Building 9766)
- Development activities (Building 9202)

Sludge samples were taken from the S-3 ponds before capping to determine whether there was any airborne (internal) exposure potential for workers who would place the cap materials. Initially, no special precautions were deemed necessary for this work, other than the normal requirements for handling DU. However, a second analysis to include the effects of strontium and thorium indicated that there was a dramatic increase in the exposure potential of ^{228}Th and ^{230}Th that contributed to 90% of the internal exposure potential (BWXT Y-12 2000, p. 111). More information is provided in the discussion of the S-3 ponds in Section 2.6.

2.8.8 Lithium

In 1951, Y-12 was brought into the lithium isotope separation project. A method for enriching natural lithium (7.6% ^{6}Li and 92.4% ^{7}Li) in the ^{6}Li isotope was needed for use in the thermonuclear weapons program. Two methods, column exchange (COLEX) and electrical exchange (ELEX), were developed and tested simultaneously. Pilot plants were built to evaluate both methods. The COLEX process was selected as the method of choice and production continued into the early 1960s (Wilcox 2001, pp. 28, 35).

Significant quantities of lithium materials were machined and crushed to fine dust. Some unmeasured quantity ended up in the ventilation system, in mop water, in cleanup solutions, and in non-homogeneous salvage that was awaiting recovery (Owings 1995, p. 77).

Impurities in lithium metal react with deuterium. In many cases, the reaction productions distill out the lithium deuteride at the reaction temperatures and condense wherever the vessel is cooler (lid and upper 2 or 3 in of the reactor). This represents a loss of deuterium that is not accounted for (Owings 1995, p. 77).

2.9 SOLUBILITY AND INSOLUBILITY

Y-12 has processed uranium mainly in the forms of UO_2 and uranium metal. Chemical conversions from UNH to both UO_2 and uranium metal have been performed as well. Although the solubility type for uranium metal is not addressed by the guidance documents, experience at uranium process facilities has shown that uranium metal generally behaves as a type M compound. However, the possibility of slow oxidation of a significant portion of the surface of the metal to UO_2 and/or U_3O_8 over time must be considered (Rucker et al., 2001, p. 5).

Y-12 defined a class Q material as a mixture of 90% class W and 10% class Y. Class Q represents the circumstance when there is only a thin layer of UO_2 on the surface of uranium metal. It can also provide a reasonable representation of the solubility half-time that has been observed for UO_2 that has not been *high-fired* (approximately 120 to 140 days) than would the assumed half-time for class W (50 days) (Rucker et al., p. 6). However, the use of the International Commission on Radiological Protection (ICRP) Publication 66 lung model (ICRP 1994) overcomes the need for the contrived class Q compound because type M assumes 90% of the material has a half-time of 140 days. Under the Publication 66 lung model, only uranium that is high-fired UO_2 or the product of slow oxidation of uranium metal should be classified as type S (Rucker et al., p. 6).

Y-12 uses three default solubility assumptions for workers who have participated exclusively in the urine bioassay program (BWXT Y-12 2003b, p. 18):

- 100% type S
- 75% type S and 25% type M
- 50% type S and 50% type M

These defaults are designed to be conservative and to provide adequate protection for workers while, at the same time, being representative of the actual exposure material. The defaults are determined by the radiological work permit (RWP) bioassay indicator code, the last character of the RWP identifier. When working with soluble materials such as uranyl nitrate, the solubility can be defaulted to 100% type M or 100% type F, depending on the material. However, to be conservative, persons working exclusively with soluble uranium are defaulted to 50% type M and 50% type S. If an individual uses RWPs that indicate the work is with insoluble uranium materials, such as uranium oxide, then the solubility should be determined by dose calculation software. If the RWP indicates the work with uranium had both a soluble and insoluble component, then the solubility should be defaulted to 25% type M and 75% type S. If the RWP is for low exposure potential to insoluble uranium that requires only urinalysis, then the solubility should be defaulted to 100% type S. The RWP bioassay indicators used for routine uranium handling jobs (F, Y, W, and M) are summarized in Table 2-5 (BWXT Y-12 2003b, p. 18).

Table 2-5. RWP bioassay indicators for routine uranium handling jobs (BWXT Y-12 2003b, p. 15).

Bioassay indicator	Solubility	Bioassay method
F	Primarily (>75%) insoluble. Derived solubility will be determined by DOSE 66	Bi-monthly urine and fecal sampling
Y	Primarily (>75%) insoluble but low exposure potential. Assumed solubility for dose calculations is 100% type S.	Quarterly urine sampling
M	Insoluble component between 25% and 75%. Assumed solubility for dose calculations is 75% type S and 25% type M.	Quarterly urine sampling
W	No insoluble component expected. Assumed solubility for dose calculation is 50% type S and 50% type M.	Quarterly urine sampling

Historically from 1990 to 1998, the default solubility type for internal dose assessments was 90% W and 10% class Y for both EU and DU (BWXT 2003a, p. 120). Almost all internal exposures at Y-12 involve uranium that has either been enriched or depleted in ^{235}U through the process of gaseous diffusion.

In 1999, DOE gave the Y-12 Radiological Control Dosimetry Department permission to use the ICRP Publication 66 (1994) lung model for estimating intakes and doses received by personnel. Before this, the ICRP 30 (1979) lung model was used from 1989-1999. The ICRP 66 (1994) report includes a considerably more detailed respiratory tract model than ICRP 30 (1979). The default material

assumptions recommended in ICRP 66 (1994) more closely reflect those observed at Y-12 (BWXT Y-12 2003b, pp. 9-11).

Y-12 developed the DOSE 66 program, and it was validated and verified in 2000 (BWXT Y-12 2003b, p.12). This program uses the ICRP Publication 66 methodology for inhalation intakes (ICRP 1994). A major advantage of the DOSE 66 program is the calculation of a derived mixture for intake material type when both urine and fecal bioassay data are available. The program calculates an intake that is based only on fecal bioassay results. It then estimates an intake that is based on the urine results. If the fecal and urine intake estimates differ by a significant amount (set by the user), it adjusts the solubility of the material until the urine estimate of intake matches that for the fecal data (BWXT Y-12 2003b, p. 12).

Several Y-12 studies have been conducted in an attempt to better characterize the work area in relation to material solubility at Y-12 using the DOSE 66 program. These studies include a 3-month investigation with participants from various areas from October to December 1999, recalculation of solubility of 1999 incident investigations, and a review of the 2000 incident investigation (BWXT Y-12 2003b, p. 12). The results of these studies have been combined and are given in Table 2-6.

Table 2-6. Solubility of material for various buildings and work areas as calculated by DOSE 66 program (BWXT Y-12 2003b, p. 15).

Building	N[a]	% type S	% type M
9202	1	51	49
9206	2	31	69
9212	48	68	32
9215	54	82	18
9995	4	78	22
9998	2	64	36
9201-5	2	36	64
9201-5N	12	77	23
9204-2E	5	89	11
9204-4	8	74	26
9704-2	1	0	100

a. N represents the number of data points.

Uranium is considered to be primarily an internal dosimetric hazard because it emits alpha particles, beta particles, and only weak gamma and X-ray photons. Y-12 is unique in that workers are assumed to be routinely exposed to low levels of uranium (BWXT Y-12 2003b, p.9). This chronic intake assumption places a premium on the accurate assessment of the committed effective dose equivalents (CEDE) received by workers.

A review of the DOSE 66 data reveals a high correlation between the assumed solubility type and the estimated CEDE values when only urine bioassay data is used. As the solubility of the material is increased, the CEDE values drop dramatically. This phenomenon, coupled with the potential for exposure of workers to varying solubility mixtures, illustrates the importance of solubility in internal dose assessments. Fecal sampling is the preferred bioassay method for areas and work that could lead to significant insoluble uranium intakes. For areas and work functions that could lead to intakes that are both soluble and insoluble, urine sampling alone is sufficient if the insoluble intake results in a CEDE of less than 100 mrem (BWXT Y-12 2003b, p.20).

2.10 ATTRIBUTIONS AND ANNOTATIONS

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

Karin Jessen served as one of the initial Subject Experts for this document. Ms. Jessen was previously employed at Y-12 and her work involved management, direction, or implementation of radiation protection and/or health physics program policies, procedures, or practices related to atomic weapons activities at the site. This revision has been overseen by a Document Owner who is fully responsible for the content, including all findings and conclusions. Ms. Jessen continues to serve as a Site Expert for this document because she possesses or is aware of information relevant for reconstructing radiation doses experienced by claimants who worked at the site. In all cases where such information or prior studies or writings are included or relied upon by Ms. Jessen, those materials are fully attributed to the source. Ms. Jessen's Disclosure Statement is available at www.oraucoc.org.

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GLOSSARY

alpha stage
The first stage of the calutron that enriched uranium up to 20% ^{235}U.

beta stage
The second stage of the calutron process that further enriched the uranium from the alpha stage up to 98% ^{235}U.

calutron
An electromagnetic apparatus for separating isotopes according to their masses. Strong magnetic fields were used to separate the lighter ^{235}U isotope from the heavier, more naturally abundant ^{238}U isotope.

class Q
A mixture of 90% class W and 10% class Y uranium. The class Q represents the circumstance when there is only a thin layer of UO_2 on the surface of uranium metal.

column exchange (COLEX)
A column-based chemical exchange process to enrich natural lithium in its ^{6}Li isotope.

committed effective dose equivalent (CEDE)
The sum of the committed dose equivalents to various tissues in the body, each multiplied by its weighting factor, for 50 years post intake. It does not include contributions from external doses. Committed effective dose equivalent is expressed in units of rem or sievert.

depleted uranium (DU)
A form of uranium that contains less than 0.72% ^{235}U.

electrical exchange (ELEX)
An electrical process to enrich natural lithium in its ^{6}Li isotope.

enriched uranium (EU)
Contains more than the natural abundance of ^{235}U than found in natural uranium (0.72%).

feed material
Uranium tetrachloride (UCl_4) produced by the conversion of uranium oxides (including UO_2, UO_3, and U_3O_8) for use in the calutrons.

fusion
The process in which nuclei of lighter elements (e.g., deuterium and tritium) combine to form the nucleus of a heavier element, with the release of energy.

highly enriched uranium (HEU)
Uranium having enrichment above 20 percent of the fissionable isotope ^{235}U.

low enriched uranium
Uranium having enrichment below 20 percent of the fissionable isotope ^{235}U.

natural uranium (NU)

Uranium as it is found in nature. It consists of two principal isotopes, ^{235}U (0.72%) and ^{238}U (99.28%), and includes a trace amount of ^{234}U by mass (0.0055%).

normal uranium (NU)

Uranium that has been isotopically blended to approximate the natural isotopic range of uranium.

recycled uranium (RU)

Any uranium that has been irradiated in a reactor. As a result, RU contains transuranic material, fission products, and reactor-generated uranium products.

solubility type

Type F, M, and S are inhalation solubility types established by the ICRP. Type F material is very soluble, type M material is moderately soluble, and type S material is relatively insoluble. These types are equivalent to the older class D, W, and Y, respectively.

source material

(1) Material containing any combination of uranium or thorium in any physical or chemical form, or (2) ores containing 0.05 wt % or more uranium, thorium, or both. Source material excludes Special Nuclear Material.

special nuclear material (SNM)

Plutonium or uranium enriched to a higher-than-natural assay, and includes plutonium-239, uranium-233, uranium containing more than the natural abundance of uranium-235, or any material artificially enriched in one of these isotopes.

thermal neutrons

Low speed neutrons that are in thermal equilibrium with their surroundings and have energies less than approximately 0.5 electronvolt.

transuranic (TRU)

Elements with an atomic number greater than uranium (atomic number 92), e.g., $^{238, 239, 240}Pu$ and ^{237}Np.

ATTACHMENT A
SITE DESCRIPTION
Page 1 of 6

TABLE OF CONTENTS

LIST OF TABLES

ATTACHMENT A
SITE DESCRIPTION
Page 2 of 6

A.1 SOURCES OF EXPOSURE

Y-12 became a highly sophisticated nuclear weapons component manufacturing facility and development engineering organization. The plant receives, stores, and protects uranium and lithium materials and parts, dismantles nuclear weapons components, and serves as a government repository for EU. In addition, Y-12 has many treatment, storage, and disposal facilities for hazardous and radioactive materials.

Today, the current mission at Y-12 includes the:

- production, rework, and dismantlement of nuclear weapon components;
- receipt, storage, and protection of special nuclear materials;
- quality evaluation/enhanced surveillance of the nation's nuclear weapon stockpile;
- prevention of the spread of weapons of mass destruction; and
- support to DOE, other federal agencies, and other national priorities through a complementary work program.

Table A-1 shows the radionuclides of concern. Table A-2 shows the locations of known sealed radiation sources. Some building numbers and their corresponding radionuclides are not available at this time.

Table A-1. Radionuclides of concern.[a]

Radionuclide	Type of emission	Radioactive half life (y)
^{99}Tc	Beta	2.13×10^{5}
^{228}Th	Alpha	1.91×10^{0}
^{230}Th	Alpha	7.54×10^{4}
^{232}Th	Alpha	1.45×10^{10}
^{234}U	Alpha	2.47×10^{5}
^{235}U	Alpha, some gamma	7.4×10^{8}
^{236}U	Alpha	2.34×10^{7}
^{238}U	Alpha	4.47×10^{9}
^{237}Np	Alpha	2.14×10^{6}
^{238}Pu	Alpha	8.64×10^{1}
^{239}Pu	Alpha	2.4×10^{4}
^{241}Am	Alpha	4.32×10^{2}

a. Adapted from BWXT Y-12, 2003a, pp. 30–31).

Table A-2. Known sealed radiation sources (CCCC 1951, p. 10).

Sources	Building
Ra-Be, Po-Be	9203
Ra, Co, Ta, Po-Be	9983
Po-Be, Ra-226	9737, 9201-2, 9204-3
Ra-226	9212
Ra-226, Co	9212
Ra-226	9206,9706-2

ATTACHMENT A
SITE DESCRIPTION
Page 3 of 6

A.2 CHRONOLOGY OF URANIUM OPERATIONS

Tables A-3 and A-4 contain descriptions of historical Y-12 uranium process operations. Specific key buildings and their functions are highlighted to better understand the Y-12 uranium operations. Y-12 experienced significant changes from the original mission of electromagnetic enrichment to the current multiple missions of storing HEU, weapons disassembly, and major efforts in environmental and waste management.

Table A-3. Primary uranium operations (ChemRisk 1999, pp. 172-184; Y-12 2007).

Key uranium operations	Buildings involved	Dates of operation
Electromagnetic enrichment	Alpha buildings 9201-1,2,3,4,5 Beta buildings 9204-1,2,3,4	1943–1947
Feed preparation and product processing	9202, 9203, 9206, 9212	1943–1947
Uranium reclamation	9202, 9203, 9206, 9212	1945–1951
Uranium recycle	9202, 9203, 9206, 9212	1953–1990s
Uranium salvage	9206, 9207, 9211	1945–1951
Uranium preparation/recycle	9202, 9206, 9211, 9212	1953–1995
Uranium forming/machining	9201-5, 9204-4, 9215, 9998	1952–1995
Uranium component assembly	9202, 9204-2, 9204-2E	1952–1995
Stockpile stewardship and management	9201-5, 9204-4, 9215	1952–2007

Table A-4. Process chronology by building of operations (ChemRisk 1999, p. 171; Oliver 2003, 2007).

Building	1943–1948	1949–1951	1952–1963	1964–1995	1996–2007
9201-1	Tracks 1 and 2, α - I calutrons (uranium enrichment).	Uranium enrichment operations.	Uranium reclamation and salvage operations.	Fusion energy research operations.	General manufacturing for tooling, including work for others. Almost all clean work.
9201-2	Tracks 3 and 4, α - I calutrons (uranium enrichment).	Uranium enrichment operations.	COLEX lithium/ mercury enrichment operations.	Research and development operations.	ORNL facility.
9201-3	Track 5, α - I calutrons.	Uranium enrichment operations.	Uranium reclamation and salvage operations.	Fusion energy research operations.	Currently used for office space.
201-4	Tracks 6 and 7, α - II calutrons (uranium enrichment).	Uranium enrichment operations.	COLEX lithium/ mercury enrichment operations.	Engineering and administrative facilities.	Awaiting D&D.
9201-5	Tracks 8 and 9, α – II calutrons (uranium enrichment).	Uranium enrichment operations.	COLEX lithium/ mercury enrichment operations.	NU/DU press, rolling, and machining operations.	NU/DU press, rolling, and machining operations; building evacuated (2007); surveillances occur; storage; awaiting D&D.

ATTACHMENT A
SITE DESCRIPTION
Page 4 of 6

Building	1943–1948	1949–1951	1952–1963	1964–1995	1996–2003
9202	Alpha and chemical preparation and reclamation operations.	Uranium product reclamation operations.	Uranium process development & improvement operations.	Uranium process development & improvement operations.	Technology development.
9203	^{235}U analysis and initial uranium product processing.	Uranium product reclamation operations.	Reclamation and salvage operations.	Y-12 production development and research operations.	Technology development.
9204-1	Tracks 1 and 2, ß calutrons (uranium enrichment)	Uranium enrichment operations.	Stable isotope separation operations.	Fusion energy research operations.	ORNL facility; however BWXT Y-12 occupies office space.
9204-2	Tracks 3 and 4, β calutrons (uranium enrichment).	Uranium enrichment operations.	Special material operations.	Special material operations.	Special material operations.
9204-2E	--	--	--	Uranium assembly operations.	Uranium assembly operations.
9204-3	Tracks 5 and 6, β calutrons (uranium enrichment).	Uranium enrichment operations.	Stable isotope (*e.g.*, copper) separation operations.	Stable isotope (*e.g.,* copper) separation operations.	ORNL facility.
9204-4	Tracks 7 and 8, β calutrons(uranium enrichment).	Uranium enrichment operations.	ELEX lithium/mercury pilot-scale operations.	NU/DU press and rolling operations.	Material storage operations.
9206	β chemical reclamation and product processing.	Uranium product reclamation and salvage operations.	Uranium chemical processing and metal production operations.	Uranium chemical processing and metal production operations.	Currently undergoing deactivation. No longer a Material Access Area; D&D has been initiated.
9207	Uranium reclamation and salvage operations.	Uranium reclamation and salvage operations.	Maintenance, reclamation and salvage operations.	ORNL biological research operations.	ORNL facility (vacated in 2005); awaiting D&D.
9211	Uranium reclamation and salvage operations.	Uranium salvage and product recovery operations.	Uranium salvage and product reclamation operations.	ORNL biological research operations.	ORNL biological research operations (vacated in 2005); awaiting D&D.
9212	β product processing.	Uranium conversion and reclamation operations.	UF_6 conversion, chemical operations, and weapons production operations.	Chemical operations and weapons production operations.	Chemical operations and weapons production operations.

ATTACHMENT A
SITE DESCRIPTION
Page 5 of 6

Building	1943–1948	1949–1951	1952–1963	1964–1995	1996–2003
9215	--	--	EU machining and metal finishing operations.	EU machining and metal finishing operations.	EU machining and metal finishing operations; DU H-1 foundry operations.
9998	--	NU H-1 foundry operations.	DU H-1 foundry operations.	DU H-1 foundry operations.	DU processing.

A.3 SOLUBILITY OF RADIONUCLIDES

Workers at Y-12 have routinely performed work with various compounds of uranium. These compounds have different retention times and clearance pathways. Because the clearance of soluble materials is primarily through the blood, urine bioassay is the preferred method for detecting these forms of compounds. For insoluble compounds, the material is cleared from the lungs. The majority of the insoluble material is excreted via the feces, with only a small fraction clearing through the urine. (BWXT Y-12 2003b p. 11) Tables A-5 and A-6 show the solubility types for specific radionuclides and default solubility for radioelements present at Y-12.

Table A-5. Radionuclides and solubility types (BWXT 2003a, p. 31)

Radionuclides	Solubility types
Tc-99	F and M
Np-237	M
Pu-238	M
Pu-239	S
Am-241	M

Table A-6. Radioelements and default solubility types (BWXT 2003a, p. 38)

Radioelement	Solubility types
Americium	M
Neptunium	M
Plutonium	S
Strontium	S
Technetium	M
Thorium	Y
^{3}H	Vapor
Uranium	As determined by RWP

Y-12 uses three default solubility assumptions for workers who participate exclusively in the urine bioassay program: 100% type S, 75% type S and 25% type M, and 50% type S and 50% type M. These defaults are designed to be conservative and provide adequate protection for workers while at the same time being representative of the actual exposure material (BWXT Y-12 2003b, p. 18). Table A-7 summarizes the bioassay indicators.

Studies have been conducted in an attempt to better characterize the work areas at Y-12 in relation to material solubility. These studies have included a 3-month investigation with participants from various areas from October to December 1999. The results are shown in Table A-8 (BWXT Y-12 2003b, p 15).

ATTACHMENT A
SITE DESCRIPTION
Page 6 of 6

Table A-7. RWP bioassay indicators for routine uranium handling jobs (BWXT Y-12 2003b, p. 18).

Bioassay indicator	Solubility	Bioassay method
F	Primarily (>75%) insoluble. Derived solubility will be determined by DOSE 66	Bi-monthly urine and fecal sampling
Y	Primarily (>75%) insoluble but low exposure potential. Assumed solubility for dose calculations is 100% type S.	Quarterly urine sampling
M	Insoluble component between 25% and 75%. Assumed solubility for dose calculations is 75% type S and 25% type M.	Quarterly urine sampling
W	No insoluble component expected. Assumed solubility for dose calculation is 50% type S and 50% type M.	Quarterly urine sampling

Table A-8. Solubility of material for various buildings and work areas as calculated by DOSE 66 program (BWXT Y-12 2003b, p. 15)

Building	N[a]	% type S	% type M
9202	1	51	49
9206	2	31	69
9212	48	68	32
9215	54	82	18
9995	4	78	22
9998	2	64	36
9201-5	2	36	64
9201-5N	12	77	23
9204-2E	5	89	11
9204-4	8	74	26
9704-2	1	0	100

a. N represents the number of data points.