SEC Petition Evaluation Report
Petition SEC-00143

Report Rev #: 0 Report Submittal Date: April 16, 2010

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Site Expert(s):	N/A

Petition Administrative Summary

Petition Under Evaluation

Petition #	Petition Type	Petition Receipt Date	Petition Qualification Date	DOE/AWE Facility Name
SEC-00143	83.13	April 29, 2009	September 11, 2009	Weldon Spring Plant

Petitioner Class Definition

All employees of the Department of Energy, Department of Energy contractors, or subcontractors who worked in any area at the Weldon Spring Plant in Weldon Spring, Missouri, during the applicable covered operational period from January 1, 1957 through December 31, 1966.

Class Evaluated by NIOSH

All employees of the Department of Energy, Department of Energy contractors, or subcontractors who worked in any area at the Weldon Spring Plant in Weldon Spring, Missouri, during the applicable covered operational period from January 1, 1957 through December 31, 1967.

NIOSH-Proposed Class(es) to be Added to the SEC

None

Related Petition Summary Information

SEC Petition Tracking #(s)	Petition Type	DOE/AWE Facility Name	Petition Status
SEC-00144	83.13	Weldon Spring Plant	Merged with SEC-00143

Related Evaluation Report Information

Report Title	DOE/AWE Facility Name
N/A	N/A

ORAU Lead Technical Evaluator: Monica Harrison-Maples

ORAU Review Completed By: Karin Jessen

Peer Review Completed By:	[Signature on file] *Mark Rolfes*	4/16/2010 *Date*
SEC Petition Evaluation Reviewed By:	[Signature on file] *Brant Ulsh*	4/19/2010 *Date*
SEC Evaluation Approved By:	[Signature on file] *Stuart L. Hinnefeld*	4/21/2010 *Date*

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Evaluation Report Summary: SEC-00143, Weldon Spring Plant

This evaluation report by the National Institute for Occupational Safety and Health (NIOSH) addresses a class of employees proposed for addition to the Special Exposure Cohort (SEC) per the *Energy Employees Occupational Illness Compensation Program Act of 2000*, as amended, 42 U.S.C. § 7384 *et seq*. (EEOICPA) and 42 C.F.R. pt. 83, *Procedures for Designating Classes of Employees as Members of the Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act of 2000*.

Petitioner-Requested Class Definition

Petition SEC-00143 was received on April 29, 2009, and qualified on September 11, 2009. The petitioner requested that NIOSH consider the following class: *All employees of the Department of Energy, Department of Energy contractors, or subcontractors who worked in any area at the Weldon Spring Plant in Weldon Spring, Missouri, during the applicable covered operational period from January 1, 1957 through December 31, 1966.*

Class Evaluated by NIOSH

Based on its preliminary research and finding that shut-down activities were occurring at Weldon Spring Plant through 1967, NIOSH extended the petitioner-requested class. NIOSH evaluated the following class: All employees of the Department of Energy, Department of Energy contractors, or subcontractors who worked in any area at the Weldon Spring Plant in Weldon Spring, Missouri, during the applicable covered operational period from January 1, 1957 through December 31, 1967.

NIOSH-Proposed Class to be Added to the SEC

Based on its full research of the class under evaluation, NIOSH has obtained uranium bioassay monitoring data, airborne dust study data with uranium and thorium applications, environmental air concentration measurements, personnel whole-body dosimetry, and medical diagnostic X-ray records for the Weldon Spring Plant. Based on its analysis of these available resources, NIOSH found no part of the class under evaluation for which it cannot estimate radiation doses with sufficient accuracy.

Feasibility of Dose Reconstruction

Per EEOICPA and 42 C.F.R. § 83.13(c)(1), NIOSH has established that it has access to sufficient information to: (1) estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class; or (2) estimate radiation doses of members of the class more precisely than an estimate of maximum dose. Information available from the site profile and additional resources is sufficient to document or estimate the maximum internal and external potential exposure to members of the evaluated class under plausible circumstances during the specified period.

Health Endangerment Determination

Per EEOICPA and 42 C.F.R. § 83.13(c)(3), a health endangerment determination is not required because NIOSH has determined that it has sufficient information to estimate dose for the members of the evaluated class.

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SEC Petition Evaluation Report for SEC-00143

1.0 Purpose and Scope

This report evaluates the feasibility of reconstructing doses for all employees of the Department of Energy, Department of Energy contractors, or subcontractors who worked in any area at the Weldon Spring Plant in Weldon Spring, Missouri, during the applicable covered operational period from January 1, 1957 through December 31, 1967. It provides information and analyses germane to considering a petition for adding a class of employees to the congressionally-created SEC.

This report does not make any determinations concerning the feasibility of dose reconstruction that necessarily apply to any individual energy employee who might require a dose reconstruction from NIOSH. This report also does not contain the final determination as to whether the proposed class will be added to the SEC (see Section 2.0).

This evaluation was conducted in accordance with the requirements of EEOICPA, 42 C.F.R. pt. 83, and the guidance contained in the Division of Compensation Analysis and Support's (DCAS) *Internal Procedures for the Evaluation of Special Exposure Cohort Petitions*, OCAS-PR-004.[1]

2.0 Introduction

Both EEOICPA and 42 C.F.R. pt. 83 require NIOSH to evaluate qualified petitions requesting that the Department of Health and Human Services (HHS) add a class of employees to the SEC. The evaluation is intended to provide a fair, science-based determination of whether it is feasible to estimate with sufficient accuracy the radiation doses of the class of employees through NIOSH dose reconstructions.[2]

42 C.F.R. § 83.13(c)(1) states: *Radiation doses can be estimated with sufficient accuracy if NIOSH has established that it has access to sufficient information to estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class, or if NIOSH has established that it has access to sufficient information to estimate the radiation doses of members of the class more precisely than an estimate of the maximum radiation dose.*

Under 42 C.F.R. § 83.13(c)(3), if it is not feasible to estimate with sufficient accuracy radiation doses for members of the class, then NIOSH must determine that there is a reasonable likelihood that such radiation doses may have endangered the health of members of the class. The regulation requires NIOSH to assume that any duration of unprotected exposure may have endangered the health of members of a class when it has been established that the class may have been exposed to radiation during a discrete incident likely to have involved levels of exposure similarly high to those occurring during nuclear criticality incidents. If the occurrence of such an exceptionally high-level exposure has not been established, then NIOSH is required to specify that health was endangered for those workers who were employed for at least 250 aggregated work days within the parameters established for the

[1] DCAS was formerly known as the Office of Compensation Analysis and Support (OCAS).
[2] NIOSH dose reconstructions under EEOICPA are performed using the methods promulgated under 42 C.F.R. pt. 82 and the detailed implementation guidelines available at http://www.cdc.gov/niosh/ocas.

class or in combination with work days within the parameters established for other SEC classes (excluding aggregate work day requirements).

NIOSH is required to document its evaluation in a report, and to do so, relies upon both its own dose reconstruction expertise as well as technical support from its contractor, Oak Ridge Associated Universities (ORAU). Once completed, NIOSH provides the report to both the petitioner(s) and to the Advisory Board on Radiation and Worker Health (Board). The Board will consider the NIOSH evaluation report, together with the petition, petitioner(s) comments, and other information the Board considers appropriate, in order to make recommendations to the Secretary of HHS on whether or not to add one or more classes of employees to the SEC. Once NIOSH has received and considered the advice of the Board, the Director of NIOSH will propose a decision on behalf of HHS. The Secretary of HHS will make the final decision, taking into account the NIOSH evaluation, the advice of the Board, and the proposed decision issued by NIOSH. As part of this decision process, petitioners may seek a review of certain types of final decisions issued by the Secretary of HHS.[3]

3.0 SEC-00143, Weldon Spring Plant Class Definitions

The following subsections address the evolution of the class definition for SEC-00143, Weldon Spring Plant. When a petition is submitted, the requested class definition is reviewed as submitted. Based on its review of the available site information and data, NIOSH will make a determination whether to qualify for full evaluation all, some, or no part of the petitioner-requested class. If some portion of the petitioner-requested class is qualified, NIOSH will specify that class along with a justification for any modification of the petitioner's class. After a full evaluation of the qualified class, NIOSH will determine whether to propose a class for addition to the SEC and will specify that proposed class definition.

In this case, the petitioner-requested class differs from the covered period as determined by the Department of Energy (DOE) Office of Health, Safety and Security, which lists the time period as 1955-1967. There is no evidence of the existence of radioactive materials onsite prior to 1957, when construction was completed and operations were begun. The earliest indication of radioactive material onsite is the start of operations in June 1957. Documentation indicates that the Atomic Energy Commission (AEC) decided early in 1966 to close the Weldon Spring Plant site at the end of that year. The workforce began to decline as employees sought other employment. Shutdown activities occurred throughout 1967.

3.1 Petitioner-Requested Class Definition and Basis

Petition SEC-00143 was received on April 29, 2009, and qualified on September 11, 2009. The petitioner requested that NIOSH consider the following class: *All employees of the Department of Energy, Department of Energy contractors, or subcontractors who worked in any area at the Weldon Spring Plant in Weldon Spring, Missouri, during the applicable covered operational period from January 1, 1957 through December 31, 1966.*

The petitioner provided information and affidavit statements in support of the petitioner's belief that accurate dose reconstruction over time is impossible for the Weldon Spring Plant workers in question.

[3] See 42 C.F.R. pt. 83 for a full description of the procedures summarized here. Additional internal procedures are available at http://www.cdc.gov/niosh/ocas.

NIOSH deemed the following information and affidavit statements sufficient to qualify SEC-00143 for evaluation:

> The SEC-00143 petitioner provided an affidavit that included the statement: “To the best of my knowledge and research, there are no monitoring records/measurements to account for exposures to thorium.”

Records show that in 1958, 44 kg of thorium were received at the Weldon Spring Plant. An interview with a senior chemical processing engineer formerly employed at Weldon Spring indicates that the thorium was not processed (Personal Communication, 2009g). The next indication of thorium material onsite at Weldon Spring Plant is November 6, 1963 (i.e., fiscal year 1964), when the first chemical processing operations involving thorium began. Thorium operations are summarized in Table 2-1 of the *TBD for Weldon Spring Plant – Site Description* (ORAUT-TKBS-0028-2). While there are personnel and area monitoring data that can be evaluated to estimate thorium exposure at Weldon Spring Plant, NIOSH concurred that the sufficiency of area monitoring data for thorium is uncertain.

Based on its Weldon Spring Plant research and data capture efforts, NIOSH determined that it has access to uranium urinalysis, medical X-ray, and film badge external dosimetry data for Weldon Spring Plant workers during the time period under evaluation. However, NIOSH also determined that records related to potential thorium exposure may not be sufficient for adequate reconstruction of internal exposure. NIOSH concluded that there is sufficient uncertainty to support, for at least part of the requested time period, the petition basis that internal thorium radiation exposures and radiation doses may not have been adequately monitored at Weldon Spring Plant, either through personal monitoring or area monitoring. In addition, the petition identified a number of concerns which individually are not supported; however, NIOSH concurred that *en masse* these concerns warranted evaluation of their relevance to and impact on the dose reconstruction of individual Weldon Spring Plant workers. The information and statements provided by the petitioner qualified the petition for further consideration by NIOSH, the Board, and HHS. The details of the petition basis are addressed in Section 7.4.

3.2 Class Evaluated by NIOSH

Based on its preliminary research and finding that shutdown activities were occurring at Weldon Spring Plant through 1967, NIOSH extended the petitioner-requested class to include 1967. Therefore, NIOSH defined the following class for further evaluation: All employees of the Department of Energy, Department of Energy contractors, or subcontractors who worked in any area at the Weldon Spring Plant in Weldon Spring, Missouri, during the applicable covered operational period from January 1, 1957 through December 31, 1967.

3.3 NIOSH-Proposed Class to be Added to the SEC

Based on its research of the class under evaluation, NIOSH has obtained uranium bioassay monitoring data, airborne dust study data with uranium and thorium applications, environmental air concentration measurements, personnel whole-body dosimetry, and medical diagnostic X-ray records for the Weldon Spring Plant. Based on its analysis of these available resources, NIOSH found no part of the class under evaluation for which it cannot estimate radiation doses with sufficient accuracy.

4.0 Data Sources Reviewed by NIOSH to Evaluate the Class

As a standard practice, NIOSH completed an extensive database and Internet search for information regarding the Weldon Spring Plant site. The database search included the DOE Legacy Management Considered Sites database, the DOE Office of Scientific and Technical Information (OSTI) database, the Energy Citations database, the Atomic Energy Technical Report database, and the Hanford Declassified Document Retrieval System. In addition to general Internet searches, the NIOSH Internet search included OSTI OpenNet Advanced searches, OSTI Information Bridge Fielded searches, Nuclear Regulatory Commission (NRC) Agency-wide Documents Access and Management (ADAMS) web searches, the DOE Office of Human Radiation Experiments website, and the DOE-National Nuclear Security Administration-Nevada Site Office-search. Attachment One contains a summary of Weldon Spring Plant documents. The summary specifically identifies data capture details and general descriptions of the documents retrieved.

In addition to the database and Internet searches listed above, NIOSH identified and reviewed numerous data sources to determine information relevant to determining the feasibility of dose reconstruction for the class of employees under evaluation. This included determining the availability of information on personal monitoring, area monitoring, industrial processes, and radiation source materials. The following subsections summarize the data sources identified and reviewed by NIOSH.

4.1 Site Profile Technical Basis Documents (TBDs)

A Site Profile provides specific information concerning the documentation of historical practices at the specified site. Dose reconstructors can use the Site Profile to evaluate internal and external dosimetry data for monitored and unmonitored workers, and to supplement, or substitute for, individual monitoring data. A Site Profile consists of an Introduction and five Technical Basis Documents (TBDs) that provide process history information, information on personal and area monitoring, radiation source descriptions, and references to primary documents relevant to the radiological operations at the site. As part of NIOSH's evaluation detailed herein, it examined the following TBDs for insights into Weldon Spring Plant operations:

- *TBD for Weldon Spring Plant – Introduction*, ORAUT-TKBS-0028-1; Rev. 00 PC-1; June 30, 2008; SRDB Ref ID: 45869

- *TBD for Weldon Spring Plant – Site Description*, ORAUT-TKBS-0028-2; Rev. 00; June 24, 2005; SRDB Ref ID: 20186

- *TBD for Weldon Spring Plant – Occupational Medical Dose*, ORAUT-TKBS-0028-3; Rev. 00; June 24, 2005; SRDB Ref ID: 20187

- *TBD for Weldon Spring Plant – Occupational Environmental Dose*, ORAUT-TKBS-0028-4; Rev. 00; June 28, 2005; SRDB Ref ID: 20188

- *TBD for Weldon Spring Plant – Occupational Internal Dose*, ORAUT-TKBS-0028-5; Rev. 00; June 28, 2005; SRDB Ref ID: 20189

- *TBD for Weldon Spring Plant – Occupational External Dose*, ORAUT-TKBS-0028-6; Rev. 00; June 24, 2005; SRDB Ref ID: 20190

- *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium*, Battelle-TBD-6001; Rev. F0; December 13, 2006; SRDB Ref ID: 30673

4.2 Technical Information Bulletins (TIBs)

A Technical Information Bulletin (TIB) is a general working document that provides guidance for preparing dose reconstructions at particular sites or categories of sites. NIOSH reviewed the following TIBs as part of its evaluation:

- *TIB: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures,* ORAUT-OTIB-0006; December 21, 2005; SRDB Ref ID: 20220

- *TIB: Estimation of Ingestion Intakes*, OCAS-TIB-009; April 13, 2004; SRDB Ref ID: 22397

- *TIB: Estimation of Neutron Dose Rates from Alpha-Neutron Reactions in Uranium and Thorium Compounds*, ORAUT-OTIB-0024; April, 7, 2005; SRDB Ref ID: 19445

- *TIB: Assignment of Missed Neutron Doses Based on Dosimeter Records*, ORAUT-OTIB-0023; May 14, 2008; SRDB Ref ID: 43937

- *TIB: Default Assumptions and Methods for Atomic Weapons Employer Dose Reconstructions*, Battelle-TIB-5000; April 2, 2007; SRDB Ref ID: 32016

4.3 Facility Employees and Experts

To obtain additional information, NIOSH interviewed nine former Weldon Spring Plant employees. NIOSH selected individuals based on their known experience and likelihood that they would be knowledgeable about (1) workplace radiation fields, hazards, and practices to control worker exposure; (2) potential radionuclide intakes as evidenced by workplace controls, monitoring policies and procedures, and bioassay data; and (3) measurements of the beta, photon, and neutron exposure to workers.

- Personal Communication, 2009a, *Personal Communication with Former Weldon Spring Plant Chemical Operator and Pipefitter*; Telephone Interview by ORAU Team; October 23, 2009; SRDB Ref ID: 76964

- Personal Communication, 2009b, *Personal Communication with Former Weldon Spring Plant Utility Operator*; Telephone Interview by ORAU Team; October 24, 2009; SRDB Ref ID: 76968

- Personal Communication, 2009c, *Personal Communication with Former Weldon Spring Plant Employee*; Telephone Interview by ORAU Team; October 25, 2009; SRDB Ref ID: 76962

- Personal Communication, 2009d, *Personal Communication with Former Weldon Spring Plant Chemical Operator and Rigger*; Telephone Interview by ORAU Team; October 25, 2009; SRDB Ref ID: 76965

- Personal Communication, 2009e, *Personal Communication with Former Weldon Spring Plant Production Operator*; Telephone Interview by ORAU Team; October 25, 2009; SRDB Ref ID: 76967

- Personal Communication, 2009f, *Personal Communication with Former Weldon Spring Plant Metallurgical Engineer*; Telephone Interview by ORAU Team; October 26, 2009; SRDB Ref ID: 76969

- Personal Communication, 2009g, *Personal Communication with Former Weldon Spring Plant Employee*; Telephone Interview by ORAU Team; October 27, 2009; SRDB Ref ID: 76966

- Personal Communication, 2009h, *Personal Communication with Former Weldon Spring Plant Design Engineer*; Telephone Interview by ORAU Team; October 29, 2009; SRDB Ref ID: 76970

- Personal Communication, 2009i, *Personal Communication with Former Weldon Spring Plant Health Technician and Health Supervisor*; Telephone Interview by ORAU Team; November 6, 2009; SRDB Ref ID: 76963

4.4 Previous Dose Reconstructions

NIOSH reviewed its NIOSH OCAS Claims Tracking System (NOCTS) to locate EEOICPA-related dose reconstructions that might provide information relevant to the petition evaluation. Table 4-1 summarizes the results of this review. (NOCTS data available as of March 12, 2010)

Table 4-1: No. of Weldon Spring Plant Claims Submitted Under the Dose Reconstruction Rule

Description	Totals
Total number of claims submitted for dose reconstruction	258
Total number of claims submitted for energy employees who meet the definition criteria for the class under evaluation (January 1, 1957 through December 31, 1967)	244
Number of dose reconstructions completed for energy employees who meet the definition criteria for the class under evaluation (i.e., the number of such claims completed by NIOSH and submitted to the Department of Labor for final approval)	180
Number of claims for which internal dosimetry records were obtained for the identified years in the evaluated class definition	207
Number of claims for which external dosimetry records were obtained for the identified years in the evaluated class definition	192

NIOSH reviewed each claim as well as the transcripts from the computer-assisted telephone interviews (CATI) to determine whether internal and/or external personal monitoring records could be obtained for the employees. Of the 244 claims submitted for energy employees whose employment meets the definition criteria for the class under evaluation, three have not yet received a dosimetry response from the Department of Energy (DOE), five have been administratively closed, and forty-six have been pulled either because of an SEC designation for other employment or for administrative reasons. Of the remaining 190 claims, as indicated in the table above, 180 have completed dose reconstructions submitted to the Department of Labor (DOL) for final approval.

4.5 NIOSH Site Research Database

NIOSH also examined its Site Research Database (SRDB) to locate documents supporting the assessment of the evaluated class. Eight hundred forty-four documents in this database were identified as pertaining to the Weldon Spring Plant site. These documents were evaluated for their relevance to this petition. The documents include historical background on radiation safety program descriptions and policies, external and internal radiation reports, survey and routine monitoring summary reports, description of health and safety-related studies, environmental reports, exposure incident reports, and air sample reports.

4.6 Documentation and/or Affidavits Provided by Petitioners

In qualifying and evaluating the petition, NIOSH reviewed the following documents submitted by the petitioners:

- *Petition Form B for SEC-00143*; April 29, 2009; OSA Ref ID: 108678 (Form B, 2009a)
- *Petition Form B for SEC-00144*; April 29, 2009; OSA Ref ID: 108677 (Form B, 2009b)
- *Portion of Correspondence Regarding Record Center*, correspondence to Dr. T. F. Mancuso with an attached conference agenda; Mont G. Mason; 1972; OSA Ref ID: 108678 (Mason, 1972)
- *Portions of the Draft Review of the NIOSH Site Profile for the Weldon Spring Site in Weldon Spring, Missouri*; S. Cohen & Associates; February 2009; OSA Ref ID: 108678 (SCA, 2009)
- *Portions of Transcript from the 31st Meeting of the Advisory Board on Radiation and Worker Health*; July 6, 2005; OSA Ref ID: 108678 (ABRWH, 2005a)
- *Portion of Correspondence Regarding Mallinckrodt SEC Recommendation*, correspondence to The Honorable Michael O. Leavitt; Advisory Board on Radiation and Worker Health; September 15, 2005; OSA Ref ID: 108678 (ABRWH, 2005b)
- *Page from Draft Review of the NIOSH Site Profile for Mallinckrodt Chemical Company, St. Louis, Missouri*; S. Cohen & Associates; January 31, 2005; OSA Ref ID: 108678 (SCA, 2005)
- *Portion of Worker Radiation Dose Records Deeply Flawed*, Volume 6, Number 2 of "Science for Democratic Action"; Arjun Makhijani and Bernd Franke; November 1997; OSA Ref ID: 108678 (Makhijani, 1997)

5.0 Radiological Operations Relevant to the Class Evaluated by NIOSH

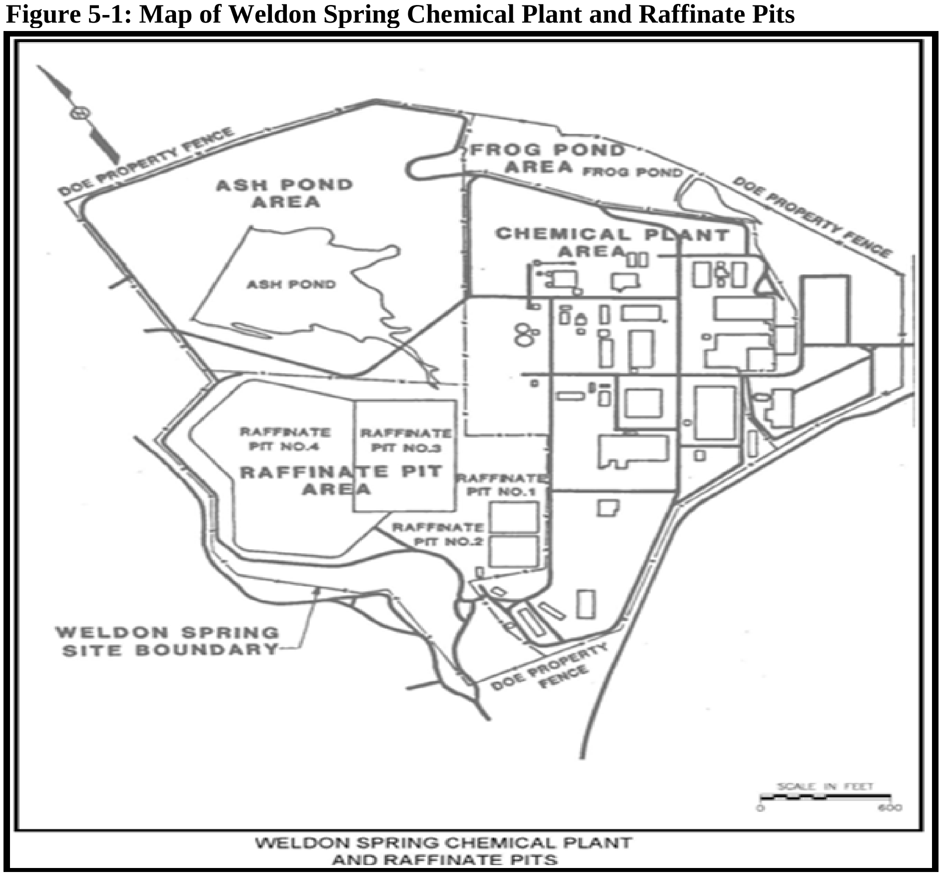
The following subsections summarize both radiological operations at the Weldon Spring Plant site from January 1, 1957 through December 31, 1967 and the information available to NIOSH to characterize particular processes and radioactive source materials. From available sources NIOSH has gathered process and source descriptions, information regarding the identity and quantities of each radionuclide of concern, and information describing processes through which radiation exposures may have occurred and the physical environment in which they may have occurred. The information included within this evaluation report is intended only to be a summary of the available information.

5.1 Weldon Spring Plant and Process Descriptions

ATTRIBUTION: Section 5.1 was completed by Monica Harrison-Maples and Ray Clark, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

The AEC began designing a feed materials plant in 1954. In 1956 and 1957, the AEC constructed a plant (now referred to as the Weldon Spring Plant) for the purpose of processing uranium and thorium feed stocks into metal and intermediate products. Construction was completed in February 1957. Initial operations began in June 1957, and the plant operated through December 1966 (DOE, 1957, p. 28-46; Niedermeyer, 1976). The plant was designed specifically to process uranium mill concentrates (yellowcake) produced elsewhere in the United States and Canada. These materials were shipped to the Weldon Spring Plant 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 (ORAUT-TKBS-0028-2). Shutdown procedures for the plant were initiated and completed in 1967 (ORAUT-TKBS-0028-2). During shutdown, several buildings were used for interim storage of drummed yellowcake. In August 1967, the Weldon Spring Plant site was returned to U.S. Army control for construction of an herbicide production facility (Niedermeyer, 1976). Figure 5-1 shows a map of the Weldon Spring Plant site.

Figure 5-1: Map of Weldon Spring Chemical Plant and Raffinate Pits



Source: Adapted from ORAUT-TKBS-0028-2.

The Health Protection program in place when operations began at the Weldon Spring Plant site in 1957 is not specifically detailed in any of the technical reports available at this time. However, since Mallinckrodt Chemical Works transferred many of its activities and employees from the Destrehan Street site in St. Louis, at the startup of the Weldon Spring Plant, it is likely that the Weldon Spring Plant program closely resembled that documented in the report titled *Mallinckrodt Chemical Works Health Program Policies, Status, and Summary* **(**Mason, 1955). If anything, changes to the Health Protection program were likely more effective due to experience gathered in previous years of involvement in uranium-processing operations. According to a descriptive report of the Mallinckrodt contributions between 1942 and 1967, the design of the Weldon Spring Plant "took advantage of the Company's and the Atomic Energy Commission's accumulated wealth of experience concerning the handling of health and contamination problems encountered in uranium processing" (Fleishman-Hillard, 1967). The Weldon Spring Plant layout was planned with the goal of minimizing the spread of contamination; advanced dust-control systems were used, and onsite health facilities were provided. This 1967 document states, "...existing health programs were continued… at the new site, and a number of supplemental programs were initiated at the Weldon Spring plant" (Fleishman-Hillard, 1967).

5.1.1 Materials Processed at Weldon Spring Plant

ATTRIBUTION: Section 5.1.1 was completed by Ray Clark and Monica Harrison-Maples, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

The Weldon Spring Plant site was operated by the Uranium Division of Mallinckrodt Chemical Works and processed materials from June 1957 through December 1966. DOE estimates that approximately 600 employees worked at the site for the Uranium Division; of those 600 employees, 300 would have handled the materials processed at the Weldon Spring Plant site (DOE, 2000). Four types of nuclear material were processed in the DOE-owned Weldon Spring Plant: (1) natural uranium, (2) depleted uranium, (3) slightly-enriched uranium, and (4) natural thorium (DOE, 1986). Table 5-1 summarizes the total material receipts by fiscal year of operation.

Table 5-1: Annual Uranium and Thorium Mass Receipts (kg)
Table 5-1 and its corresponding notes span two pages.

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

Notes:

Source: ORAUT-TKBS-0028-2

[a] The fiscal year begins on July 1st of the previous calendar year and ends on June 30th of the calendar year corresponding to the designated fiscal year. Thorium received in fiscal year 1964 was actually processed in November and December of 1963, as shown in Table 5-2 of this report.

[b] Includes the startup period in fiscal year 1957.

Natural uranium was received as continental ore concentrates that were refined to extract the uranium, after which the uranium was converted to various compounds and metal forms and shipped off the site. Processing natural uranium was a continuous operation throughout the life of the plant (DOE, 1986). Some plant documentation and interviews with former Weldon Spring Plant workers show that the feed material was “ore.” This issue was explored with a chemical engineer who was associated with the Weldon Spring chemical processes (Personal Communication, 2009g) as well as with a former health physicist (Personal Communication, 2009h) and another former employee (Personal Communication, 2009c). All three individuals confirmed that raw ore was never processed at the Weldon Spring Plant. They explained that the term “ore” was often used to describe ore concentrates.

Depleted uranium was received as metal and various intermediate chemical forms, processed on an intermittent basis, and used primarily in product development activities. This form of uranium was used primarily in product development activities and flow-sheet improvements. Use was confined primarily to Pilot Plant activities (DOE, 1986).

Uranium enriched to 1% or less uranium-235 by weight was also received and processed on an intermittent basis. This type of uranium was typically received in the form of scrap metal or residues. The uranium contents were recovered, processed to various chemical forms, and shipped off the site (DOE, 1986).

An average of 1.2×10^7 kg (1.4×10^4 tons) of uranium-containing material was processed per year (DOE, 1986). Natural uranium processing accounted for more than 98% of the nuclear materials throughput.

Natural thorium was typically received in either a nitrate or an oxide form and processed on an intermittent batch basis in the refinery and oxide production/firing systems (DOE, 1986). The same processing equipment was used for thorium and uranium processing (Personal Communication, 2009g). Only a limited area of the Weldon Spring Plant was exposed to thorium, as described in Table 5-2 and Table 6-5. Thermal denitration of thorium nitrate, followed by sol-gel processing, was used to produce thorium dioxide, which is also known as thoria or thorium oxide. Thorium nitrate solution or thorium nitrate tetrahydrate (TNT) crystals were placed in a reaction pot and reacted with steam. The reaction product, low density ("light") thorium oxide, precipitated to the bottom of the reaction pot. After cooling, the low density thorium oxide was hand-scooped or vacuum-scooped from the reaction pot and placed in a sol tank. (Eventually it was found that vacuum scooping introduced too much air and resulted in a poor quality product.) Demineralized water was added to the sol tank and the solution was acidified using nitric acid. The solution in the sol tank was agitated at mildly elevated temperature becoming the "sol". A stable sol was attained when the ionic charge on individual particles in solution was sufficient for the particles to repel each other and did not aggregate or flocculate. The sol was decanted and dried, becoming a "gel" (NLCO, 1966; Sloat, 1965). A gel, as discussed in this context, is a solid glassy ceramic-like material which can be oxidized, or "fired", at high temperature to drive off volatile impurities and complete the processing.

Table 5-2: Chronological Summary of Thorium Operations at Weldon Spring Plant					
Operation Title	**Building**	**1963**	**1964**	**1965**	**1966**
TNT crystal repackaging	403	Nov-Dec	May-Sep	-	-
TNT crystal repackaging	301	-	Oct-Dec	-	-
Denitration of TNT crystals and sol drying-hand unloading	103	Nov-Dec	May-Aug	-	-
Denitration of TNT crystals and sol drying-vacuum unloading	103	-	Sep-Dec	-	-
Denitration of TNT liquor and sol drying-vacuum unloading	103	-	-	Jan-Jul	-
Denitration by fluid bed-product packaged in drums	403	-	-	May-Jul	-
Denitration by fluid bed-liquor feed and sol product	403	-	-	Aug-Dec	Jan; June-Sep
Denitration of TNT liquor-scoop and pail transfer to sol tank	103	-	-	Oct-Nov	-
Sol drying-vacuum unloading	103	-	-	Aug-Dec	Jan; Jun-Sep
Thorium dioxide high firing-recast furnace	301	Nov-Dec	May-Sep	-	-
Thorium dioxide high firing-billet heaters	301	-	Oct-Dec	Jan-Dec	Jan; Jun-Sep
Thorium dioxide product packaging	403	Nov-Dec	May-Jul; Sep-Dec	Jan-Sep	-
Thorium dioxide product packaging	103	-	Aug	-	-
Thorium dioxide product packaging	301	-	-	Oct-Dec	Jan; Jun-Sep
Rotary kiln calcining of sump cake	301	-	-	-	Apr-Jul
Digest feed repackaging	101	-	-	-	Apr-Aug
Scrap digestion and raffinate disposal	103	-	-	-	May-Sep
Extraction	105	-	-	-	Jun-Sep

Notes:

Source: Created with information from *Weldon Spring Feed Materials Plant, Summaries of Dust Concentrations at Production Jobs* (MCW, 1958-1966).

- Indicates that no operations were conducted.

5.1.2 Buildings and Activities at Weldon Spring Plant

ATTRIBUTION: Section 5.1.2 was completed by Ray Clark and Monica Harrison-Maples, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

Weldon Spring Plant's main activity was converting uranium concentrate (yellowcake) to uranium trioxide, uranium tetrafluoride, and uranium metal. Before entering the refinery, the ore concentrate underwent a sampling and preparation process in the sampling plant. Described below are some of the buildings and activities associated with the yellowcake conversion process and outside the yellowcake conversion process that had potential for radiological exposure occurring at the Weldon Spring Plant site.

BUILDINGS INVOLVED IN THE YELLOWCAKE CONVERSION PROCESS

Described below are some of the buildings and activities associated with the yellowcake conversion process that had potential for radiological exposure occurring at the Weldon Spring Plant site.

Building 101

Building 101 was the sampling building. Ore concentrate of about 60% to 70% uranium content arrived in drums. Concentrate in opened drums was sampled using one of the two sampling methods—auger or mechanical sampling—and 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. 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 (Meshkov, 1986, pp. 27-28).

Building 103

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 (Meshkov, 1986, p. 31). Following processing in Building 105, 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 uranium trioxide (ORAUT-TKBS-0028-2, p. 13). In 1967, Building 103 was transferred to the Army for herbicide production.

Building 105

Building 105 was the purification building where a highly purified uranyl nitrate hexahydrate (UNH) solution was produced by means of extraction columns, process vessels, evaporators, and tributyl phosphate and hexane reaction tanks (ORAUT-TKBS-0028-2, p. 13). In 1967, Building 105 was transferred to the Army for herbicide production.

Building 201

Building 201 (Green Salt Building) was used for converting uranium trioxide to uranium dioxide and uranium tetrafluoride. Excess hydrogen-fluoride gas from the process was filtered through carbon filters to recover uranium, which was recycled to black oxide (U_3O_8). Discharge from the uranium-tetrafluoride 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 uranium-tetrafluoride dust, and there was a reverter in the building to convert uranium tetrafluoride into U_3O_8. The green salt was then packaged in transfer hoppers and moved to Building 301 for conversion into solid uranium metal (Meshkov, 1986, p. 22).

Building 301

As previously mentioned, magnesium was used to convert uranium tetrafluoride into solid uranium metal using a multistep process in Building 301. The reaction occurred in refractory-lined steel "bomb" shells that were charged with a mixture of green salt and magnesium chips. The green salt and magnesium were mixed in a blender, and the mixture was then placed into individual steel shells at the filling machine where the shells were then sent to the furnaces for firing. Within the furnace, the shells were heated to about 500°F and the charge was electrically ignited. Once ignited, the reaction proceeded spontaneously. Complete shells were moved to an outdoor cooling pad for about three days. Besides uranium metal, the process generated uranium tetrafluoride 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 convert them to U_3O_8. One standard dust collector was used for the dusty discharge, mostly U_3O_8, produced in this operation (ORAUT-TKBS-0028-2, p. 15).

BUILDINGS OUTSIDE THE YELLOWCAKE CONVERSION PROCESS

Described below are some of the buildings and activities outside the yellowcake conversion process that had potential for radiological exposure occurring at the Weldon Spring Plant site. These activities may have been in support of the primary mission but were not directly part of that process.

Building 301

Uranium fuel cores were produced in Building 301. Uranium billets were extruded to rods of suitable size to produce cores for use in reactors. The rods were straightened, cut to lengths, heat-treated, degassed, machined, inspected, and shipped. All acceptable cores were packaged in boxes and shipped by rail directly to reactor sites (Niedermeyer, 1976, p. 46).

Buildings 403/404

Buildings 403 and 404 housed the Chemical and Metallurgical Pilot Plants, respectively. The Chemical and Metallurgical Pilot Plants 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 these 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. A process for the simultaneous denitration of uranyl nitrate and reduction of uranium trioxide was also studied. The Metallurgical Pilot Plant was equipped for large-scale development of the bomb-reduction step of the process (Niedermeyer, 1976, p. 47).

Building 407

The Analytical and Research laboratories were housed in Building 407. The Analytical laboratory had four sections: (1) production, (2) spectrographic, (3) method development, and (4) special analysis. 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. The special analysis section performed analytical work for the Research laboratory and Pilot Plants, in addition to running production and uranium inventory samples (Niedermeyer, 1976, pp. 35-36).

The Research laboratory consisted of three sections: (1) dry chemistry, (2) wet chemistry, and (3) instrumental techniques. 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 for qualitative and quantitative analysis, particle-size distribution studies, identification of minerals, and studies of physical properties (Niedermeyer, 1976, p. 36).

Waste Streams

Between 1958 and 1964, in order to contain process wastes from the plant, four raffinate pits were constructed in the southwest portion of the Weldon Spring Plant site. Pits 1 and 2 were constructed in

1958, and were used for almost two years. The design volume of each of these two pits was 14,000 m^3 (500,000 ft^3) (NLCO, 1977).

Because of the high production rate, the first two raffinate pits filled rapidly, requiring the construction of the third and, eventually, fourth pit. Pit 3 was constructed and put into operation in 1959, with a design volume of 127,000 m^3 (4.5×10^6 ft^3). Pit 4 was constructed and put into operation in 1964, and its design volume was 340,000 m^3 (12×10^6 ft^3) (NLCO, 1977, p. 20).

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 into 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 1986; ORAUT-TKBS-0028-2). The raffinates from thorium-232 processing were deposited in Raffinate Pit 4.

In 1958, the AEC acquired the Weldon Spring Quarry, which was previously part of the U.S. Army's Weldon Spring Ordnance Works (ORAUT-TKBS-0028-2). The Weldon Spring Quarry was first used by the Weldon Spring Plant site for storing radioactive waste in 1959, when an estimated 150 m^3 (5,400 ft^3) of drummed 3.8%-thorium residues were placed there. In 1963 and 1964, uranium- and radium-contaminated building rubble, equipment, and soils were deposited into the Weldon Spring Quarry following demolition of the Mallinckrodt Chemical Works' Destrehan Street Feed Plant. In 1966, approximately 13,500 ft^3 of drummed and bulk 3%-thorium residues were deposited in the Weldon Spring Quarry (ORAUT-TKBS-0028-2).

5.1.3 Plant Shutdown Activities

<u>ATTRIBUTION</u>: Section 5.1.3 was completed by Ray Clark and Monica Harrison-Maples, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

In early 1966, the AEC decided to close Weldon Spring Plant at the end of the year because the plant was made obsolete by more cost-efficient processes. The workforce began to decline 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 (initiated in 1967), hoppers and process lines were emptied and dust collectors and other points of material accumulation were cleaned out. All 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 were awaiting turnover to the Department of Defense (DOD) for use as an herbicide facility. The transfer of facilities to DOD had begun by March 1968.

Only a few pounds of pure compounds were present in any single piece of equipment. The bulk of the radiological materials that remained on the site were outside the primary production lines in building sumps and in secondary pieces of process equipment and piping without routine access ports. Some of the buildings were used for interim storage of drummed yellowcake from other mills. This yellowcake was later shipped to various plants for refining and processing.

5.2 Radiological Exposure Sources from Weldon Spring Plant Operations

ATTRIBUTION: Section 5.2 was completed by Robert Morris and Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

The primary feed material at Weldon Spring Plant was natural uranium in the form of yellowcake. Weldon Spring Plant also processed depleted uranium and slightly-enriched (up to 1%) uranium, as well as natural thorium. Table 5-3 lists the quantity and percentage of each type of feed material processed.

Table 5-3: Mass and Percentage of Feed Materials

Material	Mass (kg)	Percent of Total Mass
Natural Uranium	122,015,944	98.43
Depleted Uranium	167,823	0.14
Slightly-Enriched Uranium	842,585	0.68
Natural Thorium	941,347	0.76
Total	**123,967,712**	

Source: ORAUT-TKBS-0028-2

The following subsections provide an overview of the internal and external exposure sources for the Weldon Spring Plant class under evaluation.

5.2.1 Internal Radiological Exposure Sources from Weldon Spring Plant Operations

ATTRIBUTION: Section 5.2.1 was completed by Robert Morris and Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

The principal source of internal deposition of radionuclides for the Weldon Spring Plant site was inhalation of dust generated during the operations, initial cleanup, and maintenance periods. Table 5-4 lists the history of dust-generating operations.

Table 5-4: History of Dust-Generating Activities at Weldon Spring Plant

Period	Activity
June 1957-December 1966	Operation of the uranium feed materials plant • Uranium concentrates converted to uranium trioxide, uranium tetrafluoride, and uranium metal • Some thorium processing between 1965 and 1966 • Raffinate from processing removed and sent to raffinate pits • 14,500 metric tons of uranium materials received for processing and sampling per year between 1958 and 1964
December 1966	Plant closed • Hopper and process lines emptied • Dust collectors cleaned out
1967	Site used as interim storage depot for yellowcake later shipped to other plants for refining and processing

Source: This table was modified from Table 5-1 in ORAUT-TKBS-0028-5.

Table 5-5 shows the potential radionuclide exposure for production buildings at the Weldon Spring Plant site.

Table 5-5: Potential Internal Radionuclide Exposure for Production Buildings

Building Number	Building Description	Potential Radionuclide Exposures
101	Sampling	Natural uranium dust Radium-226 Thorium-230 Polonium-210 Lead-210 Radon-222 and its short-lived decay products Thorium-232 and decay products (in 1966)
103	Digestion	Natural uranium dust (as yellowcake and uranium trioxide) Radium-226 Thorium-230 Polonium-210 Lead-210 Radon-222 and its short-lived decay products Thorium-232 and decay products (beginning November 1963)
105	Purification	Uranium dust or thorium (in 1966) Radon-222 and short-lived decay products
108	Acid Recovery	Radon gas and its decay products
201	Uranium Tetrafluoride (Green Salt) Plant	Uranium exposure as green salt dust or natural thorium (1965-1966)
301	Metals Plant	Uranium as green salt dust and U_3O_8 or natural thorium (1965-1966) Thorium-232 and decay products (beginning November 1963)
403	Chemical Pilot Plant	Natural uranium dust Radium-226 Thorium-230 Polonium-210 Lead-210 Radon-222 and its short-lived decay products Thorium-232 and decay products (starting November 1963)
404	Metallurgical Pilot Plant	Uranium as green salt dust and U_3O_8 or natural thorium (1965-1966)
407	Analytical and Research Laboratories	Natural uranium dust Radium-226 Thorium-230 Polonium-210 Lead-210 Radon-222 and its short-lived decay products Thorium-232 and decay products (1965-1966)

Source: This table was modified from a table in ORAUT-TKBS-0028-2.

5.2.1.1 Uranium

ATTRIBUTION: Section 5.2.1.1 was completed by Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

During the entire operations period, the Weldon Spring Plant facility primarily handled uranium concentrates (e.g., yellowcake) received from uranium-milling facilities, consisting of uranium-234, uranium-235, and uranium-238 in their natural abundances with very low concentrations of decay products. Historical documents report that Weldon Spring did not receive the high-quality pitchblende ores that were processed at the Mallinckrodt Destrehan Street facility (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 (Personal Communication, 2009c; Personal Communication, 2009g; Personal Communication, 2009h). The plant processed uranium concentrates into uranium trioxide, uranium tetrafluoride, and uranium metal (Meshkov, 1986). Uranium dioxide was an intermediate product in the conversion of uranium trioxide to uranium tetrafluoride (ORAUT-TKBS-0028-2). Production at Weldon Spring waned during the later part of its operational period.

Ore concentrates containing 60% to 70% yellowcake were sampled on receipt in Building 101. Some of the material was repackaged into drums and some sent directly for processing. The concentrates were digested with nitric acid in Building 103 to produce uranium-nitrate solution that was then purified by solvent extraction in Building 105 and denitrated in Building 103 to produce uranium trioxide. Uranium trioxide was converted to uranium tetrafluoride (green salt) in Building 201. Green salt was one of the final products of the plant.

Uranium metal was produced using magnesium to convert uranium tetrafluoride to the metallic form in Building 301. A rotary kiln was used to convert uranium metal chips to U_3O_8. Uranium fuel cores were also produced in Building 301 and shipped directly to reactor sites.

The process wastes from uranium processing were sent to four raffinate pits, constructed between 1958 and 1964. The uranium-process wastes contained relatively low-level concentrations of uranium. The radionuclide of most concern in the raffinate pits was thorium-230, due to its high activity concentration and its radiotoxicity. Thorium-230 is discussed further in Section 5.2.1.2 of this evaluation report. It is estimated that 152,382 kg of natural uranium, 46 kg of depleted uranium, and 2,808 kg of slightly enriched uranium was discharged in to the raffinate pits (DOE, 2000, Table 2-23, p. 86).

Additional details regarding uranium processing are contained in ORAUT-TKBS-0028-2. The annual uranium and thorium mass receipts are shown in Table 5-1 of this evaluation report.

5.2.1.2 Uranium Decay Products and Other Impurities

ATTRIBUTION: Section 5.2.1.2 was completed by Eugene W. Potter and Bryce L. Rich, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

Uranium decay products and other impurities were present in the uranium ore concentrates processed at the Weldon Spring Plant. No bioassay program was in place for these materials since they were considered a minor hazard of the operations as compared to the uranium itself. The *Weldon Spring Historical Dose Estimate* (Meshkov, 1986) is a historical offsite dose estimate study that estimates the activities of thorium-230 and radium-226 in yellowcake to be 5% and 1% of uranium-238 activity, respectively. The final Weldon Spring Plant product was essentially pure uranium, with thorium-230 and other impurities having been removed in the raffinates and sent to the disposal pits.

Raffinate Pits 1, 2, and 3 received mostly uranium raffinates, and Pit 4 received both uranium and thorium raffinates. In the first three pits, thorium-230 constituted greater than 80% of the total activity. An upper estimate of the thorium-230 activity in the ore concentrates is 100% of the uranium-234 activity (its parent), or 50% of the total uranium activity (approximately 0.34 nCi/mg uranium). Measurements of the activity concentrations in Raffinate Pits 1, 2, and 3 can be used to determine the relationship between thorium-230 and other impurities during the initial uranium processing in Building 101 before any separations occurred. The shorter-lived decay products for which no raffinate measurements were made (e.g., lead-210 and polonium-210) can be assumed to be present similarly to the measured activity level of the radium-226 parent in the raffinate pits (see Table 7-4 below). Following the purification of the uranium during the initial processing of the ore concentrates to uranium trioxide, the removal of the uranium decay products would have eliminated them as a potential exposure source in the general operating areas of the plant. There was some natural thorium (e.g., thorium-232 and thorium-228) present in the uranium ore concentrates, which was also separated and sent to the raffinate pits. Measurements of thorium-232 in the raffinate pits were made by alpha spectroscopy, but these measurements were not considered to be reliable because of the interference from the thorium-230 alpha peak. Measurements of thorium-228 in Raffinate Pits 1, 2, and 3 are available to NIOSH (MK-Ferguson, 1989). Given that radium-228 (the parent of thorium-228) was largely removed by the milling process, and that thorium-232 (the parent of radium-228) has a long half-life, the build-up of thorium-228 in the short term is minor. Meanwhile the thorium-228, which was originally in approximate equilibrium with thorium-232, decays significantly because of a half life of only 1.9 years. The delay time from milling to processing of 1.2 years equates to an approximate thorium-228 activity to thorium-232 activity of 65% (65% equilibrium). Using this relationship, the amount of thorium-232 can be estimated from the thorium-228 measurements.

5.2.1.3 Recycled Uranium

ATTRIBUTION: Section 5.2.1.3 was completed by Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

In 1999, DOE initiated the complex-wide Recycled Uranium Mass Balance Project, which identified the Weldon Spring Plant as a site that likely received recycled uranium in relatively small quantities of materials after 1961 (ORAUT-TKBS-0028-2). The significance of these shipments of recycled uranium is that this material contained trace amounts of residual transuranic elements (including plutonium and neptunium), fission products (such as technetium), and reactor-produced uranium isotopes (such as uranium-236) (DOE, 2000).

Contaminant radionuclides in recycled uranium that could be dosimetrically significant are plutonium (assume plutonium-239), neptunium (neptunium-237), and technetium (technetium-99). Site records do not include the level of detail needed for an accurate estimate of the amount of recycled material received and processed at the Weldon Spring Plant site. However, greater than 99% (by weight) of the slightly enriched uranium received at the Weldon Spring Plant site was from Fernald (DOE, 2000, p. 1,130). For the purpose of this evaluation, the uranium source term is considered to be:

- Prior to 1961, natural uranium,

- 1961-1967, recycled uranium.

For the periods that included recycled uranium, Table 5-6 contains maximum values for the recycled uranium contaminants as a fraction of uranium intake based on material that is likely to have been received by Weldon Spring (DOE, 2000, p. 1,140).

Table 5-6: Maximum Recycled Uranium Contaminant Levels

Contaminant	Average Concentration (ppbU)	Observed Range (ppbU)	Bounding Value[a]		
			ppbU	pCi/µgU	pCi/pCiU
Plutonium	2.9	0.60-15	6.3	3.9E-04	5.7E-04
Neptunium-237	390	55-3,200	1,800	1.3E-03	1.9E-03
Technetium-99	8,600	800-19,000	21,000	0.36	0.53

Note:
[a] Calculated as the 95th percentile of an unblended uranium trioxide PUREX source, assuming a lognormal distribution. This provides the highest values for the two subgroups of recycled uranium likely received by Weldon Spring (DOE, 2000).

5.2.1.4 Thorium

ATTRIBUTION: Section 5.2.1.4 was completed by Robert Morris, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

Thorium processing operations at the Weldon Spring Plant site began in November 1963. These operations are included in the chronological summary of thorium operations found in ORAUT-TKBS-0028-2, Table 2-1. In 1965 and 1966, first pure and then impure thorium oxide was processed, initially on a pilot scale in Buildings 403 and 404, and later on a large scale in Buildings 101, 103, 105, and 301(Argonne, 1985). Natural thorium was typically received in either a nitrate or an oxide form and processed on an intermittent batch basis in the refinery and oxide production/firing systems. Only a limited area of the Weldon Spring Plant site was exposed to the material. An average of 3.1×10^5 kg of natural thorium was processed per year during 1964 through 1966, with an associated total material balance closure of 98.52% (DOE, 1986; ORAUT-TKBS-0028-2). Wastes were deposited in Raffinate Pit 4.

The AEC acquired the Weldon Spring Quarry in 1958 as a location to dispose of thorium residues as well as uranium- and radium-contaminated building rubble and equipment and soils from the Destrehan Street site. These materials were deposited into the Weldon Spring Quarry between 1959 and 1966. The estimated maximum thorium-232 concentration in materials deposited in the Weldon Spring Quarry was 4200 pCi/g (DOE, 1991; ORAUT-TKBS-0028-5).

5.2.1.5 Radon

ATTRIBUTION: Section 5.2.1.5 was completed by Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

As indicated in Section 5.2.1.1 of this report, there is no suggestion in the historical records that the Weldon Spring Plant facility ever processed the high-activity concentration pitchblende, which contained significant concentrations of radium. The ore concentrates processed at Weldon Spring 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.

The radon trapped in the ore concentrates was released during the acid digestion process in Building 103. The off gasses 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/year based on throughput (Meshkov, 1986, p. 48).

Impurities generated in the uranyl-nitrate purification process were bled off in the raffinate, which were pumped to raffinate pits. The raffinate contained a conglomerate of radionuclides, including small concentrations of thorium and radium (Unknown, 1967; ORAUT-TKBS-0028-2). Due to the presence of water in the pits, wastes disposed of in the raffinate pits were not a significant source of airborne radionuclides during the operational period. It is unlikely that a significant portion of the sediments became sufficiently dry to be considered a source term, even though the report, *Weldon Spring Site Environmental Monitoring Report, Calendar Year 1983* reported that Pits 1 and 2 could become dry during the summer months (Bechtel, 1984). The report, *Study of Radioactive Waste Storage Areas at ERDA-Weldon Spring Site* concluded that the inherent consistency of the raffinate material precluded sufficient drying, and the pits did not pose a significant source of airborne contaminants (NLCO, 1977). Radon measurements in the pit area in the late 1970s and early 1980s (before remediation) averaged 0.92 ± 1.0 pCi/L, indicating that the pits were not a major source of radon (Meshkov, 1986, p. 101). This value is limiting for the operational period since the amount of radium-226 in the pits was at its maximum at the end of operations, and it would not have decayed or leached out of the pits significantly before the measurements were made.

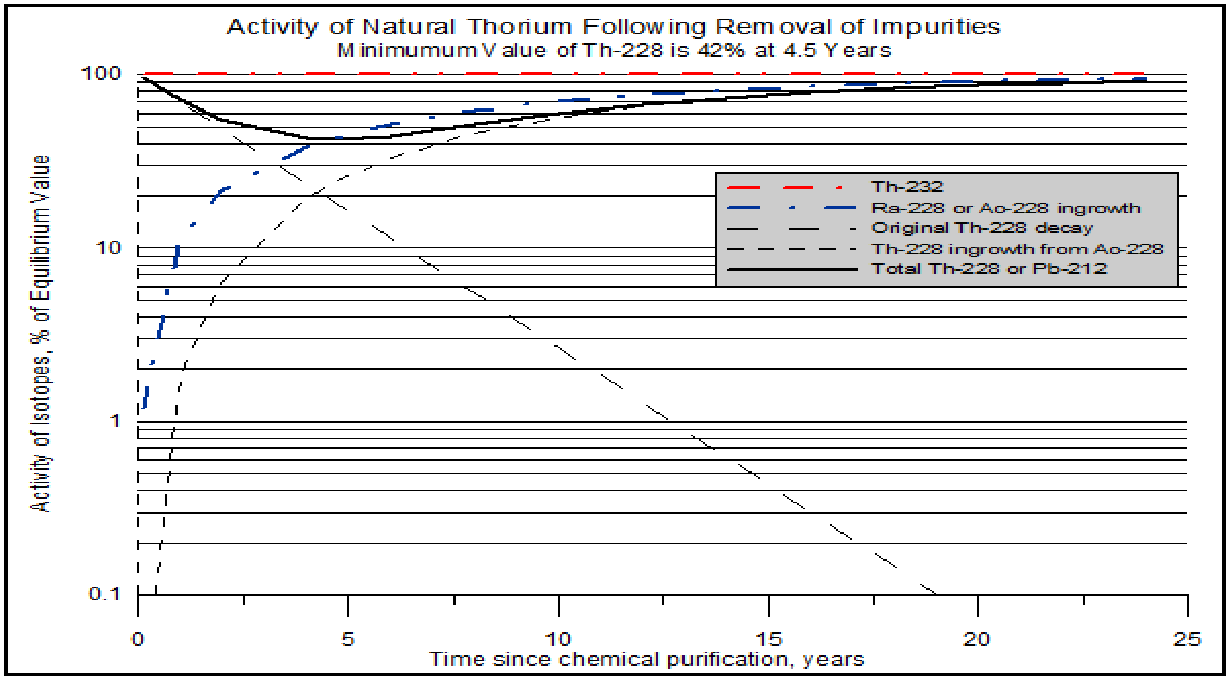
Prior to 1963, the quarry only contained drummed thorium wastes that were likely submerged and not a significant source of radon. In 1963 and 1964, an estimated 38,000 m^3 of uranium- and radium-contaminated rubble, equipment, and soil were placed in the quarry following demolition of the Destrehan Street site, with a majority of this waste not submerged, providing a potential source of radon exposure (Unknown, 1967; ORAUT-TKBS-0028-4). Measurements in the quarry area in the late 1970s and early 1980s (before remediation) averaged 0.65 ± 0.41 pCi/L, indicating that the quarry was not a major source of radon (Meshkov, 1986, p. 101). As in the case of the raffinate pits, this value would be limiting for the operational period.

5.2.1.6 Thoron

ATTRIBUTION: Section 5.2.16 was completed by Bryce L. Rich, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

Thoron is the second daughter product of thorium-228, and after a couple of weeks, following the processing of thorium ores for thorium purification, can be considered to be in full equilibrium with the parent, thorium-228. Thorium-228 is the third daughter product of the long-lived thorium-232, and is generally in 40-65% equilibrium for materials processed at the Weldon Spring Plant. The degree of equilibrium is dependent upon both the decay of thorium-228 (without replenishment from the 5.7 year half life of radium-228) after removal of the thorium daughters and the time it takes the radium-228 to build into equilibrium with thorium-232.

Figure 5-2: Decay and Buildup of Thorium-228 and Daughters Following Processing



Thoron was present and a portion was released during the processing and storage of thorium at the Weldon Spring Plant and the associated waste storage locations. The thoron, with its subsequent daughter products, would act as a potential source of internal exposure in the thorium process buildings and at waste storage locations.

There are several aspects of the release and buildup of thorium daughter products that mitigate the exposure to thoron in process and storage configurations. These include the following:

- Because of the very short half life of thoron (56 seconds), much of the isotope decays within the material matrix; therefore, the diffusion distance in soils is in the range of approximately one inch. Only the quantities of thoron in the first inch of material represent the source term. Table 5-7 provides the half life information for thoron and its daughters.
- In process equipment, the release of thoron gas is largely contained within the containment system and/or the ventilation system. Essentially, the dose from exposure to thoron comes entirely from the daughters lead-212 and bismuth-212. A thoron working level (WL) requires 375 pCi/l thoron and polonium-216 to produce measured daughter products lead-212 and bismuth-212 at 7.5 pCi/l.

Table 5-7: Thoron and Isotopic Daughters

Isotope	Half Life	Atoms/7.5 pCi	• MeV/atom	PAEC[1] MeV per 7.5 pCi
Radon-220	56 sec	23	14.6	335
Polonium-216	0.15 sec	<1	Incl	-
Lead-212	10.64 hr	15476	7.8	1.21E+5
Bismuth-212	60.6 min	1469	7.8	0.12E+5
Polonium-212	0.3 μsec	-	Incl	-
Thallium-208	3 min	73	no •	-
Total				**1.33E+5**

Notes:
[1] Potential Alpha-Energy Concentration (PAEC)

The primary focus of the radiological safety programs for thorium was to define the air concentrations in the work place, the results of which provided the means of limiting worker exposures to levels below the permissible levels. Weldon Spring Plant records do not indicate specific analyses to define the concentrations of thoron daughter activities; however, it was standard practice to provide delayed counts on the air samples for up to 96 hours to allow the short- lived radon and thoron daughter products to decay.

5.2.2 External Radiological Exposure Sources from Weldon Spring Plant Operations

ATTRIBUTION: Section 5.2.2 was completed by Ray Clark, Monica Harrison-Maples, and Edward D. Scalsky, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

The principal source of external radiation doses for members of the evaluated class, other than medical X-rays required as a condition of employment, was direct beta-gamma exposures from uranium processing. The uranium processed at the Weldon Spring Plant site was natural, slightly enriched, and depleted uranium. The natural uranium, which accounted for more than 97% of the nuclear materials throughput, was received as continental ore concentrates. A limited amount of thorium was also processed at the Weldon Spring Plant site from November 1963 through 1966, the chronology of which is presented in ORAU-TKBS-0028-2. Although low, there was also some potential for external exposure associated with working in proximity to the raffinate pits and quarry. Uranium and thorium processing generated several chemical and radioactive waste streams, which were piped into the raffinate pits.

External ambient exposure at the Weldon Spring Plant site would have been a result of gamma and X-ray radiation emitted from radionuclides in the ore concentrate stored on the site during the operational period, and to a lesser extent from radionuclides in the raffinate pits and quarry. Considerable shielding would have occurred at the quarry from the water covering most of the deposited materials. An aerial radiological survey of the Weldon Spring Plant site (Jobst, 1976) indicated that for most of the site the normal terrestrial gamma exposure rate was 3 to 6 µR/hour at 1 meter above ground level, and the average cosmic exposure rate was approximately 4 µR/hr.

Summary reports indicate that natural uranium was the radiological material that the workers came into contact with most frequently. Radiation fields most often consisted of a complex mixture of beta and gamma energies. There was a low potential to encounter neutrons in several buildings (discussed further in Section 5.2.2.3 of this report). The relative magnitude of each type of exposure can be found in employee records. The majority of the exposure would have consisted of beta particles, which, depending on the energy spectrum of the particles, can deliver substantial doses to bare skin in relatively close proximity to the source, but which do not penetrate deeply into the body.

Table 5-8 lists the beta and gamma emissions of the radionuclides of major external exposure concern. ORAUT-TKBS-0028-6 (Figures 6-1 to 6-3) shows complete decay chains of uranium-238, uranium-235, and thorium-232. Protactinium-234m is likely the most important contributor to skin dose because of its frequent high-energy beta emission. Protactinium-234m also emits higher energy gamma rays, albeit less frequently, than other radionuclides of concern at the Weldon Spring Plant site.

Table 5-8: Beta and Gamma Emissions of Primary Interest		
Radionuclide	**Beta Energy (MeV, max.)**	**Gamma Energy (MeV)**
Uranium-238	None	None
Thorium-234	0.10 (19%)	0.063 (3.5%)
	0.193 (79%)	0.093 (4%)
Protactinium-234m	2.28 (99%)	0.766 (0.2%)
		1.00 (0.6%)
Uranium-235	None	0.144 (11%)
		0.163 (5%)
		0.186 (54%)
		0.205 (5%)
Thorium-231	0.205 (15%)	
	0.287 (49%)	0.026 (15%)
	0.304 (35%)	0.084 (6.5%)
Uranium-234	None	0.053 (0.1%)
Thorium-232	None	0.059 (0.19%)
		0.126 (0.04%)
Radium-228	0.0389 (100%)	0.0067 (6 x 10^{-5}%)
Actinium-228	0.983 (7%)	0.338 (11.4%)
	1.014 (6.6%)	0.911 (27.7%)
	1.115 (3.4%)	0.969 (16.6%)
	1.17 (32%)	1.588 (3.5%)
	1.74 (12%)	-
	2.08 (8%)	-
	(+33 more • s)	-
Thorium-228	None	0.084 (1.19%)
		0.132 (0.11%)
		0.166 (0.08%)
		0.216 (0.27%)
Bismuth-212	1.59 (8%)	0.040 (1%)
	2.246 (48.4%)	0.727 (11.8%)
	-	1.620 (2.75%)
Lead-208	None	2.614 (100%)

Notes:

Source: Radiological Health Handbook, 1998

A more complete list for uranium and thorium progeny can be found in the Radiological Health Handbook, 1998

5.2.2.1 Photon

ATTRIBUTION: Section 5.2.2.1 was completed by Ray Clark and Edward D. Scalsky, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

Weldon Spring Plant records indicate that depleted and enriched uranium were routinely handled with some shielding, but the type and amounts of shielding are not known. Enriched and depleted uranium received at the Weldon Spring Plant site for processing is assumed to have been relatively fresh with little or no ingrowth of decay products having occurred at the time that the material was processed at the Weldon Spring Plant site.

Protactinium-234m is a decay product in the uranium-238 decay chain that emits a 2.29-MeV beta particle. The bremsstrahlung photons associated with this high energy beta are in the intermediate energy range (30 to 250 keV). Protactinium-234m was present in equilibrium quantities for most depleted uranium that was processed at the Weldon Spring Plant site.

Although enriched uranium has significantly less ingrowth of protactinium-234m, uranium-235 and its decay products emit a 185.7-keV photon 57% of the time and a 143.8-keV photon 11% of the time. These photons dominate the measured photon energy spectra. Natural uranium was processed in Buildings 101, 103,105, 106, 108, 109, 110, 201, 301, 403, 404, 405 A & B, 407, 414, 415, and 431, as well as Area 102 A & B. Slightly enriched uranium was processed in Buildings 103, 105, 201, and 301. Depleted uranium was processed in Buildings 403 and 404. Natural thorium was processed in Buildings 103, 105, 201, and 301. The default assumptions for the distribution of the photon energies, as defined for the purpose of dose reconstruction for the Weldon Spring Plant site, are relayed in Table 5-9.

Table 5-9: Default Photon Energy Distribution for Weldon Spring Plant Materials

Energy	Natural Uranium	Depleted Uranium	Slightly Enriched Uranium	Natural Thorium
<30 keV	0%	0%	0%	0%
30-250 keV	50%	40%	100%	25%
>250 keV	50%	60%	0%	75%

Source: ORAUT-TKBS-0028-6

5.2.2.2 Beta

ATTRIBUTION: Section 5.2.2.2 was completed by Ray Clark, Monica Harrison-Maples, and Edward D. Scalsky, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

Beta radiation fields are usually the dominant external radiation hazard in facilities that involve contact work with unshielded forms of uranium. This was the case at the Weldon Spring Plant site for natural and depleted uranium work. The most common exposure at the Weldon Spring Plant site was to natural uranium, but depleted uranium was present at the site on an intermittent basis; in addition, slightly-enriched uranium (less than 1% uranium-235 by weight) was also present at times in the form of scrap metal or residues. Table 5-8 provides the energies of the beta emissions from the primary isotopes of concern at the Weldon Spring Plant site.

Beta doses were determined by the use of film badges. Several studies were done to evaluate the time required to perform potentially high exposure jobs, to determine the shielding that could be applied to reduce the beta exposures, and to determine the primary exposure source during various phases of the job. The Health and Safety program employees provided reports to management at the Weldon Spring Plant that were used to evaluate worker exposures, and thus determine who should be rotated or removed from exposure sources in order to ensure individuals' doses were below the existing standards.

Additional beta exposure data are available for lathe operators and for jobs in the casting area. These data are from a study of various operations and times of exposure in the casting area (MCW, unknown date).

5.2.2.3 Neutron

ATTRIBUTION: Section 5.2.2.3 was completed by Ray Clark, Monica Harrison-Maples, and Edward D. Scalsky, Oak Ridge Associated Universities (ORAU) and Leo G. Faust, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

The Weldon Spring Plant was operated as an integrated facility for the conversion of uranium ore concentrates and small quantities of recycled scrap to pure uranium trioxide, uranium tetrafluoride, and uranium metal (DOE, unknown date). During these processes and during the storage of uranium tetrafluoride, neutrons were not anticipated at the Weldon Spring Plant. Any neutrons would have resulted from the alpha-neutron reaction from uranium tetrafluoride (green salt) or processing the slightly-enriched (<1%) uranium.

Most Weldon Spring operational employees were involved with the processing of natural and depleted uranium and were assigned the regular beta-gamma dosimeter badge monitors. However, in a special study at the Feed Materials Production Center site (Fernald), neutron measurements were made in and around the arrays of drums of stored uranium tetrafluoride, up to 2% enrichment, to determine the potential for neutron exposures. The study included the use of Landauer Neutrak-ER dosimeters as area badges over the period of one quarter, and a special survey using a Nuclear Research Corporation Model NP-2 portable neutron meter. The results of the study indicate neutron exposures were minimal: a maximum of 0.089 mrem/hour for the area badges, and less than the minimum detectable (0.02 mrem/h) for the portable neutron monitor. Calculations performed for Battelle-TBD-6001 on similar materials are in agreement with the Fernald measurement data and support the conclusion that neutron dosimetry is not needed when processing uranium tetrafluoride under these parameters because there is no significant potential for neutron exposures.

Even though the Weldon Spring Plant received enriched uranium, it was always <1%; therefore, the potential for neutron exposure was very low. The slightly-enriched uranium was processed in Buildings 103, 105, 201, and 301, and those employees that processed the slightly-enriched uranium were assigned special neutron dosimeter badges to be worn in conjunction with their regular film badge dosimeters. Neutron dose results for these Weldon Spring employees have not been located, plausibly because there was no measured neutron dose.

5.2.3 Incidents

ATTRIBUTION: Section 5.2.3 was completed by Lori Arent, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

NIOSH did not identify any documented accidents at the Weldon Spring Plant site that resulted in exceptionally high personnel exposure levels (such as a criticality event). Interviews conducted with former site employees discussed several anecdotal radiological or contamination events, but none of the people interviewed reported that the events resulted in exceptionally high exposures (Personal Communication, 2009a; Personal Communication, 2009b; Personal Communication, 2009c; Personal Communication, 2009e; Personal Communication, 2009f; Personal Communication, 2009h).

The Health and Safety Division maintained annual logbooks of forms and memos 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 5-10 are included to demonstrate Weldon Spring's management of and response to high bioassay results (Weldon, 1960;

Weldon, 1961; Weldon, 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, 1962; MCW, 1960).

Table 5-10: 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: • Action Level 1 Monday 0.030 to 0.100 mg/l • Action Level 1 Friday 0.060 to 0.100 mg/l • Action Level 2 0.100 to 0.200 mg/l • Action Level 3 0.200 to 0.300 mg/l • Action Level 4 >0.300 mg/l
7357	Urinary Uranium Data for Week	Weekly summary of the Monday/Friday average urinary uranium concentrations by location, number of operators participating, percent of employees sampled with results less than the action level, and the names of the "peak men" (highest exposed employees).
7463	Urinary Uranium	Weekly summary of the Monday/Friday samples by cost center, concentration ranges, number of employees in each range, names of employees above the Monday or Friday limits (>0.030 or 0.060 mg/l respectively), and the number of scheduled and reporting employees.

Sources: Weldon, 1960; Weldon, 1961; Weldon, 1962-1965; MCW, 1960; MCW, 1962

6.0 Summary of Available Monitoring Data for the Class Evaluated by NIOSH

The following subsections provide an overview of the state of the available internal and external monitoring data for the Weldon Spring Plant class under evaluation.

6.1 Available Weldon Spring Plant Internal Monitoring Data

ATTRIBUTION: Section 6.1 and its related subsections were completed by Lori Arent and Billy P. Smith, M.H. Chew and Associates, Inc., and Monica Harrison-Maples, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

Details regarding the various analyses used and the associated minimum detectable activities are presented in the Technical Basis Document for the Weldon Spring Plant-Occupational Internal Dose (ORAU-TKBS-0028-5). A summary of the available internal data applicable to this evaluation is presented below.

6.1.1 Uranium Urinalysis Monitoring Data

The ORAU Center for Epidemiological Research (CER) database contains nearly 30,000 uranium urinalysis records collected during the period from 1957 through 1966 for approximately 1,800 employees. Data fields include the employee social security number, name, clock number, sample data, department/job/area, and results in units of mg/l (CER Data, 2009).

ORAUT-TKBS-0028-5 contains a table of composite uranium urine data for routine monitoring during the years 1958 through 1966, with the median, 95th percentile, maximum concentration results, and the number of records for each year. There are also tables for each individual year where the data are summarized by cost center. These tables were created from the records in the CER database.

Table 6-1 shows the urinary uranium and thorium count data found in the SRDB documents. The table shows (identified by an X in the appropriate row and column) the months and years in which raw data and/or quarterly and annual summary data are available.

Table 6-1: Urinary Uranium and Thorium Count Data in the SRDB Documents
Table 6-1 and its corresponding notes span two pages.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Data Description	SRDB Sources
1957				X	X	X	X	X	X	X	X	X	Raw urinary uranium results by individual name	9213[a]
1958	X	X	X	X				X	X	X	X	X	Raw urinary uranium results by individual name	9213[a] 15634[b]
1959	X	X	X	X	X	X	X	X	X	X	X	X	Raw urinary uranium results by individual name (Jan-Apr) Quarterly average urinary uranium results by name/clock no. Yearly average urinary uranium summary table	15634[b] 15898[c] 15907[d]
1960	X	X	X	X	X	X	X	X	X	X	X	X	High urinary uranium log (names and results) Quarterly average urinary uranium results by name/clock no. Quarterly & annual average urinary uranium summary tables	15874[e] 15898[c] 13763[d] 15901[d]
1961	X	X	X	X	X	X	X	X	X	X	X	X	High urinary uranium log (names & results) (Jul-Dec) Quarterly average urinary uranium results by name/clock no. Quarterly & annual average urinary uranium summary tables	15865[e] 15898[c] 13735[d] 13736[d] 13745[d] 13752[d]

Table 6-1: Urinary Uranium and Thorium Count Data in the SRDB Documents *Table 6-1 and its corresponding notes span two pages.*														
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Data Description**	**SRDB Sources**
1962	X	X	X	X	X	X	X	X	X	X	X	X	High urinary uranium log (names & results) (Jul-Dec) Quarterly average urinary uranium results by name/clock no. Quarterly average urinary uranium summary tables	15890[f] 15898[c] 13732[d]
1963	X	X	X	X	X	X	X	X	X	X	X	X	High urinary uranium log (names & results) Quarterly average urinary uranium by group no. (no names)	15890[f] 15866[g]
1964	X	X	X	X	X	X	X	X	X	X	X	X	High urinary uranium log (names & results)	15890[f]
1965	X	X	X	X	X	X	X	X	X	X	X	X	List of employees providing urine samples for uranium & dates (no data) Monthly average urinary uranium by group no. (no names)	15890[f] 15914[g]
1966							X						Chest count summary results for thorium	12400[h]

Notes:

[a] USAEC NYOO Form NY-99 with plant name and mailing address, analyze for x in urine, sample no., sample type, date and hour of sample collection, sample description (typed employee name, plant & job), and results (handwritten). NOTE: some plant and job information appears to be for the Mallinckrodt Destrehan Street facility (St. Louis), but the address on the form is listed as Weldon Spring.

[b] Logbook with handwritten dates, names, and results organized alphabetically; clearly identifies St. Louis and Weldon Spring data.

[c] MCW Form 7184, computer printout with clock no., name, department, period, date, average urinary uranium results by quarter for Monday and Friday samples.

[d] Tables published in the Personnel and Environmental Monitoring Reports prepared quarterly and annually. Data include the number and names of employees with average urinary uranium concentrations above Monday and Friday action levels, as well as the percent of employees in each concentration range by cost center.

[e] Logbook for high urinary uranium results containing forms as described in Table 5-10.

[f] Logbook for high urinary uranium results containing forms as described in Table 5-10 for 1962-1964; “Urinary Uranium Collection Report” for 1965 with handwritten names and dates (no data).

[g] Computer printout with group no., no. of employees monitored, and average, high and low urinary uranium results by month or quarter.

[h] Based on a memo (Ingle, 1991) summarizing thorium chest counting results (no names; semi-quantitative results only).

Tables 6-2 and 6-3 include summaries of the average urinary uranium data that were readily available from the Mallinckrodt Chemical Works Uranium Division Personnel and Environmental Monitoring reports prepared quarterly and annually in the 1959-to-1963 timeframe.

Table 6-2: Personnel Quarterly and Annual Average Urinary Uranium Concentration Range Analysis—Monday Before Work Samples

		Average Urinary Uranium Concentration Number of Results by Concentration Range (mg/l)					
Year	**Period**	**0.000-0.009**	**0.010-0.019**	**0.020-0.029**	**>0.030**	**Total No. Personnel Monitored**	**SRDB Ref ID**
1958	Annual	-	-	-	10	-	15907
1959	Quarter 1	-	-	-	-	-	N/A
	Quarter 2	-	-	-	-	-	N/A
	Quarter 3	265	79	7	1	352	15907
	Quarter 4	494	91	16	5	606	15907
	Annual	-	-	-	1	-	15907
1960	Quarter 1	281	145	28	2	456	15901
	Quarter 2	214	234	31	5	484	15901
	Quarter 3	260	212	46	5	523	15901
	Quarter 4	166	218	46	2	432	13763
	Annual	481	466	43	0	990	13763
1961	Quarter 1	191	224	67	4	486	13752
	Quarter 2	241	183	28	4	456	13745
	Quarter 3	195	219	29	1	444	13736
	Quarter 4	237	162	13	0	412	15375
	Annual	434	454	41	0	929	16375
1962	Quarter 1	159	124	28	2	313	13732
	Quarter 2	379	274	34	3	690	13732
	Quarter 3	236	110	2	4	352	13732
	Quarter 4	-	-	-	-	-	N/A
	Annual	-	-	-	-	-	N/A
1963	Quarter 1	130	198	104	13	445	15866
	Quarter 2	163	196	107	11	477	15866
	Quarter 3	277	301	71	18	667	15866
	Quarter 4	86	215	124	16	441	15866
	Annual	-	-	-	-	-	N/A

Notes:

- indicates no data.

Table 6-3: Personnel Quarterly and Annual Average Urinary Uranium Concentration Range Analysis—Friday After Work Samples								
		Average Urinary Uranium Concentration Number of Results by Concentration Range (mg/l)						
Year	**Period**	**0.000-0.009**	**0.010-0.019**	**0.020-0.029**	**0.030-0.059**	**>0.060**	**Total No. Personnel Monitored**	**SRDB Ref ID**
1959	Annual	-	-	-	-	14	-	13735
1960	Quarter 1	56	61	25	44	11	197	13752
	Quarter 2	35	88	33	40	15	211	13745
	Quarter 3	42	61	54	58	12	227	13763
	Quarter 4	46	84	55	55	9	249	13763
	Annual	73	173	106	98	19	469	13763
1961	Quarter 1	25	50	70	65	6	216	13752
	Quarter 2	40	67	61	36	7	211	13745
	Quarter 3	44	67	60	30	2	203	13736
	Quarter 4	69	100	51	28	4	252	13735
	Annual	72	168	138	66	7	451	13735
1962	Quarter 1	18	38	21	36	2	115	13732
	Quarter 2	69	143	58	57	4	331	13732
	Quarter 3	31	70	24	19	4	148	13732
	Quarter 4	-	-	-	-	-	-	N/A
	Annual	-	-	-	-	-	-	N/A
1963	Quarter 1	53	116	53	56	9	287	15866
	Quarter 2	46	91	51	45	9	242	15866
	Quarter 3	80	114	42	58	7	301	15866
	Quarter 4	42	80	66	75	14	277	15866
	Annual	-	-	-	-	-	-	N/A

Notes:

- indicates no data.

Weldon Spring Plant Urinary Uranium Program procedures provide additional information on the bioassay program (MCW, 1960; MCW, 1962). Fluorometric urinalysis procedures used at the Weldon Spring Plant are also available to NIOSH (Weldon, unknown date-a; Weldon, unknown date-b).

6.1.2 Thorium *In Vivo* Chest Counting Data

From July 11 through July 27, 1966, Oak Ridge Y-12 personnel provided a portable whole-body counter for *in vivo* lung region measurements to evaluate the thorium lung burdens of employees at the Weldon Spring Plant site. A total of 200 measurements were collected for 148 employees. Twenty minute counts were made in a shielded geometry using a 9-inch sodium iodide crystal adjacent to the workers back while the worker was in a supine position (Hibbs, 1966). According to a knowledgeable health physicist, the most exposed individuals were highly likely to be included in the population of monitored individuals and were much more likely to be counted than workers who were less exposed (Personal Communication, 2009h). The individual results were summarized without identifying information in a memo (Ingle, 1991) as negative, trace, or positive with the following interpretation:

- Negative: Net counts less than 60 counts per 20 minutes had less than the detectable amounts of thorium in their lungs.

- Trace: Net counts in more than 60, but less than 204 counts per 20 minutes.
- Positive: Net counts in excess of 204 counts for 20 minutes. A person who showed 204 counts for 20 minutes was considered to have at least one lung burden.

The overall results showed that workers involved in principal exposure positions in Plants 101 (Sampling), 103 (Digestion, Denitration, Packaging), 301 (Metals), and 403 (Chemical Pilot), and the Maintenance and Health and Safety personnel had a more frequent occurrence of “trace” detections. No workers monitored during this period had a “positive” designation (Ingle, 1991), and consequently, the maximum observed count rate can be specified as 204 counts per minute in the thallium-208 region of interest (thallium-208 is a gamma emitter in the thorium-228 decay chain). Information regarding the Oak Ridge counting technique, calibration, interpretation, limit of sensitivity, and error details used at the Weldon Spring Plant are available to NIOSH. This information may assist in interpretation of the *in vivo* count data. The Weldon Spring calibration was based on the response to a “Remab” manikin loaded with a 42-mg thorium source in equilibrium, which was considered to be typical of the source to which employees might have been exposed. The result was a calibration factor of 8.2 net counts per 20 minutes per mg of thorium.

The ORAU CER database contains 148 *in vivo* individual lung-region counting results measured during July 1966. The 2.6 MeV-gamma from thallium-208, a daughter of thorium-228, was used in the evaluation of thorium burdens. Data fields include the employee name, pay status (wage or salary), job/area, sample data, and results in units of net counts per 20 minutes (CER Data, 2009). The information in the job/area field was evaluated to understand the kinds of workers who were evaluated with these *in vivo* measurements. Forty-five chemical operators were monitored, 19 of whom were associated with Building 103 where thorium denitration occurred. The other chemical operators were associated with Building 101 (3 employees), Building 201 (5), Building 301 (7), Building 403 (7), and Building 404 (4). Twenty-one foremen and supervisors were monitored. Other monitored job titles included: millwrights (10), pipefitters (9), technicians (9), riggers (7), chemists (6), yard operators (6), instrument mechanics (5), and machinists (4). The remaining monitored job titles accounted for no more than two people each; specific location data were not associated with these jobs.

6.1.3 Airborne Dust Studies

A summary of the Weldon Spring Plant dust studies for various production jobs from 1957 through 1966 was published (MCW, 1958-1966). The studies evaluated the Weldon Spring worker environment relative to airborne uranium and thorium dusts. Component task concentrations were time-weighted and integrated to give a daily weighted average (DWA) concentration for the job. Work group indices were obtained by weighting the daily averages for jobs by manpower distributions for each plant. This index was calculated to account for job rotations within each work group. Both breathing zone and general area air samples were collected and the samples were analyzed by direct alpha count with laboratory scintillation counters. For uranium, a counting delay of 24 hours was employed to permit decay of short half-lived daughters; the delay time for thorium counting was 100 hours. Tables 6-4 and 6-5 include the summary dust concentrations for uranium and thorium production jobs respectively. ORAUT-TKBS-0028-5 provides a summary of the dust study results and descriptions of the sampling protocols and calculations. In some instances the original air sample data that were used to calculate DWA values are available.

Table 6-4: Dust Concentrations for Uranium Production Jobs												
Plant Name & No.	**Materials**	**Work Group Title**	**No. of Job Titles**	**Daily Weighted Average (DWA) Index per Year for Workgroup (μg/m^3)**								
				1958	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**
Sampling 101	Uranium concentrates	Sampling & Repackaging	11	65	55	45	55	32	31	20	60	-
Digest/ Raffinate/ Acid 103-108	Uranium concentrates & scrap	Digest-Raffinate	4	17	7[a]	7	20[a]	-	11	8	7	-
Extraction 105	Uranium concentrate feeds	Extraction	5	4	-	3	-	5	-	2	2	-
Refinery Pot Room 103	Uranium trioxide & uranyl nitrate hexahydrate	Denitration (Pot Room)	4	117	42[a]	70	17[a,b]	22[c]	-	45[c]	16	-
Green Salt 201	Uranium trioxide to uranium tetrafluoride	Green Salt	8	40	37	37	53	53	16	16	22	-
Metals 301	Natural uranium as uranium tetrafluoride & U_3O_8	Dingot Reduction	11	-	37[a]	115	65	-	150	150[d]	78	50
Metals 301	Uranium	Metal-other than reduction	10	-	-	[e]	44	52	63	40	55	10[a]
Metals 301	Uranium metal-natural	Core Area	11	-	-	20	-	-	-	-	-	-
Chemical Pilot 403 & Scrap Plant	Uranium	Pilot/Scrap Plants	10	-	-	-	50[f]	-	50[f]	50[f]	50[f]	50[f]
Metal Plant 404	Uranium	Special Projects	4	-	-	-	-	-	320[a]	190[a]	[g]	-

Notes:

Source: Information used to create this table is from MCW, 1958-1966.

- indicates no data

[a] An index was not calculated; this is a DWA for one job title.

[b] Airline masks were specified for shaking bags in dust collectors during uranium trioxide packaging; if no allowance was made, the concentrations would range about 10 times this value.

[c] Airline masks were specified for shaking bags in dust collectors during uranium trioxide packaging; if no allowance was made, the concentrations would range about 10 times this value. Uranium trioxide packaging was one of three job titles that contributed to the index per year for the Denitration (Pot Room) work group title.

[d] Airline masks were used for dingot cleaning by sandblasting during dingot reduction; no allowance was made for the use of the respirator. Dingot cleaning by sandblasting one of six job titles that contributed to the index per year for the Denitration (Pot Room) work group title.

[e] An index was not calculated; this is a DWA for two job titles. For each of the two job titles, the individual DWA result was 13 ug/m^3.

[f] Overall average (not weighted).

[g] An index was not calculated; the individual DWAs for 3 job individual titles were 42, 72, and 92 μg/m^3.

Table 6-5: Dust Concentrations for Thorium Production Jobs
Table 6-5 and its associated notes span five pages.

Plant Name & No.	Materials	Work Group Title & Cost Center[a]	Job Title[b]	Time Period[c]	Workers/Day	Daily Weighted Average (DWA) Concentrations (alpha d/m/m^3)				Notes
						1963	1964	1965	1966	
Sampling 101	Extracted thorium-natural	Sampling 0402	Oven drying ThO_2 sol-pan transfer	Mar 1965	2	-	-	3	-	Test date: Mar 30, 1965. Five ovens operated on a 24-hour cycle at 400 lbs/oven. Experimental, intermittent operation.
			Oven drying ThO_2 sol-vacuum unload	Aug 1965	2	-	-	16	-	Test date: Aug 9, 1965. Experimental, intermittent operation.
			Repackaging ThO_2 feeds for digestion-drum dumping	Apr-Aug 1966	1	-	-	-	9	Total project operating time estimated at 1 week or 10 shifts intermittent operation.
			Repackaging ThO_2 feeds for digestion-hopper packaging	Apr-Aug 1966	1	-	-	-	12	Total project operating time estimated at 1 week or 10 shifts.
			Repackaging ThO_2 feeds for digestion-outgoing drum conveyor	Apr-Aug 1966	1	-	-	-	7	Total project operating time estimated at 1 week or 10 shifts (empty drums).
Refinery 103	Extracted & re-extracted thorium-232 & daughters	Digest-Raffinate 0501	Hopper feed & digestion	Apr-May 1966	3	-	-	-	6	Test date: Apr 22, 1966. One hopper (15,000 pounds) made 1 tank batch, 20,000 lbs/day product on first cycle; recycle is liquid feed.
			Raffinate treatment & disposal	May-Sep 1966	3	-	-	-	2	-
			Misc. digestion of drummed scrap-wet feed	May-Sep 1966	2	-	-	-	4	Test date: May 3, 1966. Material was damp to wet; floor sweepings were used as feed. Non-routine job.

Table 6-5: Dust Concentrations for Thorium Production Jobs

Table 6-5 and its associated notes span five pages.

Plant Name & No.	Materials	Work Group Title & Cost Center[a]	Job Title[b]	Time Period[c]	Workers/Day	Daily Weighted Average (DWA) Concentrations (alpha d/m/m^3)				Notes
						1963	1964	1965	1966	
Refinery Pot Room 103	Extracted thorium-natural	Pot Room 0502[d]	Pot denitration & sol drying-hand transfers	Nov-Dec 1963; May-Aug 1964	6	88	88	-	-	Test dates: Nov 1963 and May 1964. Airline masks used to enter pot sections.
			Pot denitration (crystals) & sol drying-vacuum unload	Aug-Dec 1964	6	-	60	-	-	Test samplings for vacuuming and packaging collected from Sep 1964 to Oct 1965. Airline masks prescribed for entrance into pot or packaging sections. Small crucibles packaged.
			Pot denitration (liquor) & sol drying-vacuum unload	Jan-Aug 1965	6	-	-	48	-	Airline masks prescribed for packaging and unloading; half-face dust respirators (Comfo) for misc. attending duties in pot sections. Small crucibles packaged.
			Sol drying (fluid bed sol)-vacuum unload	Aug 1965-Jan 1966; Jun-Sep 1966	6	-	-	38	38	Packaging in small crucibles (500 lbs). Comfo respirators prescribed in pot sections.
			Pot denitration-hand unload & bucket dump to sol tank	Oct-Nov 1965	6	-	-	144	-	Pot denitration used for special project and to maintain production at scheduled rate when fluid bed was down. Airline masks prescribed for dumping and scooping. Comfo respirators were used for vacuuming and packaging activities.
			ThO_2 repackaging-multi-purpose hood	Aug 1964	2	-	260	-	-	Short-term operation. Airline masks used in hood.
			DWA index for the Pot room work group	Apr 1964-Dec 1965	-	-	78	50	-	For Apr-Dec 1964, approximately 45% of the effort (manpower) was on thorium jobs. For 1965, approximately 50% of the effort was on thorium jobs. Results are yearly indices and represent DWAs for 3 job titles.

Table 6-5: Dust Concentrations for Thorium Production Jobs
Table 6-5 and its associated notes span five pages.

Plant Name & No.	Materials	Work Group Title & Cost Center[a]	Job Title[b]	Time Period[c]	Workers/Day	Daily Weighted Average (DWA) Concentrations (alpha d/m/m^3)				Notes
						1963	1964	1965	1966	
Extraction 105	Extracted thorium and thorium-232 daughters	Extraction	Pumper decanter, pulse column, strippers, and NOK (product liquor)	Jun-Sep 1966	9	-	-	-	2	-
Metals 301	Extracted thorium-natural	Metals-other than Reduction 0702	High-firing 1,000 lb crucibles at recast (furnace)	Nov-Dec 1963; May-Sep 1964	6	21	21	-	-	Test dates included Dec 1963, May 1964, and Oct 1964. Airline masks used for entrance into enclosure for thermocouple change and inspection; operation performed 7 days/week.
			TNT repackaging	Oct-Dec 1964	2	-	3	-	-	Test date: Oct 5, 1964. For part of this period, crushing was done externally by electric grabs and transferred to the refinery without repacking TNT.
			High-firing 500 lb crucibles in billet heaters	Sep 1964-Jan 1966; Jun-Sep 1966	3	-	11	11	11	Test date Nov 4, 1964. Four heaters were installed, each handling a 500-lb crucible on a 24-hourcycle.
			Repackaging ThO_2 in recast enclosure	Oct-Dec 1965; Jan 1966; Jun-Sep 1966	2	-	-	2060 (55)	55	The DWA result of 2,060 d/m/m^3 is for Oct 1965; airline masks and cover clothing were used inside the transfer enclosure which exhausted to the dust collector. Test dates: Sep 16, 1965 (experimental batch) and Sep 27, 1965- improvements were recommended. The DWA result of 55 d/m/m^3 is for Nov 1965 and later. Test dates: Feb 24, 1966 and Jul 14, 1966. Airline masks were used for all scooping operations.

Table 6-5: Dust Concentrations for Thorium Production Jobs
Table 6-5 and its associated notes span five pages.

Plant Name & No.	Materials	Work Group Title & Cost Center[a]	Job Title[b]	Time Period[c]	Workers/Day	Daily Weighted Average (DWA) Concentrations (alpha d/m/m^3)				Notes
						1963	1964	1965	1966	
			Kiln calcining of NLO sump cake	Apr-Jul 1966	3	-	-	-	20	Test dates: Apr 21, 1966; Jun 8-9, 1966. Comfo (MSA) dust respirators used on dumping platform and at packaging stations. Feed was normally wet, ranging from damp to a surface water layer.
			DWA index for the Metals (other than Reduction) work group	May 1964-Dec 1965	-	-	17	113	-	For 1964, approximately 50% of the (manpower) effort was on thorium jobs, but none (on thorium) during the first 4 months. For 1965, approximately 60% of effort was on thorium jobs. Results are yearly indices and represent DWAs for 2 to 3 job titles.
Scrap Plant 403	Extracted thorium-natural	Scrap Plant 0601[e]	TNT crystals-repackaging	Nov-Dec 1963; May-Sep 1964	6	15	15	-	-	Equivalent production rate of 1 ton of ThO_2/day.
			ThO_2 repackaging-from recast crucibles	Nov-Dec 1963; May-Sep 1964	6-8	290	290	-	-	After Sep 1964, smaller crucibles were used. Airline masks were used on all scooping operations; operations conducted inside multi-purpose walk-in hoods. Exhaust was filtered by auto-air-mat (paper rolls). Manpower for 1964 was variable (5 in May to 15 in Jul); normal manpower was 6 to 8. ThO_2 repackaging included screening, blending, and product packaging.
			ThO_2 repackaging-from billet heater crucibles	Sep 1964-Oct 1965	4	-	20	20	-	Test date: May 24, 1965. Airline masks used on all scooping operations. Shallow crucibles could be scooped with breathing zone more distant from the opening than with recast crucibles (lower concentrations observed). Long-handles scoops were used in the blender drum.

Table 6-5: Dust Concentrations for Thorium Production Jobs
Table 6-5 and its associated notes span five pages.

Plant Name & No.	Materials	Work Group Title & Cost Center[a]	Job Title[b]	Time Period[c]	Workers/Day	Daily Weighted Average (DWA) Concentrations (alpha d/m/m^3)				Notes
						1963	1964	1965	1966	
			Fluid bed denitration-product to drums	May-Jul 1965	6	-	-	44	-	Test date Jun 1965. Experimental use of NLO liquor during May.
			Fluid bed denitration-wet feed & product	Aug 1965-Jan 1966; Jun-Sep 1966	6	-	-	29	29	Liquor feed and sol product at 1 ton/day production rate.
			DWA index for Scrap Plant work group	Nov 1963-Dec 1965	-	180	117	28	-	The 1963 index was for a 6-man group (Nov-Dec) with 17% of manpower on thorium. The 1964 index was for a 6-man group with 60% of manpower on thorium. The 1965 index was for a 12-man group (Jan-Jun) and a 6-man group (Jul-Dec) with 80% of manpower on thorium. Results are yearly indices and represent DWAs for 2 to 3 job titles.

Notes:

Source: Information used to create this table is from MCW, 1958-1966.

- indicates no data

[a] "Cost Center" refers to an employer charge code. Cost center codes are published in some TBDs and can be used for identifying employee work areas.

[b] "Job Title" is the term used in the referenced report; this term more accurately represents a task description rather than an employee job title.

[c] "Time Period" was recorded from the air sampling data sheets and was estimated if date ranges were incomplete.

[d] Manpower in this group ranged from 18 to 21 men during the years 1963 through 1965; base production rate was 1 ton ThO_2/day.

[e] Average production rate was 1 ton ThO_2/day.

6.1.4 Environmental

Available occupational environmental monitoring data include summarized results of uranium air concentration measurements made at the site perimeter and two offsite locations from 1959 to 1965 (Meshkov, 1986) and general air sample results collected onsite during the cleaning of six 5-ton hoppers in 1960 (Holt, 1960a). Estimated average perimeter air concentrations and onsite air concentrations during the hopper cleanout are provided in ORAUT-TKBS-0028-4 for 1957 to 1967 for the chemical plant, quarry, and raffinate pit locations.

6.2 Available Weldon Spring Plant External Monitoring Data

ATTRIBUTION: Section 6.2 and its related subsections were completed by Billy P. Smith, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

External monitoring data available to NIOSH consist of film badge results representing the entire operational period under evaluation. NIOSH does not have access to area survey or monitoring records beyond what is described in Section 6.1.3 of this report, Airborne Dust Studies.

Details regarding the various analyses used and the associated minimum detectable activities are presented in the Technical Basis Document for the Weldon Spring Plant in ORAUT-TKBS-0028-6. A summary of the available external data applicable to this evaluation is presented below.

6.2.1 Film Badges

NIOSH has access to the ORAU CER database which contains nearly 8,000 film badge records collected from 1957 to 1967 for approximately 1,850 employees. Data fields include the employee's last name, social security number, date, beta results (i.e., mrem), gamma results (i.e., mrem), total records (identified as TORECS), the number of weeks that the reported doses did not exceed the administrative limits (identified as OKGAMWKS), and the number of weeks the individual was monitored during the year (identified as MONWKS) (CER Data, 2009).

Table 6-6 in ORAUT-TKBS-0028-6 summarizes several different formats in which health personnel recorded external dosimetry information for the Weldon Spring Plant site. Many of the dosimetry reports did not specify the reporting units, but a June 16, 1956, memorandum from K. E. Brandner to J. W. Miller details the change from roentgen and rep to rad for both gamma and beta radiation (ORAUT-TKBS-0028-6). The memorandum specifies that, beginning June 18, 1956, units for both gamma and beta radiation “should be standardized to the ‘rad’ unit.” Table 6-6 of ORAUT-TKBS-0028-6 includes descriptions of personal monitoring summary records and reports, descriptions of how the result quantities are noted in the reports, and NIOSH’s interpretation of zeros and blanks in the monitored exposure results.

Tables 6-6 and 6-7 provide the annual average gamma and beta dose (mR) by job category from 1957 through 1966.

Table 6-6: Average Annual Gamma Exposure (mR) by Job Category

Job Category	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Engineer	110	102	43	121	83	75	94	244	170	94
Equipment Operator	135	-	135	168	154	151	176	177	164	278
Foreman	233	85	150	183	190	186	154	130	192	102
Laboratory Worker	220	89	71	71	134	175	204	285	575	155
Manager	52	-	37	517	102	41	142	112	78	64
Non-Radiation Job	125	-	48	96	105	72	93	226	181	33
Operator	305	129	151	234	369	371	640	516	413	298
Safety, Security	168	75	265	59	65	83	415	273	119	183
Unknown	411	48	85	141	170	223	184	294	292	248
Worker	240	132	67	142	140	216	317	303	198	177

Table 6-7: Average Annual Beta Exposure (mR) by Job Category

Job Category	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Engineer	228	23	191	579	486	572	277	308	186	90
Equipment Operator	190	1	878	1170	710	788	283	279	514	190
Foreman	328	45	492	1293	804	919	1336	735	637	257
Laboratory Worker	382	133	343	463	796	724	367	327	340	278
Manager	107	35	199	1160	1099	403	204	128	91	181
Non-Radiation Job	248	135	123	378	538	204	224	243	142	50
Operator	761	274	1122	2642	2695	1648	1309	1018	884	297
Safety, Security	198	60	94	170	301	463	107	98	197	91
Unknown	524	128	297	890	1427	1146	338	401	453	205
Worker	697	93	472	923	1070	1107	780	354	473	317

6.2.2 Medical

NIOSH has access to the ORAU CER database which contains over 9,900 medical diagnostic X-ray records for approximately 2570 employees collected during the period 1957 to 1967. Data fields include the employee name, date, number of X-rays, area of X-ray (e.g., chest PA LL, thumb), age, race, sex, "origin" or type of X-ray (e.g., pre-employment, routine, termination, special, re-exam), and diagnosis (e.g., yes/no) (CER Data, 2009).

Table 3-4 in ORAUT-TKBS-0028-3 shows the organ dose estimates for chest X-rays (rem) for the period of pre-1970**.**

6.2.3 Environmental

Table 4-12 in ORAUT-TKBS-0028-4 shows the estimated maximum site-wide ambient dose exposure to workers for years 1957-1967.

7.0 Feasibility of Dose Reconstruction for the Class Evaluated by NIOSH

The feasibility determination for the class of employees under evaluation in this report is governed by both EEOICPA and 42 C.F.R. § 83.13(c)(1). Under that Act and rule, NIOSH must establish whether or not it has access to sufficient information either to estimate the maximum radiation dose for every type of cancer for which radiation doses are reconstructed that could have been incurred under plausible circumstances by any member of the class, or to estimate the radiation doses to members of the class more precisely than a maximum dose estimate. If NIOSH has access to sufficient information for either case, NIOSH would then determine that it would be feasible to conduct dose reconstructions.

In determining feasibility, NIOSH begins by evaluating whether current or completed NIOSH dose reconstructions demonstrate the feasibility of estimating with sufficient accuracy the potential radiation exposures of the class. If the conclusion is one of infeasibility, NIOSH systematically evaluates the sufficiency of different types of monitoring data, process and source or source term data, which together or individually might ensure that NIOSH can estimate either the maximum doses that members of the class might have incurred, or more precise quantities that reflect the variability of exposures experienced by groups or individual members of the class. This approach is discussed in DCAS's SEC Petition Evaluation Internal Procedures which are available at http://www.cdc.gov/niosh/ocas. The next four major subsections of this Evaluation Report examine:

- The sufficiency and reliability of the available data. (Section 7.1)
- The feasibility of reconstructing internal radiation doses. (Section 7.2)
- The feasibility of reconstructing external radiation doses. (Section 7.3)
- The bases for petition SEC-00143 as submitted by the petitioner. (Section 7.4)

7.1 Pedigree of Weldon Spring Plant Data

This subsection answers questions that need to be asked before performing a feasibility evaluation. Data Pedigree addresses the background, history, and origin of the data. It requires looking at site methodologies that may have changed over time; primary versus secondary data sources and whether they match; and whether data are internally consistent. All these issues form the bedrock of the researcher's confidence and later conclusions about the data's quality, credibility, reliability, representativeness, and sufficiency for determining the feasibility of dose reconstruction. The feasibility evaluation presupposes that data pedigree issues have been settled.

7.1.1 Internal Monitoring Data Pedigree Review

ATTRIBUTION: Section 7.1.1 was completed by Lori Arent and Robert Morris, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

Uranium in Urine Data

The ORAU CER obtained electronic files along with hardcopy records of uranium in urine results from a prior epidemiology effort headed by Dr. T. F. Mancuso. In December 1979, the data were subjected to a 10% sampling validation prior to being accepted for use by CER (MCW, 1979). Data from the CER database were extracted into a Microsoft Access table (CER Data, 2009) and the CER data were compared to the applicable hardcopy records in the SRDB.

For the period from 1957 through 1959, raw urinary uranium results are available to NIOSH as hardcopy documents located in the SRDB. A statistical evaluation was conducted to determine the number of the SRDB results that were successfully captured in the CER database. Five percent of the available hardcopy urinalysis results were compared with the entries in the CER database and the results of the evaluation are presented in Table 7-1.

Table 7-1: Statistical Evaluation of CER Database and SRDB Results for Urinary Uranium, 1957-1959

Year	Evaluation Periods Covered in SRDB Documents	No. of SRDB Results[a]	No. of SRDB Results[a] Matched in CER Database	SRDB Results[a] Captured in CER Database (%)	No. of Errors found in CER Database[b]	SRDB Ref ID
1957	Apr-Jul	56	34	61%	4	9213
1958	Jan-Apr; Aug-Dec	49	44	90%	0	9213; 15634
1959	Jan-Apr	31	29	94%	1	15634

Notes:

Sources: Weldon, 1957-1958; Weldon, 1958-1959

[a] The number and percent of SRDB results refer to individual urinalysis.

[b] Errors include minor date (several days) or result (hundredths or less of a decimal place) discrepancies and do not affect dose reconstruction outcomes.

For the period from 1960 through 1964, NIOSH has access to hardcopy documents (located in the SRDB), including logbooks of high urinary uranium results reported on MCW Forms 7273, 7274, and 7463; descriptions of these forms are included in Table 5-10. All of the available SRDB results were compared with the CER database results and the findings of this evaluation are presented below in Table 7-2.

Table 7-2: Statistical Evaluation of CER Database and SRDB Results for Urinary Uranium, 1960-1964						
Year	**Evaluation Periods Covered in SRDB Documents**	**No. of SRDB Results[a]**	**No. of SRDB Results[a] Matched in CER Database**	**SRDB Results[a] Captured in CER Database (%)**	**No. of Errors found in CER Database[b]**	**SRDB Ref ID**
1960	Jan-Dec	407	165	41%	3	15874
1961	Jan-Dec	162	76	47%	0	15865
1962	Jan-Dec	79	44	56%	7	15890
1963	Jan-Dec	101	100	99%	1	15890
1964	Jan-Aug	78	78	100%	1	15890

Notes:

Sources: Weldon, 1960; Weldon, 1961; Weldon, 1962-1965

[a] The number and percent of SRDB results refer to individual urinalysis.

[b] Errors include minor date (several days) or result (hundredths or less of a decimal place) discrepancies and do not affect dose reconstruction outcomes.

While there are nearly 2,900 urinalysis results in the CER database for 1965 and over 2,100 results for 1966, NIOSH does not have hardcopy results for 1965-1966. NIOSH does have the 1965 urinary uranium collection report with handwritten names and dates, which implies that samples were collected; however, NIOSH is not sure this is a one-to-one correlation (i.e., the name/date of collection corresponding to an individual sample result). In addition, there are checkmarks and dates crossed out that make the collection reports difficult to interpret (Weldon, 1962-1965). The CER database does not include any results for 1967, nor does NIOSH have hardcopy urinalysis data for this year.

As demonstrated in Tables 7-1 and 7-2, the Microsoft Access table (which contains data extracted from the CER database) appears to be a faithful reproduction of the uranium in urine sample results for 1958 and 1959, as well as for January 1963 through August 1964.

For 1957, 61% of the hardcopy records were represented in the CER database. NIOSH has access to various handwritten logs of bioassay urine processing results on New York Atomic Energy Commission Form NY-99 (Weldon, 1957-1958), but it is difficult to determine if the results are for Weldon Spring Plant workers during the period when both the Mallinckrodt Destrehan Street Facility (St. Louis) and Weldon Spring Plant were operating. For example, some records with a Weldon Spring mailing address have St. Louis job titles/locations (e.g., Plant 6). There are many results that have a generic job title (e.g., office, operator, etc.) that could be assigned to either location. There are also results for AEC employees and possibly for United Nuclear Corporation workers from the Hematite Plant (concurrent operations). Because of these uncertainties, NIOSH did not include these data with the CER data.

For the period from 1960 through 1962, the data in the Microsoft Access tables appear to be accurate but are incomplete, including less than half of the uranium in urine sample results that were recognized contemporarily as being elevated and worthy of management attention. NIOSH has extracted the Microsoft Access data into an Excel spreadsheet and has added the missing elevated urinary uranium data. The number of urinary uranium results, both originally in the CER database and those added from other documentation, and the number of individuals represented in the CER database by year are shown in Table 7-3.

Table 7-3. Numbers of Urinary Uranium Results and Individuals Represented in the CER Database				
Year	**No. of Results in Original CER Database**	**No. of SRDB Results Added to CER Database**	**New Total No. of Results in CER Database**	**No. of Workers Represented in CER Database[a]**
1957	1,038	0	1,038	815
1958	1,872	0	1,872	1,207
1959	2,284	14	2,298	1,053
1960	4,396	242	4,638	1,019
1961	4,184	86	4,270	945
1962	3,083	36	3,119	811
1963	3,481	0	3,481	664
1964	3,476	0	3,476	636
1965	2,980	0	2,980	604
1966	2,128	0	2,128	511
Total	**28,926**	**378[b]**	**29,304**	**1,890[c]**

Notes:

Source: CER Data, 2009

[a] Includes number of workers for SRDB hardcopy results added by NIOSH.

[b] Of the 378 results added, 331 (88%) were equal to or above the lower limit of Action Level 1 (i.e., 0.03 mg/l) and 47 (12%) were below this level; the results lower than Action Level 1 were typically follow-up samples on dates -after a recorded high result. A total of 116 results were listed as Action Level 1 through Action Level 4 (i.e., no numerical result); these results were added to the CER database at the upper bound of the stated action level range. [Example: "Action Level 1" with a range up to 0.1 mg/l was entered as < 0.1 mg/l in the CER database.] Action Level ranges are described in Table 5-10.

[c] This value is the number of individual names represented in the CER database, including the data added by NIOSH. This is not a sum of the number of workers for each year. An individual worker routinely has results for multiple years.

For 1965, there are 2,980 results in the CER database representing 604 individuals. For 1966, there are 2,128 results representing 511 individuals (Table 7-3). Taking the decreased production rates into account, the numbers of sample results and workers represented in 1965 and 1966 appear reasonable when compared with previous years. Although hard-copy data for these years have not been discovered, NIOSH believes it is reasonable to assume the CER data are complete and accurate for 1965 and 1966.

According to a health physicist who was recently interviewed by NIOSH, the most highly exposed workers were always captured in the bioassay program. Any high uranium-in-urine sample was promptly re-sampled using 24-hour catches. Follow-up medical monitoring of individuals with elevated results was overseen by the assigned physician (Personal Communication, 2009h).

There are over 29,000 urinary uranium results available for 1,890 individuals during the 1957 through 1966 timeframe. More than 330 "high-biased" results (i.e., results that were above the reporting threshold) were added following the data capture and review efforts. The few errors noted in the CER database as compared to the hardcopy records were minor date or result discrepancies. In summary, NIOSH believes the CER database is of sufficient quality to use to bound internal doses for Weldon Spring Plant employees.

Thorium Whole-Body/Chest Count Data

The thorium *in vivo* counting data described in Section 6.1.2 are available in a spreadsheet derived from CER data. Unlike the hardcopy summary report (Ingle, 1991), the spreadsheet contains individually identifiable data. The number of individuals and the total number of analyses in the spreadsheet match the hardcopy summary information. The spreadsheet data are entirely consistent with the data summarized in the hardcopy report.

7.1.2 External Monitoring Data Pedigree Review

ATTRIBUTION: Section 7.1.2 was completed by Monica Harrison-Maples, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

As discussed in Section 6.2.1 of this report, NIOSH has access to film badge records for approximately 1,850 employees over the evaluated period.

There are documented reports of the practice of nearly universal external monitoring using film badges (Mason, 1955, p. 21), with confirmatory accounts from former Weldon Spring workers stating that workers (other than female administrative workers) were required to wear a combination film badge/security badge (Personal Communication, 2009b; Personal Communication, 2009e; Personal Communication, 2009f).

In summary, the available external dosimetry monitoring data are available in sufficient quantity and quality to adequately represent external beta and photon dose for the Weldon Spring Plant class under evaluation for the period from January 1, 1957 through December 31, 1967. NIOSH did not identify any neutron dosimetry data; therefore, a pedigree review of neutron external dosimetry data was not possible.

7.2 Evaluation of Bounding Internal Radiation Doses at Weldon Spring Plant

The principal source of internal radiation doses for members of the class under evaluation was inhalation of particulate radiological materials during routine operations, initial cleanup, and maintenance periods. Ingestion is routinely assessed by NIOSH concurrently with inhalation exposure. The following subsections address the ability to bound internal doses, methods for bounding doses, and the feasibility of internal dose reconstruction.

7.2.1 Evaluation of Bounding Process-Related Internal Doses

The following subsections summarize the extent and limitations of information available for reconstructing the process-related internal doses of members of the class under evaluation.

7.2.1.1 Urinalysis Information and Available Data

ATTRIBUTION: Section 7.2.1.1 was completed by Robert Morris and Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

Uranium

Urine bioassay was the primary method of determining uranium intakes during the operational period. The bioassay program was set up in accordance with the general health physics practices of the period. Grab (single-void) urine samples were collected and analyzed for uranium by photofluorimetric analysis. Results of the photofluorimetric analysis were reported as the mass of uranium in milligrams, or sometimes micrograms, per liter of urine (ORAUT-TKBS-0028-5).

From 1957 to mid-May 1959, urine sampling was conducted at random times during the week. From mid-May 1959 through September 1959, sampling occurred primarily on Fridays. Starting in October 1959, the routine sampling program was changed to a workgroup monitoring program and continued through 1966. Under this program, one or more persons from each operational group in the plant were sampled each week. The selected individuals were asked to submit samples on Monday morning, Friday after work, and the following Monday morning. The sample from each person was added to their individual summary. Each exposed person was scheduled three or more times per year. Unexposed persons were scheduled less frequently. Workers also submitted urine samples as part of the hiring and termination processes. A repeat sample was required if the result of the Monday morning sample was greater than 100 µg/L or if the result of the Friday afternoon sample was greater than 200 µg/L. Special urine samples were required for known or suspected significant intakes (MCW, 1965; ORAUT-TKBS-0028-5).

Details on the reporting levels, minimum detectable amounts, and uncertainties are available to NIOSH (MCW, 1965; ORAUT- TKBS-0028-5). Many Weldon Spring Plant workers were assigned to the St. Louis facility before being assigned to Weldon Spring. All of the urine data reports contain data from both facilities. When no other specific information is available, it is reasonable to assume that Weldon Spring/Mallinckrodt Chemical Works uranium urine data starting in 1957 is associated with Weldon Spring Plant**.**

Data summaries covering most of the operational period have been discovered. In addition, NIOSH has located approximately 28,000 urine bioassay results for the operational period (See Section 6.0). Tables 5-8 through 5-17 of ORAUT-TKBS-0028-5 provide median, 95th-percentile, and maximum concentrations for routine urine bioassay samples by year. These data are adequate to support bounding the dose from uranium intakes because the program was specifically designed so that workers not sampled in a given period would be represented by the workgroup sample.

7.2.1.2 Airborne Levels

ATTRIBUTION: Section 7.2.1.2 was completed by Robert Morris and Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

Whereas the matter of uranium intake bounding is addressed above in Section 7.2.1.1, no further discussion of uranium airborne levels will be provided. Uranium airborne data are available as detailed in Section 6.1.3 and specifically in Table 6-4 for use on a case-by-case basis if applicable.

Thorium airborne dust concentrations were routinely measured and evaluated throughout the operating period. These data, in the form of DWA concentrations, were summarized for the thorium processing period of 1963 through 1966 (MCW, 1958-1966) and are reproduced in Table 6-5. Reduction in actual intake rate due to use of respiratory protection is not incorporated in the calculation of DWA. Thorium airborne dust levels are of particular interest because no thorium bioassay method was available until the mobile *in vivo* counter became available for a one-time use in 1966. When combined with the methods and assumptions described in *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium* (Battelle-TBD-6001) and *Default*

Assumptions and Methods for Atomic Weapons Employer Dose Reconstruction (Battelle-TIB-5000), the DWA thorium data can be used to define bounding thorium intake rates, as discussed in Section 7.2.3.

7.2.2 Evaluation of Bounding Ambient Environmental Internal Doses

ATTRIBUTION: Section 7.2.2 was completed by Robert Morris and Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

An evaluation of the ambient environmental internal radiation doses from releases of particulates/aerosols of uranium, the associated recycled uranium contaminants, and decay products (e.g., thorium-230) is not necessary because the most highly exposed plant employees were monitored by routine uranium bioassay sampling, either individually or as members of a workgroup. Thus, these doses are accounted for in the process-related internal dose evaluations.

In the few years that thorium-232 was processed, operational area dust measurements (see Section 6.1.3 of this evaluation report) are available. Two hundred whole-body count measurements for thorium were also collected for 148 employees, with a good cross section of Weldon Spring Plant workers being represented (see Section 6.1.2 of this evaluation report). Thus, thorium can also be accounted for in the assignment of process-related dose.

Measured air concentrations of radon are not available for the operational period. However, the maximum occupational ambient environmental exposure for radon may be calculated using the method in ORAUT-TKBS-0028-4. The estimate of radon releases based on throughput, mainly from the acid recovery plant, is between 12 and 34 Ci/year (see Section 5.2.1.5). The screening model in the National Council of Radiation Protection and Measurements (NCRP) Report No. 123 (NCRP, 1996) was used to perform the calculations. Default parameters were used with the exception of 4.2 m/s for wind speed (Weidner, 1982) and 10 m for stack height (estimated). The concentration at the receptor (within 100 m of the acid recovery plant), corresponding to a release of 34 Ci/year, was rounded to 80 Bq/m^3. ORAUT-TKBS-0028-4 added 11 Bq/m^3 to this value, since the concentration including background was desired. (Background is omitted in this analysis. Using a 2,000-hour/year occupational exposure period and an outdoor environmental radon daughter equilibrium factor of 30%, which is the upper limit of measured factors for the Weldon Spring Plant (MK-Ferguson, 2001), the result is 0.076 working-level month (WLM)/year. This value is the maximum occupational ambient environmental exposure for radon for the entire operational period.

7.2.3 Methods for Bounding Internal Dose at Weldon Spring Plant

The following subsections summarize the methods for bounding internal dose at the Weldon Spring Plant.

7.2.3.1 Methods for Bounding Operational Period Internal Dose

ATTRIBUTION: Section 7.2.3.1 was completed by Robert Morris, Eugene W. Potter, and Bryce L. Rich, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

Uranium, Uranium Decay Products, and Recycled Uranium Contaminants

The Weldon Spring Plant's urine bioassay monitoring program for uranium was extensive. The urine bioassay data are readily available to bound the dose to uranium isotopes for both monitored and unmonitored workers. Summary statistics have been published in ORAUT-TKBS-0028-5 in several tables that include the median, 95th percentile, and maximum result for each year of processing, as well as a breakdown of the results by year for each cost center (operational area). During this evaluation, a limited amount of additional data was found in hardcopy records and has been hand-entered into the NIOSH database. The analysis in Section 7.1.1 indicates that the additional data has a negligible impact on the statistics of the dataset.

As discussed in ORAUT-TKBS-0028-5, prior to 1961, doses are bounded by assuming that all uranium processed contained natural uranium isotopic abundances. Between 1961 and 1962, doses are bounded by assuming that all uranium processed was recycled natural uranium. From 1963 to 1967, doses are bounded by assuming that all uranium processed was enriched (1%) recycled uranium, even though the overwhelming majority of uranium processed remained as natural uranium (98.4%). Although the contaminant concentrations in recycled uranium were not documented for Weldon Spring, there is evidence that nearly all slightly enriched uranium that was processed came from the Feed Materials Processing Center (Fernald) (DOE, 2000, Figure B.1-10) where the contaminant concentrations in recycled uranium were well documented. Using the conservative contaminant concentrations from Fernald (as cited in ORAUT-TKBS-0028-5) together with the assumption that all uranium processed after 1961 contained these contaminants bounds the dose from the recycled uranium contaminants.

As noted in Section 5.2.1.3, Table 5-6 contains maximum values for the recycled uranium contaminants as a fraction of uranium intake. For long-term workers, the exposures would certainly have been less than the maximum values listed in the table because the workers typically rotated jobs and often worked in various areas of the plant. The maximum values documented in Table 5-6 are high enough to bound shorter-term employment exposures with a proportionally higher recycled uranium contaminant exposure time.

The doses from uranium decay products are also bounded by using ratios from intakes determined by uranium bioassay. It should be noted that the thorium-230 intakes are determined from the maximum ratio of thorium-230 to uranium and that ore concentrate processing is the only source of exposure to thorium-230 at Weldon Spring. Measurements of the activity concentrations in Raffinate Pits 1, 2, and 3 can be used to determine the relationship between thorium-230 and other impurities during the initial uranium processing in Building 101 before any separations occurred. The shorter-lived decay products for which no raffinate measurements were made (e.g., lead-210 and polonium-210) can be assumed to be present at the same activity as their radium-226 parent in the mill concentrate feeds. The other uranium streams (e.g., recycled uranium) had been previously processed and contained essentially no thorium. Table 7-4 gives the results of a statistical analysis of raffinate pit measurements. The data were taken from the *1989 Waste Assessment Radiological Characterization of the Weldon Spring Site Raffinate Pits* (MK-Ferguson, 1989).

Table 7-4: Activity Ratios of Uranium Decay Products and Other Impurities to Thorium-230 Activity in Weldon Spring Raffinate Pits						
	Pits 1 and 2		Pit 3		Pit 4	
Isotope	**Mean**	**95% UCL**	**Mean**	**95% UCL**	**Mean**	**95% UCL**
Ra-226	0.028	0.060	0.019	0.041	0.029	0.099
Ra-228	0.0033	0.0071	0.0038	0.0092	0.090	0.38
Th-228	0.0028	0.0062	0.0054	0.012	0.12	0.45
Th-232[a]	0.0043	0.0095	0.0083	0.018	0.13	0.49

Notes:

[a] Measurements of thorium-232 in Raffinate Pits 1, 2, and 3 were not used due to alpha peak interference from thorium-230 (MK-Ferguson, 1989). Thorium-232 was calculated assuming that thorium-228 was in 65% equilibrium, except for Pit 4 where reliable measurements were available.

The mean values in Table 7-4 represent the amount of each isotope that as a fraction of thorium-230 an employee would have been exposed to over the long term. It is unlikely that any employee would have been continuously exposed to fractions greater than the 95% of the upper confidence limits; therefore, the 95% upper confidence limits of the ratios to thorium-230 in Table 7-4 can be used to bound the intakes from the other potentially important radionuclides. The data for Pit 4 were not used

Table 7-5: Intakes of Uranium Decay Products and Other Impurities Based on Raffinate Pit Measurements			
Isotope	**Intakes based on Pits 1 and 2 (nCi/mg-U)**	**Intakes based on Pit 3 (nCi/mg-U)**	**Bounding Intakes (nCi/mg-U)[a]**
Pb-210[b]	0.020	0.014	0.020
Po-210[b]	0.020	0.014	0.020
Ra-226	0.020	0.014	0.020
Ra-228	0.0024	0.0031	0.0031
Th-228	0.0021	0.0040	0.0040
Th-230	0.34	0.34	0.34
Th-232	0.0032	0.0061	0.0061

in this analysis since natural thorium wastes were deposited there. The results are shown in Table 7-5.

Notes:

[a] Indicates the higher value of intakes based on Pits 1 & 2 (Column 2) and intakes based on Pit 3 (Column 3).

[b] Measurements not available; assumed to be equal to the intake of radium-226.

Thorium

Thorium intake rates will be based on DWA air sample concentration measurements of thorium dust taken during thorium processing operations; these data are summarized in Table 6-5. Although *in vivo* chest count data for thorium may be useful for individual dose reconstructions, these data are not useful for bounding exposures for the evaluated class because the measurements represent only one point in time, near the end of the multi-year thorium processing campaign. The bounding intake rate method based on DWE takes no credit for use of air-purifying or air-supplied respiratory protection equipment.

The air sample data used in the DWA analysis were counted after an appropriate delay to eliminate the short-lived radon-220 and radon-222 progeny interference with the measurement. The measured alpha air concentration will be assumed to be associated only with thorium-232 and thorium-228, which are the isotopes found in thorium processed at the Weldon Spring Plant site. No uranium is assumed to have been present in the thorium work area. The actual equilibrium between the thorium isotopes and their progeny is unknown and changes with time after chemical purification. The isotopic assumptions in Section 5.6.1.2 of ORAUT-TKBS-0028-5 are reasonable and will contribute to a bounding evaluation. Therefore, the measured alpha activity will be partitioned in a 1-to-1 ratio of thorium-232 to thorium-228. In addition, radium-228, which is a beta emitter that would not have been detected in the gross alpha count, will be added in a 1-to-2 ratio of thorium-232 to radium-228.

Intake rates will be reported in units of activity per day for use in a chronic exposure scenario. This chronic scenario assumes an exposure of 24 hours per day, 365 days per year. For inhalation, the intake rate will be based on the product of DWA, breathing rate (1.2 m^3 per hour), and number of working hours per year. For ingestion, the intake rate will be based on the guidance in the document, *Estimation of Ingestion Intakes* (OCAS-TIB-009). Normalization to adjust the number of work hours per year to conform to the 24 hours per day, 365 days per year exposure scenario will be performed in both cases.

Uncertainty in the DWA will be computed in accordance with Section 3.8 of Battelle-TIB-5000, which provides an approach for estimating overall uncertainty when only summaries of the time-weighted average data are available. The uncertainty is evaluated by fitting lognormal distributions to the data for each job title and performing a Monte Carlo simulation. The method described in Section 2.1.2.2 of Battelle-TIB-5000 may be used to determine the lognormal parameters for each task used in the simulation based on the minimum, maximum, mean, and number of observations. Furthermore, the parameters in Table 3.9 of Battelle-TIB-5000 will be incorporated in the simulation to account for the lack of representativeness of air samples. When the actual location of a worker is not known, the maximum measured DWA for that period of time and full-time occupancy during the work day will be assumed.

Radon

Conservative estimates of the amount of radon released based on the amount of uranium processed during the operational period were discussed in Section 7.2.2. Operations at the acid recovery plant, the main radon release point, were carried out in large hoods. Therefore, the radon would have been released into the outside air. Assuming that the outside air could have been drawn back into the building and that the indoor equilibrium factor was 0.5, rather than the 0.3 used for outdoors in Section 7.2.2, the estimated maximum intake is 1.3 WLM/year for 100% occupancy for 2000 hrs/year.

Thoron

As described in Section 5.2.1.6, there are several aspects of the release and buildup of the daughter products that mitigate the exposure to thoron in process and storage configurations.

From November 1963 through September 1966, natural thorium was processed on an intermittent batch basis in the refinery and oxide production/firing systems at the Weldon Spring Plant; therefore NIOSH's evaluation of operational exposures to thoron at Weldon Spring is confined to those years. During 1966 (the maximum production year), the Weldon Spring Plant processed approximately 100,000 kg of thorium per month for six months, or up to 5,000 kg of thorium per day. Typical thorium processing at other facilities averaged < 1,000 kg of thorium per day; thus, NIOSH believes this to be a very conservative default level to assume for bounding thoron releases. NIOSH recognizes that the thorium processing was not continuous, but rather was operated more on a batch basis. Given the specific activity of thoron in thorium feed materials, and assuming the feed materials were received with at least a one-year delay since processing, it is possible to calculate the amount of thoron in process per day (approximately 0.3 Ci thoron) during the period of the maximum production rate. By assuming a conservative equilibrium factor for a plant configuration with large buildings and engineered ventilation (0.02), it is possible to determine the concentration of thoron and its daughters to achieve 1 WL. The release fraction (RF) can be calculated by measuring the particulate thorium in the working environment of the process equipment, compared to the inventory amounts in process. The thoron releases are expected to be less than the particulate materials, since the gaseous state will be more easily captured by the ventilation systems. Maximizing assumptions can be applied on a case-by-case basis to occupancy factors, release fractions, and diffusion rates.

Potential exposure to thoron is mitigated by several factors, as discussed in Section 5.2.1.6, including the very short half-life of thoron and the resulting limitations on the diffusion distance within the material matrix, and the effective shielding provided by the thorium processing apparatus. Thus, thoron is not a potential source of exposure to be broadly accounted for across the evaluated class of Weldon Spring workers. It is possible to bound the dose from the release of thoron and thoron daughters during processing activities and during storage of thorium materials at Weldon Spring during the three-year period of thorium operations, as applicable, on a case-by-case basis.

7.2.3.2 Methods for Bounding Ambient Environmental Internal Dose

ATTRIBUTION: Section 7.2.3.2 was completed by Robert Morris and Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

ORAUT-TKBS-0028-4 lists relevant monitoring or other data pertinent to estimating environmental internal dose. Although available data enable dose reconstruction, in this evaluation, workers are assumed to be maximally exposed to conditions that potentially existed in operational areas. Ambient environmental dose is accounted for in the operational dose information.

7.2.4 Internal Dose Reconstruction Feasibility Conclusion

ATTRIBUTION: Section 7.2.4 was completed by Robert Morris and Eugene W. Potter, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

This evaluation concludes that NIOSH can bound internal dose (reconstruct dose with sufficient accuracy) for members of the class under evaluation. NIOSH located sufficient personnel monitoring data to support bounding internal uranium and thorium exposures at the Weldon Spring Plant for the evaluated period of January 1, 1957 through December 31, 1967. This feasibility conclusion is based on the collective availability of bioassay (urinalysis), thorium *in vivo*, and air sampling data in sufficient quantity and quality for the entire evaluated period to adequately represent the class under evaluation. Supporting information exists related to workplace activities, area monitoring, and associated source terms.

7.3 Evaluation of Bounding External Radiation Doses at Weldon Spring Plant

ATTRIBUTION: Section 7.3 was completed by Edward D. Scalsky, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

The principal source of external radiation doses for members of the evaluated class, other than medical X-rays required as a condition of employment, was direct beta-gamma exposures from processing uranium feed stocks to metal and other intermediate products for use at other AEC facilities across the weapons complex. A limited amount of thorium was also processed at Weldon Spring from November 1963 through 1966.

NIOSH has located individual external monitoring records for Weldon Spring Plant employees associated with uranium and thorium material processing during the operational period under evaluation. As expected, the highest doses were received by operations workers in the plant's processing areas. Documentation retrieved from the site verifies that the existing personnel external monitoring was sufficient to detect the photon and beta radiation from significant sources of radiation, as reflected in the individual external monitoring records. Although a routine monitoring program for neutrons did not exist at the Weldon Spring Plant, personnel working directly with slightly-enriched uranium materials were assigned neutron dosimeter badges to be worn in conjunction with the regular film badges; but, no neutron dose results for Weldon Spring Plant employees were located, plausibly because there were no measured neutron doses. Neutron measurements made on drums of stored uranium tetrafluoride and calculations performed on materials similar to that at Weldon Spring (and documented in the Mallinckrodt Site Profile) provide indications that there was no need for neutron dosimetry because there was minimal neutron exposure potential. If required, neutron doses for operational personnel working with slightly-enriched uranium and other operational personnel working with natural and depleted uranium could be determined from the Battelle-TBD-6001 measurements and information discussed in Section 5.2.2.3.

Thorium processing also contributed to external exposure to Weldon Spring personnel. The amount of thorium processed at Weldon Spring represented less than 1% of the total amount of natural, depleted, and enriched uranium processed, making the thorium contribution to the external exposure relatively minor. However, the external exposure from the thorium processing operations would be accounted for in the personnel film badge dosimeter records.

The following subsections address the ability to bound external doses, methods for bounding doses, and the feasibility of external dose reconstruction.

7.3.1 Evaluation of Bounding Process-Related External Doses

ATTRIBUTION: Section 7.3.1 and its related subsections were completed by Edward D. Scalsky, Oak Ridge Associated Universities (ORAU) and Billy P. Smith, M.H. Chew and Associates, Inc. The rationales for all conclusions in this document are explained in the associated text.

As reported in Section 6.2.1 of this report, NIOSH has access to the ORAU CER database which contains nearly 8,000 film badge records collected from 1957 to 1967 for approximately 1,850 Weldon Spring Plant employees. Individual dosimetry data are the preferred data source for evaluating the external radiation doses for members of the Weldon Spring Plant class. A subset of the class, comprised of female administrative support personnel, was unmonitored and thus necessitates that bounding methods for unmonitored employees be used to evaluate those potential external radiation doses.

As reported in Section 6.2 of this report, no area survey or monitoring records beyond airborne dust studies are available.

The following subsections summarize the extent and limitations of information available for reconstructing the process-related external doses of members of the class under evaluation.

7.3.1.1 Personnel Dosimetry Data

NIOSH has located records documenting the external monitoring program for beta and photon exposure at the Weldon Spring Plant. As reported in Section 6.2.1, NIOSH has nearly 8,000 external personnel dosimetry results. While a limited routine external monitoring program for neutron exposure did exist at the site for areas processing slightly-enriched uranium, the neutron dosimeter results have not been located by NIOSH, plausibly because no positive doses were observed. NIOSH conducted interviews with former Weldon Spring Plant workers who stated that they routinely wore a film badge (Personal Communication, 2009a; Personal Communication, 2009b; Personal Communication, 2009c; Personal Communication, 2009e Personal Communication, 2009f; Personal Communication, 2009h; Personal Communication, 2009i). A review of the CATI interview reports for information on the routine use of radiation dosimeters also supports the existence a routine badging program at the Weldon Spring Plant.

Photon

The available personnel external monitoring data, in the form of film badge results, provide external photon/gamma dose information for the personnel working during the operational period at the Weldon Spring Plant. These data are sufficient to support bounding photon dose for members of the class under evaluation, as described in Section 7.3.4.1.

Beta

The CER database includes almost 8,000 film badge records from 1957 to 1967 for approximately 1,850 employees and contains the beta doses and the necessary information needed to aid in the completion of dose reconstructions for most individuals. These data can be used to reconstruct beta dose for members of the class under evaluation. The available personnel monitoring data include data that represent the maximally-exposed worker group and work scenario during the Weldon Spring Plant operational period.

Neutron

Considering that significant neutron doses were not anticipated at the Weldon Spring Plant, a conclusion that is supported by the Mallinckrodt study mentioned in Section 7.3, the neutron monitoring that was employed was limited to the workers assigned to processing slightly-enriched uranium at the Weldon Spring Plant facility. These workers were most likely to be exposed to neutron radiation. The employees who were determined to be less likely to be exposed to neutron radiation were not monitored for neutrons. Because of the alpha-neutron reaction from uranium tetrafluoride, very low neutron radiation exposures to unmonitored workers may have occurred in buildings that processed uranium.[4] NIOSH has considered the potential source of neutrons resulting from alpha-neutron reactions and determined that in the cases where NIOSH needs to apply unmonitored neutron dose for members of the class, it can apply the methods approved in ORAUT-OTIB-0024 to support bounding the neutron dose. The applicability of this method will be assessed on a case-by-case basis for individual dose reconstructions.

As previously mentioned, neutron dose results for the Weldon Spring employees who were involved with processing slightly-enriched (<1%) uranium have not been located, plausibly because there was no measured neutron dose to record. In the absence of measured dosimeter doses, the primary method for assigning potential neutron dose is in the determination of missed neutron dose, as described in the NIOSH document, *External Dose Reconstruction Implementation Guideline* (OCAS-IG-001).

7.3.1.2 Alternative Data Sources for Bounding External Dose

As indicated in Section 5.2.2.2, additional beta exposure data are available for bounding external doses. These data are from radiation surveys in the 301 Core Area (Holt, 1960b), from drum surveys (Drum survey, unknown date), and from studies to determine the exposure rates and the sources of exposure for specific operations in the Casting Area and for lathe operations (MCW, unknown date). These can be used to support NIOSH's ability to bound doses for groups of workers in the evaluated class.

7.3.2 Evaluation of Bounding Ambient Environmental External Doses

ATTRIBUTION: Section 7.3.2 was completed by Edward D. Scalsky, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

An aerial radiological survey of the Weldon Spring Plant indicates that for most of the site, the normal terrestrial gamma exposure rate is 3 to 6 µR/hour at 1 meter above ground level, and the average cosmic exposure rate is approximately 4 µR/hour (Jobst, 1976). For continuous exposure over a year, this represents an annual ambient dose of 61 to 88 mrem/year.

Elevated terrestrial exposures over the raffinate pits and the quarry were observed, indicating the presence of man-made changes from the natural radioisotopes. Based on the results of the aerial survey, gamma radiation exposure rate isopleths drawn in the immediate vicinity of the plant and centered on the raffinate pits indicated exposure rates ranging from 116 to 164 microR/hour with decreasing levels ranging from 11.8 to 31.8 microR/hour at approximately 1,000 feet from the pits (Jobst, 1976). These measurements represent the terrestrial radiation only. The average cosmic exposure rate of 4 microR/hour should be added to the isopleths to compute the total exposure rate for personnel within the site boundary (Jobst, 1976).

Weldon Spring employees working in these areas would be monitored and their exposure accounted for in their normal dosimetry results. Since all employees in operational areas were required to wear film dosimeters, there would not be unmonitored employees subject to exposure in those areas. Therefore, doses to Weldon Spring employees for whom dosimetry results are not available would be bound by the dose that is accounted for in the occupational dose for the evaluated class. The aerial

[4] Buildings with a potential for neutron exposure are listed in Section 5.2.2.3.

survey information can be used for the purpose of a more precise estimate, applied on a case-by-case basis for individual dose reconstructions.

7.3.3 Weldon Spring Plant Occupational X-Ray Examinations

ATTRIBUTION: Section 7.3.3 was completed by Edward D. Scalsky and Monica Harrison-Maples, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

As part of the requirements for employment at the Weldon Spring Plant from 1955 through 1966 (the operational period) all employees received periodic physical examinations. The frequency and type of X-ray examinations are referenced in reports for Weldon Spring Plant workers from 1955 through 1966 (MCW, 1965). These references clearly indicate that chest X-ray examinations were performed annually from 1955 through 1966, and medical records indicate that both posterior-anterior (PA) and lateral (LAT) views were taken. There is no indication that photofluorography was ever used at the Weldon Spring Plant site.

7.3.4 Methods for Bounding External Dose at Weldon Spring Plant

There is an established protocol for assessing external exposure when performing dose reconstructions (these protocol steps are discussed in the following subsections):

- Photon Dose
- Beta Dose
- Neutron Dose
- Medical X-ray Dose

7.3.4.1 Methods for Bounding Operational Period External Dose

ATTRIBUTION: Section 7.3.4.1 was completed by Edward D. Scalsky, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

NIOSH has access to sufficient dosimetry records for individual workers exposed to beta and photon radiation during operations at Weldon Spring.

Photon Dose

Photon doses can be reconstructed using available film badge results for individual workers exposed to photon radiation during operations at the Weldon Spring Plant for all years of the evaluated period. NIOSH analyzed available Weldon Spring Plant worker data in an attempt to develop a profile of exposure for each type of job at the Weldon Spring Plant site. Job titles, as reported in computer-assisted telephone interviews, were utilized. There were over 70 different job titles identified for Weldon Spring Plant workers. These titles were grouped into nine categories, roughly representing the reported job titles. Table 6-8 of ORAUT-TKBS-0028-6 presents the annual average gamma exposures calculated for each category and shows that the operator category received the greatest exposure to gamma rays for most years. This analysis supports the contention that the operator category of workers at the Weldon Spring Plant site is included in the group of workers representing the maximally-exposed work group and work scenario during the Weldon Spring Plant operations period.

Extensive external dose information for Weldon Spring workers is available for the operational period. The records in the CER database are sufficiently detailed to support a bounding dose for the applicable exposure source of concern. While the operator category represents the maximimally-exposed work group among badged workers, unmonitored workers would not be expected to be represented in this worker category. Therefore, the engineer job category represents a more reasonable representation of unmonitored workers who would infrequently, if ever, be subjected to the exposures associated with processing work. By using the engineer job category and the associated doses, a conservative bounding dose estimate can be determined for the Weldon Spring workers who did not have a permanent badge. Therefore, the operator job category represents the maximally exposed work group, which NIOSH can use as the bounding exposure scenario. On an individual basis, additional information specific to the worker will be used to refine the bounding approach.

Beta Dose

The method used to determine the beta dose is the same as that used for the photon dose. The total beta dose is the sum of the readings of all film badges for the entire work history for which the individual was exposed to beta radiation.

As with the gamma doses, the beta doses were analyzed and determined for the nine job categories that roughly represent the 70 reported job titles mentioned in the photon discussion. Table 6-8 of ORAUT-TKBS-0028-6 lists the annual average beta exposures calculated for each category. As can be seen from the table, average exposure to beta radiation, similar to photon radiation, was substantially greater for those in the operator category than for any other job category. Therefore, as seen with respect to photon exposure, the operator job category represents the maximally exposed work group, which NIOSH can use as the bounding exposure scenario. Additional information specific to the worker will be used to refine the bounding approach on a case-by-case basis.

Neutron Dose

Based on the studies described in Section 5.2.2.3, it has been determined that neutron radiation was not a source of significant exposure at the Weldon Spring Plant and no further analysis is required.

Medical X-ray Dose

Although NIOSH has not located specific parameters associated with occupational medical X-rays (i.e., specific information on the X-ray devices), default values of entrance kerma developed for the three most commonly-used occupational medical diagnostic procedures are available in ORAUT-OTIB-0006. Additionally, a document titled *Calculations and Assumptions Used in ORAUT-TKBS-0028-3 Rev. No. 01 Weldon Spring Plant Technical Basis Document for Occupational Medical Exposure* provides details for occupational medical exposures at the Weldon Spring Plant site for available X-ray equipment and dose calculations (Morris, 2007). The ORAUT-OTIB-0006 values can be used to support bounding the medical X-ray dose for the time period under evaluation. These default values are upper limit values developed from review of patient doses as reported in the literature, machine characteristics, and knowledge of X-ray procedures used during different time periods. These default values can be used in lieu of actual measurement data or entrance kerma derived from technique factors to bound the occupational X-ray exposures for the Weldon Spring

Plant site. NIOSH believes this methodology supports its ability to bound occupational medical X-ray doses (reconstruct the medical X-ray dose with sufficient accuracy) for the class under evaluation.

7.3.4.2 Methods for Bounding Ambient Environmental External Doses

ATTRIBUTION: Section 7.3.4.2 was completed by Billy P. Smith, M.H. Chew and Associates, Inc. and Edward D. Scalsky, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

Ambient environmental dose for monitored workers is accounted for in an individual's recorded dose. Potential ambient environmental dose for unmonitored workers, such as non-badged administrative personnel, is bounded by the available data for monitored individuals as assessed in this report, but can be evaluated on an individual case-by-case basis in accordance with the method described in ORAUT-TKBS-0028-4. The methods in ORAUT-TKBS-0028-4, coupled with the background dose as determined by the aerial surveys, supports NIOSH's ability to assess ambient environmental dose more precisely than a bounding dose estimate for the Weldon Spring class evaluated in this report (Jobst, 1976).

7.3.5 External Dose Reconstruction Feasibility Conclusion

ATTRIBUTION: Section 7.3.5 was completed by Edward D. Scalsky, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

NIOSH concludes that the external dose reconstruction for members of the evaluated class is feasible based on the available personal external monitoring data, the analysis of the film badge results for the various job categories, survey data obtained during studies to determine the time to perform specific job functions and necessary shielding, and if necessary, a determination of missed and unmonitored neutron dose using the methods described in Section 5.2.2.3 for personnel working in buildings that processed uranium (because of the alpha-neutron reaction from uranium tetrafluoride). In addition, doses from the required medical X-rays and ambient environmental doses can be determined with sufficient accuracy for the evaluated class.

7.4 Evaluation of Petition Basis for SEC-00143

ATTRIBUTION: Section 7.4 and its related subsections were completed by Monica Harrison-Maples, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

The following subsections evaluate the assertions made on behalf of petition SEC-00143 for the Weldon Spring Plant site.

7.4.1 Radon

SEC-00143: The petitioner is concerned that the measured air concentration of radon during the operational period at Weldon Spring is not reported in the literature.

Response: NIOSH investigated the ability to assess radon concentrations during the operational period. As described in Section 5.1.1 of this report, the materials processed at Weldon Spring did not include radium bearing “raw” ores and thus did not produce significant amounts of radon relative to unprocessed uranium ore. Section 5.2.1.5 of this report provides detail on radon generating materials and their disposition at the site. NIOSH is able to conservatively estimate the maximum radon released given the uranium source term, as described in Section 7.2.3 of this report.

7.4.2 Thorium Bioassay

SEC-00143: The petitioner is concerned that no quantitative *in vitro* bioassay results have been found for thorium.

Response: No quantitative *in vitro* bioassay results for thorium exist at Weldon Spring. NIOSH uses various methods to bound internal exposure in the absence of bioassay data. The default exposure approach for the Weldon Spring Plant is based on the review of thorium air sampling results from samples taken during thorium processing at the site. The daily weighted average concentration for air monitoring data from the 1957-through-1966 period will be used to bound the exposures during those periods for which there are no bioassay analyses available for thorium. Section 7.2.3.1 of this report provides additional detail on how this will be achieved.

7.4.3 Recycled Uranium

SEC-00143: The petitioner is concerned that the Weldon Spring Plant site was identified as a site that likely received recycled uranium in relatively small quantities of materials after 1961, and site records do not include the level of detail needed for accurate estimates of the amount of recycled material received and processed at Weldon Spring Plant. It is known that the plant received shipments from other DOE sites that processed and shipped recycled uranium, in fiscal years 1962 through 1967, but amounts of recycled uranium versus natural uranium are not known.

Response: NIOSH investigated the receipts and processing of recycled uranium at the Weldon Spring site and acknowledges that limited quantities of recycled uranium were received at Weldon Spring for processing. The fact that the quantities of recycled uranium are unknown led DOE to assume, as a worst case, that all uranium received after 1962 was recycled uranium. DOE acknowledges that this assumption leads to the worst-case quantities of transuranic elements. These quantities do not represent what was actually processed, and in fact, DOE estimates these quantities to be significantly less (0.0 gm of plutonium-239, 12.3 to 15.3 grams of neptunium-237, and 4.9 to 6.1 grams of technetium-99, as compared to the worst case 2.4 grams, 330 grams, and 7,200 grams of plutonium, neptunium, and technetium respectively). For the purpose of defining the ability to bound dose for the evaluated class in this report, the maximum quantities have been considered as the source term for this evaluation.

7.4.4 Thorium Disequilibrium

SEC-00143: The petitioner is concerned that thorium-228 and thorium-232 may not have been in equilibrium following chemical purification of natural thorium feed materials. *In vivo* measurements were performed on some Weldon Spring Plant workers for thorium in 1966. The overall results showed that workers in Areas 101, 103, 301, 403, Maintenance, and Health and Safety (which were principal exposure positions) had a more frequent occurrence of trace detection. The quantification of thorium depositions from these *in vivo* thallium-208 measurements is therefore, uncertain without the knowledge of the degree of equilibrium of the thallium with the thorium-232 parent.

Response: The *in vivo* measurement data available to NIOSH have not been used as part of the methodology to bound thorium dose for the evaluated class. In some individual cases, the *in vivo* counts made in July 1966 may be useful, but it is more likely to be disregarded during dose reconstruction due to uncertainty about when the intake may have occurred and the solubility of the thorium compounds. The cases where such use of the *in vivo* counts would be necessary would be limited to those with very specific circumstances and information.

7.4.5 Lost or Missing Records

SEC-00143: The petitioner is concerned about a memo concerning possible lost medical records at Weldon Spring Plant. Mont Mason (deceased) could not find one complete set of medical files, which had originally been titled, *Terminated from Weldon Thru 4/28/66*.

Response: NIOSH has investigated the possibility of lost medical records as described in the Mason memo. It was unclear from the original memo if any records were in fact lost. Mont Mason indicated the problem might have been a simple filing error and asked for all medical records to be sent to Oak Ridge, Tennessee to resolve the discrepancy. NIOSH has interviewed epidemiologists familiar with Mont Mason and the work he did with the Weldon Spring records. One person interviewed recalled two data capture trips to the Weldon Spring Plant site where the boxes were thoroughly reviewed one-by-one for health and safety records, standard operating procedures, manuals, monitoring records, exposure records, medical records, incident reports, etc. The person interviewed was unaware of any missing records or any data gaps. In addition, NIOSH has a letter from T. F. Mancuso specifically requesting to the AEC that the records mentioned by M. Mason not be destroyed. NIOSH concludes, from the above interview and from the review of the data holdings for the Weldon Spring Plant site that these records were in fact saved from destruction by the efforts of Mr. Mason and Dr. Mancuso. NIOSH has no other evidence of the loss of any significant number of records or data gaps.

7.4.6 Accidents/Incidents

SEC-00143: The petitioner is concerned that all accidents may not have been documented sufficiently or that the records might not be readily available and that accidents and incidents could have lead to acute intakes and/or contamination that greatly exceeded normal levels.

Response: NIOSH has conducted a thorough investigation into documentation that gives no indication of significant accidents or incidents at the facility. While several events were identified, through document searches and interviews with former workers, there were no indications of events that could have resulted in exceptionally high personnel exposures or exposures that are not already accounted for within the data in the available records. Section 5.2.3 of this report provides additional detail on NIOSH's investigations and findings related to incidents.

7.4.7 Ambient Environmental Exposure

SEC-00143: The petitioner is concerned about the lack of "any thorium data," and believes that there "is no basis to estimate thorium releases prior to 1967." The petitioner has also expressed a belief and concern that thorium was first stored and used at Weldon Spring as far back as 1958, and that significant quantities of thorium in the Weldon Spring Quarry were not routinely sampled until after 1985.

Response: NIOSH must presume that the petitioner's concern about a lack of "any thorium data" in conjunction with the phrase "is no basis to estimate thorium releases prior to 1967" refers to potential internal exposure due to thorium released into the environment. As described in this report, the earliest thorium processing at the site began in 1963 (DOE, 1986). Prior to that, there are no indications of any processing of the material, only limited storage onsite and disposal at the Quarry. NIOSH does have DWA concentration air monitoring data from the years 1957 through 1966. The data (1957-1966) encompasses the span of thorium processing at the site.

SEC-00143: The petitioner is concerned about the lack of atmospheric monitoring data for Weldon Spring Plant during the operational period; thus, leading to insufficient data for assigning unmonitored workers internal environmental dose during the operational period. In addition, the petitioner is concerned about the TBD's use of environmental dose from protracted Fernald estimated data.

Response: The atmospheric monitoring data for Weldon Spring Plant during the operational period are limited, but sufficient to calculate estimated intakes of radioactive airborne particulates and radon, as described in Section 4.2.3.1 of ORAUT-TKBS-0028-4. These calculations pertain to both operational personnel and unmonitored personnel. As noted in Section 7.2.2 of this report, the most highly exposed plant employees were monitored or accounted for through monitoring or airborne dust measurements. These exposures would be bounding for unmonitored workers. This evaluation does not depend on the use of environmental data from Fernald estimated data.

7.4.8 Contamination Control

SEC-00143: The petitioner is concerned that there was a lack of: routine personnel contamination monitoring; a consistent and documented badging policy with geometry correction factors; a comprehensive bioassay program that encompassed all the major isotopes brought onsite; and an onsite environmental monitoring program for unmonitored workers that have resulted in gaps in some of the information and data.

Response: These broad statements were the basis for qualifying the petition. These concerns resulted in the evaluation of the petition for Weldon Spring Plant. The responses to these concerns are encompassed in this report.

7.4.9 Medical Exposure

SEC-00143: The petitioner is concerned that there is very little information available concerning the Weldon Spring Plant site's occupational medical procedures, equipment, X-ray exam frequency, etc. The petitioner is also concerned that there is no mention made of the frequency of retake exams performed, as well as no indication whether photofluorography exams were conducted at Weldon Spring Plant.

Response: Although NIOSH has not located specific policy guidance associated with the performance of occupational medical X-rays, the dose associated with occupational medical X-rays can be assessed using the default values of entrance kerma, developed for the three most commonly used occupational medical diagnostic procedures, as available in ORAUT-OTIB-0006, *Dose Reconstruction from Occupationally Related X-Ray Procedures*. These values can be used to support bounding the medical X-ray dose for the time period under evaluation.

7.4.10 Neutron Dose

SEC-00143: The petitioner is concerned about a lack of documentation and detail as related to neutron doses at Weldon Spring Plant.

Response: As discussed in Section 5.2.2.3 of this report, given the processing performed at the Weldon Spring Plant, the only source of neutron production would have resulted from the alpha-neutron reaction associated with uranium tetrafluoride. This reaction has been studied at other facilities in the DOE complex; the conclusion of these studies is that at the level of enrichment of the uranium received at Weldon Spring Plant, there was no possibility of significant neutron exposure, and therefore no neutron dosimetry was necessary.

7.5 Other Potential SEC Issues Relevant to the Petition Identified During the Evaluation

ATTRIBUTION: Section 7.5 was completed by Monica Harrison-Maples, Oak Ridge Associated Universities (ORAU). The rationales for all conclusions in this document are explained in the associated text.

During the feasibility evaluation for SEC-00143, three issues were identified that needed further analysis and resolution. The issues and their current status are:

ISSUE: A concern with the identification of the feed material processed at Weldon Spring arose early in this evaluation. During a review of interview reports, it was identified that former workers referred to the feedstock brought into the facility in several different ways, including "ore." The uranium progeny inherent in pitchblende ore causes very different exposure concerns as compared to those associated with pre-processed ores.

RESPONSE: NIOSH investigated this concern and found the use of the term "ore" to be inaccurate. According to interviews with a number of former Weldon Spring Plant workers, the Weldon Spring Plant accepted ore concentrates for processing, but never received raw ore (Personal Communication, 2009c; Personal Communication, 2009g; Personal Communication, 2009h). As discussed in Section 5.1.1, it was common practice at the site to refer to uranium concentrates that were milled in the western United States as ore. This information regarding ore that was derived from the interviews is further supported by the historical Weldon Spring Plant work reports that were reviewed by NIOSH.

ISSUE: During an interview, NIOSH was informed by a former worker that isotopes other than uranium or thorium were used as radiotracers. The interviewee stated that only him and three other workers (names were provided) worked with these tracers (Personal Communication, 2009g).

RESPONSE: An interviewee reported that three tracer isotopes, molybdenum-99, europium, and vanadium-48, were used in bench-top operations (Personal Communication, 2009g). The molybdenum-99 was used in mCi quantities and the other isotopes were used in much smaller quantities. NIOSH considered the doses which could result from intakes of these tracer radionuclides and found that they would contribute a negligible amount of additional risk to the limited number of workers that may have come in contact with them. The committed effective doses were calculated to be on the order of a few mrem/year for the molybdenum-99, a tenth of a mrem/year for the europium isotope with the highest dose coefficient, and a hundredth of a mrem/year for the vanadium-48. From the perspective of potential external exposure, the tracers would have been used in columns on a bench top, which would absorb or shield betas. The potential gamma exposure would be included in the results on the film badges.

ISSUE: During the initial review of Weldon Spring Plant documentation, NIOSH identified a single reference to a Building 441 as a facility used for storage of uranium hexafluoride cylinders. No other reference to any storage or use of uranium hexafluoride cylinders was located in the documentation. NIOSH performed additional research to determine if uranium hexafluoride was stored on the Weldon Spring site for any reason and if so, during what time frame, and how much may have been stored at the site.

RESPONSE: In addition to document research, NIOSH conducted former worker interviews to try to confirm the presence of uranium hexafluoride cylinders onsite. During interviews, two former workers provided information that uranium hexafluoride was never processed at the Weldon Spring Plant; neither had heard of uranium hexafluoride cylinders being stored at the Weldon Spring Plant (Personal Communication, 2009h; Personal Communication, 2009g). As a result of a review of the source documentation attributed by Table 2-2 of ORAUT-TKBS-0028-2 (the only reference to Building 441 as a storage location for uranium hexafluoride cylinders), NIOSH believes this reference in ORAUT-TKBS-0028-2 may be an error. No such reference to Building 441 being used in this capacity was located in the source documentation.

7.6 Summary of Feasibility Findings for Petition SEC-00143

This report evaluates the feasibility for completing dose reconstructions for employees at the Weldon Spring Plant site from January 1, 1957 through December 31, 1967. NIOSH found that the available monitoring records, process descriptions and source term data available are sufficient to complete dose reconstructions for the evaluated class of employees.

Table 7-6 summarizes the results of the feasibility findings at Weldon Spring Plant for each exposure source during the time period from January 1, 1957 through December 31, 1967.

Table 7-6: Summary of Feasibility Findings for SEC-00143
January 1, 1957 through December 31, 1967

Source of Exposure	Reconstruction Feasible	Reconstruction Not Feasible
Internal[1]	**X**	
Uranium	X	
Uranium decay products & other impurities	X	
Recycled uranium	X	
Thorium	X	
Radon	X	
Thoron	X	
External	**X**	
Gamma	X	
Beta	X	
Neutron	X	
Occupational Medical X-ray	X	

Note:
[1] Internal includes an evaluation of urinalysis (in vitro), airborne dust, and lung (in vivo) data

As of March 12, 2010, a total of 258 claims have been submitted to NIOSH for individuals who worked at the Weldon Spring Plant and are covered by the class definition evaluated in this report. Dose reconstructions have been completed for 180 individuals (~69.8%).

8.0 Evaluation of Health Endangerment for Petition SEC-00143

The health endangerment determination for the class of employees covered by this evaluation report is governed by both EEOICPA and 42 C.F.R. § 83.13(c)(3). Under these requirements, if it is not feasible to estimate with sufficient accuracy radiation doses for members of the class, NIOSH must also determine that there is a reasonable likelihood that such radiation doses may have endangered the health of members of the class. Section 83.13 requires NIOSH to assume that any duration of unprotected exposure may have endangered the health of members of a class when it has been established that the class may have been exposed to radiation during a discrete incident likely to have involved levels of exposure similarly high to those occurring during nuclear criticality incidents. If the occurrence of such an exceptionally high-level exposure has not been established, then NIOSH is required to specify that health was endangered for those workers who were employed for a number of work days aggregating at least 250 work days within the parameters established for the class or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

NIOSH's evaluation determined that it is feasible to estimate radiation dose for members of the NIOSH-evaluated class with sufficient accuracy based on the sum of information accessible from available resources. Modification of the class definition regarding health endangerment and minimum required employment periods, therefore, is not required.

9.0 Class Conclusion for Petition SEC-00143

Based on its full research of the class under evaluation, NIOSH found no part of said class for which it cannot estimate radiation doses with sufficient accuracy. This class includes all employees of the Department of Energy, Department of Energy contractors, or subcontractors who worked in any area at the Weldon Spring Plant in Weldon Spring, Missouri, during the applicable covered operational period from January 1, 1957 through December 31, 1967.

NIOSH has carefully reviewed all material sent in by the petitioner, including the specific assertions stated in the petition, and has responded herein (see Section 7.4). NIOSH has also reviewed available technical resources and many other references, including the SRDB, for information relevant to SEC-00143. In addition, NIOSH reviewed its NOCTS dose reconstruction database to identify EEOICPA-related dose reconstructions that might provide information relevant to the petition evaluation.

These actions are based on existing, approved NIOSH processes used in dose reconstruction for claims under EEOICPA. NIOSH's guiding principle in conducting these dose reconstructions is to ensure that the assumptions used are fair, consistent, and well-grounded in the best available science. Simultaneously, uncertainties in the science and data must be handled to the advantage, rather than to the detriment, of the petitioners. When adequate personal dose monitoring information is not available, or is very limited, NIOSH may use the highest reasonably possible radiation dose, based on reliable science, documented experience, and relevant data to determine the feasibility of reconstructing the dose of an SEC petition class. NIOSH contends that it has complied with these standards of performance in determining the feasibility or infeasibility of reconstructing dose for the class under evaluation.

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Weldon, 1958-1959, *Various Handwritten Log of Bioassay Urine Processing Results*; Various dates throughout 1958 and 1959; SRDB Ref ID: 15634

Weldon, 1960, *Various Bioassay Urine Reports, Including Personnel with High-Uranium-in-Urine Concentrations*; Weldon Spring Health and Safety Department (Weldon); January 1-June 30, 1960; SRDB Ref ID: 15874

Weldon, 1961, *Various Bioassay Urine Reports, Including Action Level Urinary Uranium Concentrations*; Weldon Spring Health and Safety Department (Weldon); January-December 1961; SRDB Ref ID: 15865

Weldon, 1962-1965, *Various Bioassay Urine Reports, Including Action Level Urinary Uranium Concentrations and Collection Reports*; Weldon Spring Health and Safety Department (Weldon); 1962-1965; SRDB Ref ID: 15890

Attachment One: Data Capture Synopsis

Table A1-1: Summary of Holdings in the SRDB for the Weldon Spring Plant			
Data Capture Information	**Data Capture Description**	**Completed**	**Uploaded into SRDB**
Primary Site/Company Name: Weldon Spring Plant 1955-1967; 1975-present (remediation); DOE Other Site Names: Mallinckrodt Weldon Spring Chemical Co. Weldon Spring Site Remedial Action Project (WSSRAP) WSS Successor Contacts: URS-Formerly MK-Ferguson - Brad Giles, Vice-President Environmental, Health, Safety, and Security, 208-386-7899 (Data Capture performed) Covidien-Formerly Mallinckrodt - Pat Duft, Chief Counsel, 314-654-6314, Confirmed Mallinckrodt did not retain records of personnel or operations. Bechtel National Inc Records for this period were transferred to Kansas City FRC (Data Capture performed) Jacobs Engineering - Ann Katoh, Risk Management, 626-578-3552, Confirmed records were with MK-Ferguson.	Uranium in the air at Y-12, depth doses in a slab phantom for low energy monoenergetic photons, environmental audit, historical overview, internal contamination during decontamination/decommissioning, long-term surveillance and maintenance, radiation incident, dose calculations, former Army Ordnance Works information, and Weldon Spring quarry/plant/pits information.	02/25/2010	26
State Contacted: Missouri Department of Natural Resources (MODNR) Rhonda Loveall	Summary of radiation monitoring data, inspection report, site history, engineering evaluation, characterization results, closure reports, site-specific soil guidelines, effluent levels of uranium, environmental monitoring reports, radon control and emissions, groundwater contamination, interviews with two MODNR employees, feasibility study, radiological surveys, soil sampling, safety and health plan, and a radiological control manual.	10/03/2008	66
Claimant	Work products from inter-agency working groups formed for a study of occupational hazards and illnesses in the DOE contractor workforce.	04/18/2005	1

Table A1-1: Summary of Holdings in the SRDB for the Weldon Spring Plant			
Data Capture Information	**Data Capture Description**	**Completed**	**Uploaded into SRDB**
Department of Labor/Paragon	Annual environmental monitoring reports, Cotter Corporation visit report, Surplus Facilities Management Program reports, and monthly progress reports.	12/30/2008	18
DOE Germantown	Historical nuclear materials balance report, historical review of the Mallinckrodt airport cake, and historical dose estimate information with facility descriptions.	12/17/2003	3
DOE Legacy Management - Grand Junction Office	Description of the Feed Materials Production facilities, federal facility agreement, operating history, hazardous ranking, contamination surveys and instrumentation, site material accountability, disposal of uranium contaminated building debris, rubble and residues, historical dose estimates, proposed remedial action information, environmental monitoring reports, and characterization reports.	09/02/2009	92
DOE Legacy Management - MoundView (Fernald Holdings, includes Fernald Legal Database)	Analysis of water samples, bioassay monthly reports, radon monitoring reports, environmental reports, decommissioning study, Fernald quarterly report, major thorium campaigns at NLO/Fernald, health and safety reports, electrolysis of UO2 at Mallinckrodt, plant procedures and records, Slightly-enriched Recovery Facility (SERF) Program, radioactive waste management, stabilization of raffinate pits, thorium accountability, and metallic scrap recycling and disposal of radioactive residues.	05/30/2008	49
Researcher at Southern Illinois University, Edwardsville Personal Files	Weldon Spring plot plans and historical summaries, interest in commercial use of Weldon Spring Plant, contamination information, disposal of Weldon Spring materials, long-term management of existing radioactive materials, raffinate pits, trip report, and quarry surveillance information.	11/05/2008	26
EML Library	Dust problems in refining and fabrication of uranium and the correlation between alpha surface contamination and air concentration.	02/15/2005	2
Internet - Department of Energy (DOE)	Weldon Spring Plant remedial action cleanup activities.	04/27/2005	1
Internet - DOE Comprehensive Epidemiologic Data Resource (CEDR)	No relevant data identified.	03/02/2010	0
Internet - DOE Hanford Declassified Document Retrieval System (DDRS)	Irradiation Processing Department monthly report and a test conversion of thorium nitrate to thorium oxide.	03/02/2010	2
Internet - DOE OpenNet	Linking Legacies Appendix B: The Eight Major Processes of the Nuclear Weapons Complex.	03/02/2010	1
Internet - DOE OSTI Energy Citations	No relevant data identified.	03/02/2010	0
Internet - DOE OSTI Information Bridge	Survey of the wetlands and floodplains at Weldon Spring Plant, quarterly reports, quarry residuals scoping document, quarterly environmental summary, alloyed dingot status, beta-to-alpha transformation characteristics, and remedial action information.	03/02/2010	14

Table A1-1: Summary of Holdings in the SRDB for the Weldon Spring Plant			
Data Capture Information	**Data Capture Description**	**Completed**	**Uploaded into SRDB**
Internet - Google	Engineering evaluation of contaminated water in quarry, inherent problems conducting dose assessments, air and personal monitoring, Edward Mallinckrodt Jr. papers, U238 burn, recycled uranium and transuranics, site history, waste management information, and environmental reports.	03/02/2010	22
Internet - National Academies Press (NAP)	No relevant data identified.	03/02/2010	0
Internet - National Nuclear Security Administration (NNSA) - Nevada Site Office	No relevant data identified.	03/02/2010	0
Internet - NRC Agencywide Document Access and Management (ADAMS)	Letter from MO Department of Natural Resources requesting additional information regarding DOE's plans to recycle scrap metal at the Weldon Spring Plant.	03/02/2010	1
Internet - Washington State University (U.S. Transuranium and Uranium Registries)	No relevant data identified.	03/02/2010	0
Lawrence Berkeley National Laboratory (LBNL)	Status report and hazards survey.	02/07/2007	2
Los Alamos National Laboratory (LANL)	Radioactive waste disposal and low-level mixed waste streams for the DOE complex.	12/06/2007	2
NARA Atlanta	Annual summary off-site environmental monitoring report, criticality safeguards manual, analytical bioassay procedures, Extraction Plant design criteria and health program, concerns for recycling materials, incident reports, Mallinckrodt recovery of uranium from residues, monitoring of employees for thorium burdens, various preliminary proposals, operating procedures, sale of residues at the St. Louis Airport Site, off-site environmental sampling program, thorium operations at Mallinckrodt, trip report, and information on uranium refining processes.	10/20/2005	39
NARA Kansas City	Radiological surveys, area TLD results, bioassay results and logs, description of Latty Avenue wastes, radiological and chemical characterization reports, engineering evaluation for the disposition of the raffinate pits, environmental monitoring reports, 1969 listing of buildings & occupancy, pit sludge data, radiological concentrations and exposure rates, removal of uranium from Building 434, work diary and release of Weldon Spring property, and occupational radiation exposure reports.	08/15/2009	61
National Institute for Occupational Safety and Health (NIOSH)	Personnel files.	10/21/2009	24
NIOSH OCAS Claims Tracking System (NOCTS)	Safety investigation and occupational summary.	11/18/2009	2
ORAU Team	Site information and documented communications.	12/03/2009	21

Table A1-1: Summary of Holdings in the SRDB for the Weldon Spring Plant			
Data Capture Information	**Data Capture Description**	**Completed**	**Uploaded into SRDB**
Oak Ridge Institute for Science Education (ORISE)	Dosimetry database.	11/03/2009	1
ORO Vault	Site visit reports, radiation surveys, air sample data, area monitor badges, bioassay results, personnel exposures, drum surveys, health and safety manual, maintenance job history sheets, refinery pre-operational and startup, summary of health protection practices, health physics procedures, and a raffinate radioactivity survey.	04/11/2006	134
MFG Inc. Files	External and internal dosimetry technical basis manuals, green salt production area Building 201 dust study report, Mallinckrodt claims X-ray dosimetry, and a summary of a site visit by M. E. Mason.	03/01/2010	16
Savannah River Site (SRS)	Dosimetry visitor cards and the procurement of thoria.	08/26/2008	3
Southern Illinois University	Shipping documents, classified material receipts, ammonia oxidation process, list of real property, map of Mallinckrodt site, uranium exposures within the nuclear industry, burn area no. 9 data, plant capacity and expansion estimates, Weldon Spring stockpile information, and disposal of radioactive wastes.	10/18/2008	44
Unknown	Urine and air dust samples, radiological survey, air pathway analysis, engineering evaluation of waste disposal, environmental reports, radiological characterization, significant events, radon flux monitoring, health and safety survey, employee exposures, epidemiological studies, decommissioning study, plant history, internal dosimetry technical basis manual, trip reports, progress reports, off-site population radiological assessment, record of decision for remedial action, remedial investigations, and material inventories.	06/08/2009	230
URS Corporate Records at Boise, IA	Building health and safety plan, site characterization data, environmental impact statement, remedial investigation report, waste assessment, radiological characterization of the raffinate pits, feasibility study for remedial action, radon data, results of soil sampling, vicinity properties remediation, work packages, and dismantlement risk assessment reports.	12/10/2009	36
US Army Corps of Engineers	Decontamination of storage site, Continental Mining and Milling Company assets seized by Commercial Discount Corporation, and a uranium residues historical synopsis.	03/19/2008	3
Westinghouse Site (Hematite-MO)	Urine sample results, service dates for counted employees, and employee exposure records.	04/08/2009	5
Total			**947**

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	**Keywords/Phrases**	**Hits**	**Uploaded into SRDB**
DOE CEDR http://cedr.lbl.gov/ COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson "Weldon Spring" AND "Jacobs Engineering"	3	0
DOE Hanford DDRS http://www2.hanford.gov/declass/ COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson "Weldon Spring" AND "Jacobs Engineering"	51	2
DOE OpenNet http://www.osti.gov/opennet/advancedsearch.jsp COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson	46	1

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	**Keywords/Phrases**	**Hits**	**Uploaded into SRDB**
	"Weldon Spring" AND "Jacobs Engineering"		
DOE OSTI Energy Citations http://www.osti.gov/energycitations/ COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson "Weldon Spring" AND "Jacobs Engineering"	464	0
DOE OSTI Information Bridge http://www.osti.gov/bridge/advancedsearch.jsp COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson "Weldon Spring" AND "Jacobs Engineering"	377	14
Google http://www.google.com COMPLETED 03/02/2010	"WSS" "Weldon Spring" "Weldon Spring Chemical Co." "Weldon Spring Plant" americium, OR Am241, OR Am-241, OR "AM 241", OR 241Am, OR 241-Am, OR "241 Am" "Weldon Spring Plant" ionium, OR Th230, OR Th-230, OR "Th 230", OR 230Th, OR 230-Th, OR "230 Th" "Weldon Spring Plant" polonium, OR Po210, OR Po-210, OR "Po 210", OR 210Po, OR 210-Po, OR "210 Po"	3,239,119	22

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	**Keywords/Phrases**	**Hits**	**Uploaded into SRDB**
	"Weldon Spring Plant" thorium, OR thoria, OR Th232, OR Th-232, OR "Th 232", OR 232Th, OR 232-Th, OR "232 Th", OR "Z metal", OR Z-metal, OR myrnalloy, OR "chemical 10-66", OR "chemical 1066", OR "chemical 10 66", OR "chemical 18-12" "Weldon Spring Plant" "chemical 1812", OR "chemical 18 12", OR "chemical 10-12", OR "chemical 1012", OR "chemical 10 12", OR UX1, OR UX2, OR Th-234, OR Th234, OR "Th 234", OR TH-234, OR 234-Th, OR 234Th, OR "234 Th" "Weldon Spring Plant" tritium, OR H3, OR H-3, OR mint, OR HTO "Weldon Spring Plant" uranium, OR U233, OR U-233, OR "U 233", OR 233U, OR 233-U, OR "233 U", OR U234, OR "U 234", OR U-234, OR 234U, OR 234-U, OR "234 U", OR U235, OR "U 235", OR U-235, OR 235-U, OR 235U, OR "235 U", OR U238, OR "U 238", OR U-238 "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "americium" OR "Am241" OR "Am-241" OR "Am 241" OR "241Am" OR "241-Am" OR "241 Am" OR "ionium" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "Th230" OR "Th-230" OR "Th 230" OR "230Th" OR "230-Th" OR "230 Th" OR "neptunium" OR "Np237" OR "Np-237" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "Np 237" OR "237Np" OR "237-Np" OR "237 Np" OR "palm" OR "palmolive" OR "polonium" OR "Po210" OR "Po-210" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "Po 210" OR "210Po" OR "210-Po" OR "210 Po" OR "thorium" OR "thoria" OR "Th232" OR "Th-232" OR "Th 232"		

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	**Keywords/Phrases**	**Hits**	**Uploaded into SRDB**
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "232Th" OR "232-Th" OR "232 Th" OR "Z metal" OR "Z-metal" OR "myrnalloy"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "chemical 10-66" OR "chemical 1066" OR "chemical 10 66" OR "chemical 18-12" OR "chemical 1812" OR "chemical 18 12" OR "chemical 10-12" OR "chemical 1012" OR "chemical 10 12"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "UX1" OR "UX2" OR "Th-234" OR "Th234" OR "Th 234" OR "234-Th" OR "234Th" OR "234 Th" OR "tritium"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "H3" OR "H-3" OR "mint" OR "HTO" OR "uranium" OR "U233" OR "U-233" OR "U 233" OR "233U"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "233-U" OR "233 U" OR "U234" OR "U 234" OR "U-234" OR "234U" OR "234-U" OR "234 U" OR "U235"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "U 235" OR "U-235" OR "235-U" OR "235U" OR "235 U" OR "U238" OR "U 238" OR "U-238"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "238-U" OR "238U" OR "238 U" OR "U308" OR "U 308" OR "U-308" OR "308-U" OR "308U" OR "308 U"		

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	Keywords/Phrases	Hits	Uploaded into SRDB
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "black oxide" OR "brown oxide" OR "green salt" OR "orange oxide" OR "yellow cake" OR "UO2" OR "UO3" OR "UF4"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "UF6" OR "C-216" OR "C-616" OR "C-65" OR "C-211" OR "U3O8" OR "uranium extraction" OR "uranium dioxide" OR "uranium hexafluoride"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "uranium tetrafluoride" OR "uranium trioxide" OR "plutonium" OR "Pu-238" OR "Pu238" OR "Pu 238" OR "238Pu" OR "238-Pu" OR "238 Pu"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "Pu-239" OR "Pu239" OR "Pu 239" OR "239Pu" OR "239-Pu" OR "239 Pu" OR "Pu-240" OR "Pu240" OR "Pu 240"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "240Pu" OR "240-Pu" OR "240 Pu" OR "Pu-241" OR "Pu241" OR "Pu 241" OR "241Pu" OR "241-Pu" OR "241 Pu"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "radium" OR "Ra-226" OR "Ra226" OR "Ra 226" OR "226-Ra" OR "226Ra" OR "226 Ra" OR "Ra-228" OR "Ra228"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "228Ra" OR "228-Ra" OR "228 Ra" OR "radon" OR "Rn-222" OR "Rn222" OR "Rn 222" OR "222Rn" OR "222-Rn"		

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	**Keywords/Phrases**	**Hits**	**Uploaded into SRDB**
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "222 Rn" OR "thoron" OR "Rn-220" OR "Rn220" OR "Rn 220" OR "220Rn" OR "220-Rn" OR "220 Rn" OR "protactinium" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "Pa-234m" OR "Pa234m" OR "Pa 234m" OR "234mPa" OR "234m-Pa" OR "234m Pa" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "strontium" OR "Sr-90" OR "Sr90" OR "Sr 90" OR "90-Sr" OR "90Sr" OR "90 Sr" OR "oralloy" OR "postum" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "tuballoy" OR "uranyl nitrate hexahydrate" OR "UNH" OR "K-65" OR "sump cake" OR "accident" OR "air count" OR "air dust" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "air filter" OR "airborne test" OR "alpha" OR "belgian congo ore" OR "beta" OR "bioassay" OR "bio-assay" OR "breath" OR "breathing zone" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "BZ" OR "body burden" OR "calibration" OR "chest count" OR "columnation" OR "contamination" OR "curie" OR "denitration" OR "denitration pot" "Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "derby" OR "regulus" OR "derived air concentration" OR "DAC" OR "dose" OR ""dosimeter" OR "dosimetric" OR "dosimetry" OR "electron"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR		

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	**Keywords/Phrases**	**Hits**	**Uploaded into SRDB**
	"Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "environment" OR "Ether-Water Project" OR "exposure" OR "exposure investigation" OR "radiation exposure" OR "external" OR "F machine" OR "fecal" OR "feed material"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "femptocurie" OR "film" OR "fission" OR "fluoroscopy" OR "Formerly Utilized Sites Remedial Action Program" OR "FUSRAP" OR "gamma-ray" OR "gamma ray" OR "gas proportional"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "gaseous diffusion" OR "health" OR "health instrument" OR "health physics" OR "H.I." OR "HI" OR "HP" OR "highly enriched uranium" OR "HEU"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "hydrofluorination" OR "in vitro" OR "in vivo" OR "incident" OR "ingestion" OR "inhalation" OR "internal" OR "investigation" OR "isotope"		
	"Weldon Spring Plant" OR "Weldon Spring Chemical Co" OR "Weldon Spring Site Remedial Action Project" OR " WSSRAP" OR "WSS" OR "Mallinckrodt" OR "WSCC" "isotopic" OR "isotopic enrichment" OR "JS Project"		
	Weldon Spring AND "National lead" -ocas -niosh – eeoicpa		
	Weldon Spring AND "Bechtel National" -ocas -niosh - eeoicpa		
	Weldon Spring AND Feguson -ocas -niosh - eeoicpa		
	Weldon Spring AND jacobs -ocas -niosh – eeoicpa		
	Weldon Spring AND "Bbechtel National" OR "Jacobs Engineering" OR "National lead" OR MK-Ferguson -orau -eeoicpa -niosh -mallinckrodt -wss -wscc -"Weldon Spring Site"		

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	**Keywords/Phrases**	**Hits**	**Uploaded into SRDB**
National Academies Press http://www.nap.edu/ COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson "Weldon Spring" AND "Jacobs Engineering"	819	0
NNSA - Nevada Site Office www.nv.doe.gov/main/search.htm COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson "Weldon Spring" AND "Jacobs Engineering"	0	0
NRC ADAMS Reading Room http://www.nrc.gov/reading-rm/adams/web-based.html COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson	104	1

Table A1-2: Database Searches for the Weldon Spring Plant			
Database/Source	**Keywords/Phrases**	**Hits**	**Uploaded into SRDB**
	"Weldon Spring" AND "Jacobs Engineering"		
U.S. Transuranium & Uranium Registries http://www.ustur.wsu.edu/ COMPLETED 03/02/2010	"Weldon Spring Plant" "Weldon Spring Chemical Co." "Weldon Spring Site Remedial Action Project" "WSSRAP" "WSS" "Weldon Spring" "Mallinckrodt" "Weldon Spring" "Weldon Spring" AND "National lead" "Weldon Spring" AND Bechtel Weldon Spring AND Ferguson "Weldon Spring" AND "Jacobs Engineering"	64	0

Table A1-3: OSTI Documents Ordered for Weldon Spring Plant			
Document Number	**Document Title**	**Requested Data**	**Date Received**
NLCO-1102 (Rev. 1)	Weldon Spring Radioactive Waste Management Plan, June 17, 1974	11/10/2009	Have not received
TID-5295	Uranium Oxide Refinery TBP Hexane Process, Jan 1, 1956	11/10/2009	Have not received
ORISE-98-0084	Verification Survey of the Composite and Annex Building Construction Sites and the Subcontractor Parking Lot, Dec 1, 1997	11/10/2009	Have not received
TID-7573-PAPER 7; AD-R036343	Evaluation of the Weldon Spring Sampling Plant, Paper 7 of AEC and Contractor SS Materials Management Meeting, May 19-22, 1958	11/10/2009	Have not received
MCW-1379	Production of Ionium from a Pitchblende Residue, Jul 28, 1955	11/10/2009	Have not received
MCW-1391	Recovery of Ionium and Uranium from Raffinate, Apr 1, 1957	11/10/2009	Have not received
MCW-1408	Pilot Plant Production of Ionium	11/10/2009	Have not received

Table A1-3: OSTI Documents Ordered for Weldon Spring Plant			
Document Number	**Document Title**	**Requested Data**	**Date Received**
	Concentrate, Nov 1, 1957		
M-5208	Health Hazards Resulting from the Casting of Uranium Metal at Mallinckrodt Chemical Works, Jul 2, 1953	11/10/2009	Have not received
MCW-1396	Sampling and Testing Procedures for Special Products, Jan 1, 1956	11/10/2009	Have not received
MCW-1384	Causes of Refinery Tank Explosion on December 7, 1955. Interim Topical Report, Mar 1, 1956	11/10/2009	Have not received