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Special Exposure Cohort Petition
under the Energy Employees Occupational Illness Compensation Act

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

OMB Number: 0920-0639 Expires: 07/31/2010

Special Exposure Cohort Petition — Form B

Use of this form and disclosure of Social Security Number are voluntary. Failure to use this form or disclose this number will not result in the denial of any right, benefit, or privilege to which you may be entitled.

General Instructions on Completing this Form *(complete instructions are available in a separate packet)*:

Except for signatures, please **PRINT** all information clearly and neatly on the form.

Please read each of Parts A — G in this form and complete the parts appropriate to you. If there is more than one petitioner, then each petitioner should complete those sections of parts A – C of the form that apply to them. Additional copies of the first two pages of this form are provided at the end of the form for this purpose. A maximum of three petitioners is allowed.

If you need more space to provide additional information, use the continuation page provided at the end of the form and attach the completed continuation page(s) to Form B.

If you have questions about the use of this form, please call the following NIOSH toll-free phone number and request to speak to someone in the Office of Compensation Analysis and Support about an SEC petition: 1-877-222-8570.

If you are:	☐ A Labor Organization,	Start at D	on Page 3
	☐ An Energy Employee (current or former),	Start at C	on Page 2
	☒ A Survivor (of a former Energy Employee),	Start at B	on Page 2
	☐ A Representative (of a current or former Energy Employee),	Start at A	on Page 1

A Representative Information — Complete Section A if you are authorized by an Employee or Survivor(s) to petition on behalf of a class.

A.1 **Are you a contact person for an organization?** ☐ Yes (Go to A.2) ☐ No (Go to A.3)

A.2 **Organization Information:**

Name of Organization

Position of Contact Person

A.3 **Name of Petition Representative:**

Mr./Mrs./Ms. First Name Middle Initial Last Name

A.4 **Address:**

Street Apt # P.O. Box

City State Zip Code

A.5 **Telephone Number:** ( ) -

A.6 **Email Address:**

A.7 ☐ Check the box at left to indicate you have attached to the back of this form written authorization to petition by the survivor(s) or employee(s) indicated in Parts B or C of this form. An authorization

If you are representing a Survivor, go to Part B; if you are representing an Employee, go to Part C.

Name or Social Security Number of First Petitioner: [redacted]

B Survivor Information — Complete Section B if you are a Survivor or representing a Survivor.

B.1 **Name of Survivor:** [redacted]

Mr./Mrs./Ms. First Name Middle Initial Last Name

B.2 **Social Security Number of Survivor:** [redacted]

B.3 **Address of Survivor:** [redacted]

Street Apt # P.O. Box

[redacted]

City State Zip Code

B.4 **Telephone Number of Survivor:** [redacted]

B.5 **Email Address of Survivor:**

B.6 **Relationship to Employee:**

Go to Part C.

C Employee Information — Complete Section C UNLESS you are a labor organization.

C.1 **Name of Employee:** [redacted]

Mr./Mrs./Ms. First Name Middle Initial Last Name

C.2 **Former Name of Employee** (e.g., maiden name/legal name change/other):

Mr./Mrs./Ms. First Name Middle Initial Last Name

C.3 **Social Security Number of Employee:** [redacted]

C.4 **Address of Employee** (if living):

Street Apt # P.O. Box

City State Zip Code

C.5 **Telephone Number of Employee:** ( ) -

C.6 **Email Address of Employee:**

C.7 **Employment Information Related to Petition:**

C.7a Employee Number (if known):

C.7b Dates of Employment: Start [redacted] 1959 End [redacted] 1966

C.7c Employer Name: Mallinckrodt Chemical Works

C.7d Work Site Location: Weldon Spring Plant

C.7e Supervisor's Name: [redacted]

Go to Part E.

Name or Social Security Number of First Petitioner: [redacted]

E Proposed Definition of Employee Class Covered by Petition — Complete Section E.

E.1 Name of DOE or AWE Facility: Weldon Spring Plant

E.2 Locations at the Facility relevant to this petition:
All divisions and buildings of the Weldon Spring Plant located on Highway 94 in St. Charles County, MO.

E.3 List job titles and/or job duties of employees included in the class. In addition, you can list by name any individuals other than petitioners identified on this form who you believe should be included in this class:
All Department of Energy (DOE), DOE contractors, or subcontractors or Atomic Weapons Employer (AWE) employees who worked at the Weldon Spring Plant during operational period 1958-1966.

E.4 Employment Dates relevant to this petition:

Start	1958	End	1966
Start		End	
Start		End	

E.5 Is the petition based on one or more unmonitored, unrecorded, or inadequately monitored or recorded exposure incidents?: ☒ Yes ☐ No

If yes, provide the date(s) of the incident(s) and a complete description (attach additional pages as necessary):

① No information is currently available about accidental releases of radioactive materials to the environment during operations of the Weldon Spring Plant. Dupree (1979) cites two accidental exposures of workers which occurred during plant operations and were described by Mason during a visit to ORAU in August 1979. One instance, a worker overfilled a pot with molten uranyl nitrate solution which spilled onto the floor. While attempting to turn off the valve, he fell into the material on the floor. An incident report was made (MCW 1961). In the other case, a worker inhaled soluble uranium while trapped in a dust enclosure. The worker suffered from "CNS" effect which Mason speculated was due to the chemical toxicity of uranium exposure. There are no notes about longer-term effects of either employee. (T-41)

Go to Part F.

Name or Social Security Number of First Petitioner: [redacted]

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Appendix — Continuation Page

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ES (cont)

(2) As noted in the previous SEC Cohorts for Mallinckrodt, many Weldon Spring Plant workers have given testimonials to numerous accidents that have occurred while working. [redacted], who went to WS in 1957, confirmed that while processing bombs, the bombs would often explode and spit out uranium and other contaminants which would wreck the inside of the electric furnace. He quoted that "Chemical operators, electricians, and others had the dusty and radioactive job of repairing the furnace." Sometimes explosions occurred everyday for a period of time. The workers' film badges did not measure amounts of radiation activity. The badge was just a kodak picture that measured level of radiation. It didn't record the amount. A high level of badge exposure alerted the safety department to reconstruct what is now called worksite dose reconstruction profile. The safety department would go out to worker worksites with a Geiger counter and air sampling devices and try to project the measure of radiation dosage during a specific period of time. Another worker, [redacted] advised there were production mishaps every processing step. He too mentioned an explosion in the Ether House. (T-3) During [redacted] interview, he reported that in 1963 he was required to perform electrical maintenance on the extrusion press in Bldg 301 after it exploded. He reported that the explosion released "black dust" and the solid form of uranium was involved. He stated no precautions were taken during the incident and he received no medical treatment. Since NIOSH could not locate such an incident, it's as if it didn't happen. NIOSH has not been able to resconstruct the doses for incidents nor have they been utilizing worker testimony. How is this claimant-favorable?

(3) Lack of accident documentation at the WS Site - Accidents and incidents that could potentially release material to the operations area and to unmonitored workers

Attach to Form B if necessary.

Name or Social Security Number of First Petitioner: [redacted]

Continuation Page — Photocopy and complete as necessary.

E5 (Cont)
onsite are important at the WS site, because the radiological hazards may not have been fully recognized, investigated, or documented at the time of its occurence. (T-10)
(4) Accidents may not have been documented sufficiently or be readily available. Accidents and incidents could have lead to acute intakes &/or contamination that greatly exceeded normal levels. (T-11)

Attach to Form B if necessary.

Name or Social Security Number of First Petitioner: [redacted]

F Basis for Proposing that Records and Information are Inadequate for Individual Dose — Complete Section F.

Complete **at least one** of the following entries in this section by checking the appropriate box and providing the required information related to the selection. You are not required to complete more than one entry.

F.1 ☒ I/We have attached either documents or statements provided by affidavit that indicate that radiation exposures and radiation doses potentially incurred by members of the proposed class, that relate to this petition, were not monitored, either through personal monitoring or through area monitoring.

(Attach documents and/or affidavits to the back of the petition form.)

Describe as completely as possible, to the extent it might be unclear, how the attached documentation and/or affidavit(s) indicate that potential radiation exposures were not monitored.

(1) Measured air concentrations of radon during the operational period at Weldon Spring are not reported in the literature. And no site specific ambient gamma data were available for the Weldon Spring Chemical Plant during the operational period. Furthermore, NIOSH has not been able to resolve whether there is sufficient radon data available to determine job-specific radon exposure. (T-4)
(2) No quantitative in vitro bioassay results have been

F.2 ☒ I/ We have attached either documents or statements provided by affidavit that indicate that radiation monitoring records for members of the proposed class have been lost, falsified, or destroyed; or that there is no information regarding monitoring, source, source term, or process from the site where the employees worked.

(Attach documents and/or affidavits to the back of the petition form.)

Describe as completely as possible, to the extent it might be unclear, how the attached documentation and/or affidavit(s) indicate that radiation monitoring records for members of the proposed class have been lost, altered illegally, or destroyed.

(1) Possible lost medical records, as previously stated in Mallinckrodt SEC petition. In a letter from [redacted] could not find one complete set of medical files which had been originally titled Terminated from Weldon thru 4/28/66. (T-2)
(2) Exposures were more than realized at the Weldon Spring which included thorium in Bldgs 103, 301, and 105. (T-3)

Part F is continued on the following page.

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Continuation Page — Photocopy and complete as necessary.

F1 (Cont)

found for thorium. However, dust studies for thorium operations indicate airborne thorium dust concentrations exceeded MAC for several operation studies. (T-5)

(3) Weldon Spring plant was identified as a site that likely received recycled uranium in relatively small quantities of materials after 1961. 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 U-236). Site records do not include the level of detail needed for accurate estimates of the amount of recycled material received and processed at WSP. It is known that the plant received shipments from other DOE sites that processed and shipped recycled uranium from fiscal years 1962-1967, but amounts of recycled uranium versus natural uranium are not known. (T-7)

(4) Wastes disposed of in the quarry during WSP operations present a diffuse source of particulate emissions in the air as a result of entrapment of contaminated wind-exposed surface soil or rubble. Radon-222 and Radon-220 generated from Ra-226 and Ra-224 respectively, in the quarry, also presented a diffuse source of airborne radionuclides. Most of the disposals after 1959 were not submerged. (T-6)

(5) Uranium and thorium effluents from various stacks were not directly measured. There is a lack of information available for quantifying source strengths. (T-6)

(6) Estimate of thoron release from the Weldon Spring Plant during operational period was not made, in part because the type of thorium material processed is not sufficiently described in accessible documentation. (T-7)

(7) No indication discovered so far that a routine urine-sampling program was implemented for thorium. No urine bioassay data for thorium have been found in worker files. (T-8)

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F1 (cont)

(8) A dust study of specific areas and jobs in Bldg 301 was conducted in 1961. Data was primarily used as a basis for recommending actions to reduce concentrations. There is no indication that dust concentration data were used to assess intake in calculating doses to individual workers. Dust exposure calculation worksheets were used at MCW St Louis, but worksheet columns did not list units. There is no evidence to show the same forms were used for WSP employees. The Annual Personnel Internal-External Radiation Exposure Report form, apparently in use by 1959 for WSP, included a section for average dust concentrations per minute per cubic meter by calendar quarter. None of the exposure reports reviewed had any data in that section. This indicates that the dust concentration was not routinely recorded. No specific in-plant air monitoring analysis sheets were found. (T-34)

(9) Reasonable dose estimates were unlikely possible. Mont Mason himself said that radon dose data are not sufficient except for minimum and maximum estimates. Radon exposures were primarily puff exposures, and there is no data for those puff exposures for individual exposures. (T-35)

(10) There is no data for radionuclides thorium-230, radium-226, actinium-227, and protactinium-231. (T-36)

(11) 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 WSP workers for thorium in 1966. The overall results showed 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

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Continuation Page — Photocopy and complete as necessary.

F1 (cont)
with the thorium-232 parent. (T-37)
(12) There was the potential of internal radionuclide exposure from production buildings. Bldg 103 consisted of UNAT dust (yellowcake and UO-3), ra-226, th-230, po-210, and pb-210, rn-222 and its short lived decay products, th-232 and its decay products starting in November 1963. Bldg 105 consisted rn-222 and its decay products making exposure possible. There are no measurements for these exposures. (T-38)
(13) NIOSH hasn't been able to specify radionuclide ratios for K-65 uranium extraction (including processing steps and filtration steps). Plant 6 involved K-65 residues.
(14) Uranalysis only detected uranium and was not able to accurately assign doses based on mixtures of radionuclides.
(15) In 1963 and 1964, an estimated 38,000 m³ of contaminated rubble, equipment, and soil were placed in the Weldon Spring Quarry and much of the waste not submerged. Thus, airborne concentrations of uranium and thorium resulting from use of WSQ were probably negligible before 1963 which is supported by measured concentrations of uranium in the air in 1961 and 1962. (T-39)
(16) In 1959, AEC recommended against respirator use except in emergency situations. When OSHA visited in the 1960's, all current respirators were to be disposed of because they were not appropriate for the hazard. There was not a set policy for personal protective equipment (T-40)
(17) Uranium ruptures which resulted in local tearing of the aluminum clad thereby released fission products.
(18) Relevant data for radiation exposure and exposures to toxics as well as identification of exposed vs. non-exposed population are incomplete.
(19) The Board has already recommended special exposure status be granted to employees in the Uranium

Attach to Form B if necessary.

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Continuation Page — Photocopy and complete as necessary.

F1 (cont)
Division who worked at Mallinckrodt between 1949 to 1958. And it has been noted that operations shifted to the WSP and there is no reason to believe that operations were different between the two locations. And NIOSH determined there was insufficient information to either 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 estimate the radiation doses of members of the class more precisely than a maximum dose estimate.

(20) Detailed documentation of radiation hazards, surveys, and potential exposures were not readily available or do not exist for the WS site, especially for the operational period 1957-1966. There is very limited operational-period on-site data. (T-12)

(21) Lack of routine personnel (egress contamination monitoring, consistent and document badging policy (with geometry correction factors), comprehensive bioassay program that encompassed all the major isotopes brought on site, and onsite environmental monitoring program for unmonitored workers leads to gaps in some of the information and data. (T-12)

(22) Lack of monitoring equipment and procedures to check workers for contamination in workplaces and upon leaving controlled areas. Contamination was common on workers. There is no indication that survey instruments were available and routinely used to monitor workers as they left operational areas of the WS site. (T-13 + T-14)

(23) There is no substantial site-wide atmospheric monitoring data available for the operational period to assure an accurate and integrated onsite environmental dose assessment. (T-15)

(24) Sizable fraction of WS workforce was not bioassayed on a routine basis during operational period. (T-15)

(25) Existing air monitoring data do not distinguish the source of emissions. (T-16)

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F1 (cont)

(26) Up to 50% of WS site workers were not routinely monitored. (T-16)

(27) Lack of air monitoring stations and lack of stations within particular geographic location at WSCP. (T-16)

(28) Radon indoor concentrations averaged four times that of outside radon concentrations. (T-16)

(29) Limits of detection were high in earlier years which could result in significant missed doses (T-17)

(30) No WS site documents have been located that sufficiently address the change in film badge response as a function of radionuclide exposure, especially to low-energy photons and changes in beta energies. (T-17)

(31) Lack of consistent and documented badging policy. (T-18)

(32) work performed by offsite workers could have induced fission in uranium that could emit radiation not normally encountered and expose WS workers and transporters who may not have been badged; and it could have created inhalable radioactive material for which bioassays were not performed. (T-19)

(33) Individuals or certain groups of workers may have been exposed to materials that contained greater concentrations of other forms of uranium and radionuclides, especially in or near plant locations. (T-20)

(34) workers exposed to radionuclides from recycled Uranium (plutonium, neptunium, U-236, fission products; such as Tc-99). Some workers or certain groups may have received significant portion of their inhalation dose from RU and its associated contaminants for a significant amount of time. (T-21)

(35) SC&A has not found any neutron doses recorded or columns labeled for entry of neutron doses in CER or DOE databases. It can not be determined if neutron film badges were issued or read what the results were, and if they were recorded in workers' files. (T-22)

(36) Lack of sufficient information/data or

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F1 (cont) investigation of RU and defaults to Fernald. RU from different DOE facilities contained different concentrations of radionuclides. The RU data are internally inconsistent and inconsistent with DOE documentation. RU's contribution to external and internal doses could be significant. (T-21 & T-23)

(37) There is very little information available concerning WS site occupational medical procedures, equipment, x-ray exam frequency, etc. No mention is made of the frequency of retake exams performed. No indication that photofluorography exams were conducted at WSCP (T-24 & T-25)

(38) Because Uranium was viewed as a chemical hazard and not a radiological hazard, little actual onsite environmental measurement data exist for the early years of WS operations, especially for unmonitored workers on site premises, but outside immediate operating areas. (T-26)

(39) Th-232 was not monitored routinely. (T-26)

(40) NO WS site operational measurements (T-28)

(41) NIOSH has indicated that effluent data back to the 1950s has not been found. (T-29)

(42) Lack of any thorium data as there is no basis to estimate thorium releases prior to 1967, even though thorium was first stored and used at WSCP as far back as 1958. Significant quantities of thorium in WSQ were not routinely sampled until after 1985. (T-29)

(43) Because there is no apparent environmental measurements performed during or after events, it is not possible to validate level of environmental exposure from the incident. (T-30)

(44) During operational period, WS workers were not bioassayed for other radionuclides. No thorium or radon air sampling until 1985. Limited onsite Uranium sampling. (T-30)

(45) Urine samples were not necessarily collected during everyday operations at the WS site. Urinalysis that was measured did not provide sufficient info to have

Attach to Form B if necessary.

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F1 (cont)
reliable dose assessment when there was a mixture of uranium compounds and uranium isotopes. (T-31)
(46) Lack of WS site documentation, especially in the area of neutron exposure, dosimeter response, and radiation field characterization. (T-32)
(47) No indication that routine extremity monitoring was performed at WS during operational period. (T-32 + T-33)

Attach to Form B if necessary.

Name or Social Security Number of First Petitioner: [redacted]

F2 (cont)

(3) Weldon Spring Plant workers from 1958-1966 reference the frequencies and types of x-ray examinations; however, there was no protocol for frequency of chest x-rays as a function of job category available nor is there reference to any other type of x-ray examination. Thirty percent of the time workers received two sets of chest x-rays in nine months or less and the files do not provide a reason for exams. The lack of historical records for x-ray dose estimate measurements for most years at WSP introduces a large uncertainty into the dose estimates that cannot be readily quantified. A potentially large source of uncertainty for WSP is the number and type of x-rays taken. No official protocol has been found that would rule out the possibility of other x-ray views or more frequent chest exams. (T-42)

(4) Urine bioassay data represent the primary function available to quantify uranium intake for the workers, however, data are not always available for individual workers. (T-43)

(5) Film monitors were placed at selected points throughout process areas to serve as integrating area monitors, and routine meter surveys were used to detect hot spots and provide information for decisions about protective measures. Data from the area monitors or meter surveys have not been found. (T-44)

(6) Workgroup urine data summaries have not been discovered. Data set was recreated using mixture of WSP and SEC Destrehan Street workers. If such data was used, it would only be feasible to implement a SEC for WSP workers. (T-45)

(7) Significant failure of radiological controls.

(8) Memo from [redacted] states that some St Louis employees transferred to WSP "where they are no longer being monitored for radiation exposure with film badges." This agrees with a footnote from

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F2 (cont)
individual film badge data summary sheets in 1966 that states "during start up at Weldon Spring in 1958 and later, some persons were not badged because they were not involved in radiation work." (T-47)
(9) Some workers recollect that documents were burned. (T-46)

Attach to Form B if necessary.

Name or Social Security Number of First Petitioner: [redacted]

F.3 ☐ I/We have attached a report from a health physicist or other individual with expertise in radiation dose reconstruction documenting the limitations of existing DOE or AWE records on radiation exposures at the facility, as relevant to the petition. The report specifies the basis for believing these documented limitations might prevent the completion of dose reconstructions for members of the class under 42 CFR Part 82 and related NIOSH technical implementation guidelines.

(Attach report to the back of the petition form.)

F.4 ☒ I/We have attached a scientific or technical report, issued by a government agency of the Executive Branch of Government or the General Accounting Office, the Nuclear Regulatory Commission, or the Defense Nuclear Facilities Safety Board, or published in a peer-reviewed journal, that identifies dosimetry and related information that are unavailable (due to either a lack of monitoring or the destruction or loss of records) for estimating the radiation doses of employees covered by the petition.

(Attach report to the back of the petition form.)

Go to Part G.

G Signature of Person(s) Submitting this Petition — Complete Section G.

All Petitioners should sign and date the petition. A maximum of three persons may sign the petition.

[redacted] 4/24/09

Signature Date

______________________ ____________

Signature Date

______________________ ____________

Signature Date

Notice: Any person who knowingly makes any false statement, misrepresentation, concealment of fact or any other act of fraud to obtain compensation as provided under EEOICPA or who knowingly accepts compensation to which that person is not entitled is subject to civil or administrative remedies as well as felony criminal prosecution and may, under appropriate criminal provisions, be punished by a fine or imprisonment or both. I affirm that the information provided on this form is accurate and true.

Send this form to:

SEC Petition
Office of Compensation Analysis and Support
NIOSH
4676 Columbia Parkway, MS-C-47
Cincinnati, OH 45226

If there are additional petitioners, they must complete the Appendix Forms for additional petitioners. The Appendix forms are located at the end of this document.

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F4 (1) Chemical exposures are often mixtures of substances making a risk assessment based on known toxilogical profiles of these materials nearly impossible. Several DOE reports suggest chemical hazards posed a significant health risk to both current and former DOE workers. These risks may exceed those posed by radionuclides.
(2) From the beginning of the nuclear era until 1989 radiation doses from radioactive materials inhaled or ingested by workers were not calculated or included in worker dose reports (T-48) In a DOE report from 4/7/97, One can be exposed through ingestion into the mouth or by absorption through wounds and cuts. Open wounds and cuts can not be determined for individual workers or during exposure in accidents. Also, while there was no requirement to actually calculate worker doses, the lack of internal radiation dose estimates in worker dose records means that the records of workers who were at risk of internal exposures are incomplete, misteading, and inaccurate. Information about exposures understates actual exposures. (T-48)

Attach to Form B if necessary.

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Public Burden Statement

Public reporting burden for this collection of information is estimated to average 300 minutes per response, including time for reviewing instructions, gathering the information needed, and completing the form. If you have any comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, send them to CDC Reports Clearance Officer, 1600 Clifton Road, MS-E-11, Atlanta GA, 30333; ATTN:PRA 0920-0639. Do not send the completed petition form to this address. Completed petitions are to be submitted to NIOSH at the address provided in these instructions. Persons are not required to respond to the information collected on this form unless it displays a currently valid OMB number.

Privacy Act Advisement

In accordance with the Privacy Act of 1974, as amended (5 U.S.C. § 552a), you are hereby notified of the following:

The Energy Employees Occupational Illness Compensation Program Act (42 U.S.C. §§ 7384-7385) (EEOICPA) authorizes the President to designate additional classes of employees to be included in the Special Exposure Cohort (SEC). EEOICPA authorizes HHS to implement its responsibilities with the assistance of the National Institute for Occupational Safety (NIOSH), an Institute of the Centers for Disease Control and Prevention. Information obtained by NIOSH in connection with petitions for including additional classes of employees in the SEC will be used to evaluate the petition and report findings to the Advisory Board on Radiation and Worker Health and HHS.

Records containing identifiable information become part of an existing NIOSH system of records under the Privacy Act, 09-20-147 "Occupational Health Epidemiological Studies and EEOICPA Program Records. HHS/CDC/NIOSH." These records are treated in a confidential manner, unless otherwise compelled by law. Disclosures that NIOSH may need to make for the processing of your petition or other purposes are listed below.

NIOSH may need to disclose personal identifying information to: (a) the Department of Energy, other federal agencies, other government or private entities and to private sector employers to permit these entities to retrieve records required by NIOSH; (b) identified witnesses as designated by NIOSH so that these individuals can provide information to assist with the evaluation of SEC petitions; (c) contractors assisting NIOSH; (d) collaborating researchers, under certain limited circumstances to conduct further investigations; (e) Federal, state and local agencies for law enforcement purposes; and (f) a Member of Congress or a Congressional staff member in response to a verified inquiry.

This notice applies to all forms and informational requests that you may receive from NIOSH in connection with the evaluation of an SEC petition.

Use of the NIOSH petition forms (A and B) is voluntary but your provision of information required by these forms is mandatory for the consideration of a petition, as specified under 42 CFR Part 83. Petitions that fail to provide required information may not be considered by HHS.

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The natural uranium was received as ore concentrates, from which uranium was extracted and converted to various compounds and metal forms and shipped off the site. Depleted uranium was received as metal and various intermediate chemical forms, processed on an intermittent basis, and used primarily in product development activities. Slightly enriched uranium was processed on an intermittent basis only, and was typically received in the form of scrap metal or residues. Natural thorium was received in either a nitrate or an oxide form and processed on an intermittent basis in the refinery (DOE 1986a). Table 2-7 summarizes the total receipts by fiscal year of operation.

Table 2-7. Annual uranium and thorium mass receipts (kg) (DOE 1986a).

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

a. Fiscal year begins on July 1 of the previous calendar year and ends on June 30 of the calendar year corresponding to the designated fiscal year.

b. Includes startup period in FY 1957.

* In 1999, DOE initiated the complex-wide Recycled Uranium Mass Balance Project (DOE 2000a), which identified WSP as a site that likely received recycled uranium in relatively small quantities of materials after 1961. The significance of these receipts of recycled uranium is that this material contains trace amounts of residual transuranic elements (including plutonium and neptunium), fission products (such as technetium), and reactor-produced uranium isotopes (such as ^{236}U) (DOE 2000a). Site records do not include the level of detail needed for accurate estimate of the amount of recycled material received and processed at WSP. It is known that the plant received shipments of uranium materials from other DOE sites that processed and shipped recycled uranium from fiscal years 1962 to 1967 (the period of recycled uranium shipment), but the amounts of recycled uranium versus natural uranium are not known. Due to the lack of information about recycled uranium quantities, the May 15, 2000, DOE report addressing WSP recycled uranium (DOE 2000a) assumes that all uranium receipts after 1961 (71,413,060 kg) were recycled, which is a large overestimate of the actual quantity because the same document reports that the majority of material processed through WSP was natural uranium.

2.2.4 Site Remediation

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

The purpose of the WSSRAP was to eliminate potential hazards to the public and environment and to make surplus real property available for other uses to the extent possible. The scope of work included dismantling the 44 WSCP buildings and structures and disposing of both radiologically and chemically contaminated structural materials and soils. The project also disposed of as much material

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To further our interest and as suggested by Dr. Shoup I returned to the record center on 9/1/72. (Friday) to work with Mr. Gary (asst. director) and a Mr. Gantt (Supervisor) to identify the records to be transfered. I found that in the interims since my last visit my name had been removed from the list of authorized MCW people but Mr. Beets had arranged that I could review shelf file lists. Perhaps at a later date we should reestablish my authorization through AEC, depending upon the outcome of the present proposed record transfer.

I dentified from the Record Center shelf list those records which sould be transfered and about this I make the following points.

1. In our 8/31 telephone discussion Dr. Shoup agreed with me that the Health Department file, and Medical Records for Destrehan should certainly be transfered now because this encompasses all of the important exposure people and data. Medical Records for Weldon only might remain in St. Louis if there was some reason.
2. A Possibly Serious Problem: Possible Lost Medical Records: When I again reviewed the shelf list with item 1 as a guide I could not find one complete set of medical files which we had originally titled Terminated From Weldon Thru 4/28/66. My personal records show 1186 names in this set. It is possible that these folders were later interfiled with some other group, or that the typist erred in preparing the list. It is not feasible to resolve this by examining at the rec center all the individual files at the record center. I therefore decided to list all medical records for transfer to your Oak Ridge files so that I can work with Viola and Marci to be sure there are no lost records and that each individual folder is identifiable as to locale.
3. A Serious Problem: Possible Destruction of Key Records. Included in the Record Center Shelf List is a seperate section for classified documents. I was permitted to examine this list and was shocked to find a sizeable list of titles for reports originating at Destrehan dealing with Dust Studies and other surveys which will be critical to any eventual matching of individuals to job and exposure. I recall each as being classified originally because it contained information about identity and production quantities of materials which were at that time classified. However, I think each of these was subsequently declassified as the process was declassified. The crucial point is this: I was told that each of these documents was beyond scheduled destruction date only because the record center does not have the required number of qualified observers. I believe these may be the only existing copies

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These documents make up the shelf list section designated V2161. Mr. Gary explained he had no classification authority and did not have access to these documents himself. Unless some action is taken promptly to safeguard these documents they will be destroyed at the first opportunity.

I do not know the correct procedure to safeguard, and eventuall declassify and transfer these documents. Although I classified some of them originally my present non-official status probably has no forc As a minimum, I expect that you or Al Becker should request through Dr. Benson, or Dick Evans, or Floyd Beets at O.R., that Mr. Gary at the St. Louis Federal Record Center be instructed not to destroy V2161. The next step will be follow-up with security to learn the procedure for getting the documents declassified or confirming that they are already declassified, so they can be transfered to you.

I failed to record the total volume I listed for transfer but remember it was of the order of 200 cubic feet stored in individual 1 cubic foot shelf boxes in which it will be shipped. My recollection is that all of this was contained in about 12 x 4 drawer cabinets at Weldon. I certainly agree with Marci that there should be no problem with storage space for these boxes at Oak Ridge. Incidentally, while at Oak Ridge I reassured myself that the building was essentially fire proof and well protected. However, at some point it may be wise to ask the AEC Fire Protection people to reapprove this area for the storage of critical records. Some of the existing or proposed records may qualify for fire proof files under AEC regulations.

I continue work on my report to you as time permits and hope to mail it by 9/8/72. I would like to visit O.R. again soon to review data from the computer center but think it best to wait the outcome of the expected transfer of records from St. Louis so I can help in sorting and identification. I will submit an invoice after completing my report.

Sincerely,
Mont G. Mason

DOC P 5-14 DOCA 10
PgT - only pg

[redacted]

Weldon Springs

T-3

Mallinckrodt -

Exposures and Location

Bldg.	Exposure
103	Hexane
105	Nitrous Oxide
201	Hydrofluorene Acid
301	Metal Reduction

Exposures more than realized at the Weldon Springs Plant -

Thorium in Bldgs. 103, 301 and 105

Thorium daughters - gamma radiation

Thorium - metal

also Tributyl phosphate - thousands of gallons

Hexane in thousands of gallons

(watch for liver damage)

ng

of ^{235}U in natural uranium ore concentrates represents less than 5% of the activity in natural uranium, and because the WSP processed only a small amount of slightly enriched uranium.

Radionuclide concentrations in WSP outdoor areas are based on limited environmental measurements at the site. The total amount of uranium emitted to the atmosphere has been estimated from monitoring data (Meshkov et al. 1986) and from a nuclear materials balance study (DOE 1986). Based on methods and data in these two reports, the estimated uranium activity emitted from the Plant ranged between 1 and 5 Ci/yr. An estimate of radon release, based on the amount of uranium processed during the operational period, ranges from 12 to 34 Ci/yr, assuming radium activity was 1% of uranium activity, radon was in equilibrium with radium, and all radon was released. Beginning in 1981, annual environmental monitoring reports provided estimates of air concentrations of particulate radionuclides and of radon at the WSCP and WSQ. These estimates reflect emissions during the later maintenance period, and throughout remediation activities. The TBD analysis used these data to derive annual estimates of intake for 1957 to 2004.

* Measured air concentrations of radon during the operational period are not reported in the literature. Therefore, a simplistic screening-level model was used to estimate air concentrations at the WSCP.

* Because no site-specific ambient gamma data were available for the WSCP during the operational period, this analysis evaluated ambient dose rates for the Feed Materials Plant in Fernald, Ohio, as reported in ORAU (2004). The reported net average dose rate for 1956 to 1970 was 0.18 mrem/hr, or 1,576 mrem/yr for continuous exposure. When this dose rate estimate is applied to the WSP operational period, the WSP site background rate of 99 mrem/yr (Bechtel 1986) is added to derive an ambient dose rate of 1,675 mrem/yr for continuous exposure. This corresponds to a 2,000-hr exposure of 382 mrem. Between 1982 and 2000, thermoluminescent dosimeters monitored ambient exposure at many perimeter locations around the WSCP, the WSRP, and the WSQ. These data are summarized in this TBD, which summarizes estimated ambient onsite dose for the WSRP, WSCP, and WSQ for periods between 1957 and 2004.

1.2.4 Occupational Internal Dosimetry

The WSP Occupational Internal Dosimetry TBD (ORAUT-TKBS-0028-5) discusses the internal dosimetry program and develops estimates of potential intakes. Radionuclides of concern at the site include naturally occurring isotopes of uranium (^{234}U, ^{235}U, and ^{238}U) and their decay products (primarily ^{230}Th and ^{226}Ra). Due to the amount of material processed, the primary radionuclides of concern for internal radiation dose are the uranium isotopes. Because WSP processed some natural thorium, dose reconstructors should consider ^{232}Th and its decay products, ^{228}Ra and ^{228}Th.

The primary modes of intake were chronic and acute inhalation. The internal dosimetry program required routine monitoring of environmental radon and thoron and their decay products when an individual was likely to receive an annual intake of 10% or more of the annual limit of intake. According to Revision 7 of the Internal Dosimetry Program Technical Basis Manual (DOE 2001), that threshold was never exceeded. Bioassay (urine) data estimate the activity of the radionuclide excreted in the urine following an inhalation. This TBD discusses these data, including history, sensitivity, and pertinent nuances of methods and data.

Urine bioassay data represent the primary information available to quantify uranium intake for the worker who is the subject of a claim. However, data are not always available for individual workers. These data can be supplemented by workgroup monitoring data, because essentially continuous bioassay monitoring of a worker was simulated by sampling at least one worker in the group each week, with Monday – Friday – Monday sampling for "exposed" workers.

potentially exposed workers (Section 5.3.1.1.1). The work group data have been reconstructed from urine data for all WSP workers by cost center code. Tables 5-7 to 5-16 (Section 5.3.1.1.5), list the median, the 95th percentile, and the maximum values of the uranium urine data per year for Monday samples and Friday samples by cost center and calendar year. The worker's urine data reports provide the cost center (Section 5.3.1.1.5).

If specific information is not available in the worker's file, the DR should consider the following default uranium source terms:

- Natural uranium, before 1961
- Natural uranium, recycled, 1961 to 1962
- Enriched (1%) uranium, recycled, 1963 to 1967

Because the feed uranium and uranium during processing were purified to some degree, it is reasonable to assume that the contributions of the long-lived uranium progeny, i.e., ^{230}Th and ^{226}Ra, were small in most areas of the WSP. However, for workers in Building 101 where the uranium concentrates were initially processed, the concentrations of ^{230}Th and ^{226}Ra should be assumed to be 5% of the ^{238}U activity and 1% of the ^{238}U activity, respectively as described in Section 5.2.2.

Because site-specific particle size data are not available, the default value of 5 μm AMAD should be used.

If the absorption type of the uranium to which the worker was exposed cannot be discerned from the data in the worker's file, the DR should use the absorption type that is the most claimant-favorable.

5.6.1.2 Thorium Intakes

* No quantitative *in vitro* or *in vivo* bioassay results have been observed for thorium (Sections 5.3.1.2 and 5.4.1). However, dust studies for thorium operations (Section 5.5.1.4) indicate that airborne thorium dust concentrations exceeded the MAC for several of the operations studied.

The suggested approach to assess natural thorium intakes is to use the approach in Section 5.3 of the Fernald TBD for internal dosimetry (ORAU 2004a). Application of the Fernald approach to WSP is based on the assumption that the thorium operations at Fernald are reasonably applicable to thorium operations at WSP. Assumptions and information used for the Fernald approach that also appear to be valid for WSP are:

1. Few, if any, *in vitro* analyses exist in worker files. The *in vivo* results that exist are not quantified for thorium, and there is not enough information available to quantify the thorium deposition from the *in vivo* results.

2. Although respiratory protection equipment was available and its use required, it cannot be assumed that the respirators were always used or that there was a tight seal to the face when they were used. No respiratory protection factor is assumed.

3. The MAC of 100 dpm/m^3 (4.5×10^{-11} μCi/cm^3) was used at Fernald for control purposes. The MAC of 70 dpm/m^3 was used at WSP for control purposes, or a factor of 0.7 less than the control level at Fernald.

4. Workers could have been exposed to airborne thorium above the MAC level. It is assumed that 100 hr/yr at 10 MAC accounts for intermittent exposures to high levels of airborne thorium.

However, the digestion phase of the refinery process would have released the trapped radon during the operational period. Offgases containing radon isotopes from this process were conveyed to the acid recovery plant at the WSCP. The discharge from the acid recovery plant was the prime source of radon emission and perhaps the only point source for radon isotopes.

Wastes disposed of in the raffinate pits were not a significant source of airborne radionuclides, particulate or gaseous, during the operational period due to the presence of water in the pits. It is unlikely that a significant portion of the sediments became sufficiently dry to be considered a source term during this period when they were being managed, even though Bechtel (1984a) reported that Pits 1 and 2 could become dry during the summer months. NLO (1977) concluded that the inherent consistency of the raffinate material precluded sufficient drying, and the pits did not pose a significant source of airborne contaminants.

Wastes disposed of in the quarry during WSP operations present a diffuse source of particulate emissions to the air as a result of entrainment of contaminated wind-exposed surface soil or rubble. Radon-222 and ^{220}Rn generated from ^{226}Ra and ^{224}Ra, respectively, in the quarry also present a diffuse source of airborne radionuclides. Although most of the material initially dumped in the quarry in 1959 was at an elevation below the average natural water level of 457 feet above mean sea level (MSL) reported in 1967, later disposals maintained a fill elevation of about 480 feet MSL, such that most of the waste was not submerged (*Weldon Spring Raffinate Pits and Quarry Task Force Report* 1967).

Uranium and thorium effluents from the various stacks were not directly measured. The total amount of uranium emitted to the atmosphere has been estimated from monitoring data (Meshkov et al. 1986) and from a materials balance study (DOE 1986). The reported atmospheric discharges from the materials balance study were engineering estimates derived from airflows and other process factors along with stack monitoring data, and are summarized in Table 2-8 in Part 2 of this Site Profile. Based on these two methods, the estimated amount of uranium activity emitted from the plant ranges between approximately 1 and 5 Ci/yr. Meshkov et al. estimated release rates for uranium decay products (^{230}Th, ^{226}Ra, ^{210}Pb) as a fixed percent of the estimated amount of ^{238}U released, assuming the activities of ^{230}Th, ^{226}Ra, and ^{210}Pb in the original uranium concentrate were 5%, 1%, and 1%, respectively, of that of ^{238}U. An estimate of radon release based on the amount of uranium processed during the operational period ranged from 12 to 34 Ci/yr (assuming radium activity was 1% of the uranium activity, radon was in equilibrium with radium, and all radon was released).

4.2.2.2 Post-1974 Source Terms (Monitoring and Remediation Periods)

During the monitoring and remediation periods, from 1975 to the present, diffuse emissions predominate as the source of radionuclides to the air at the WSCP, WSRP, and WSQ. Beginning in 1981, annual environmental monitoring reports have provided estimates of air concentrations of particulate radionuclides and of radon at the WSCP and WSQ. These estimates reflect emissions during the later monitoring period and throughout remediation activities.

4.2.3 Annual Intake of Radionuclides

As noted in Section 4.2.2, releases of radioactive particulates or radon to the atmosphere have not been fully quantified at the WSP for the operational period or the monitoring and remediation periods. Meshkov et al. (1986) attempted to quantify point source emissions for the operational period by considering monitoring data and the results of a materials balance study. However, in considering exposure to radionuclides, material released from stacks provides only a partial picture of how radioactivity becomes airborne. Diffuse sources resulting from wind entrainment or other mechanical

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Q = stack or building vent release rate (Ci/s)
f = wind frequency
u = wind speed (m/s)
h = height of effluent release (m)
K = constant (m)

Values used for the independent factors f and K correspond to the defaults in NCRP (1996), such that f is assumed equal to 0.25 (the maximum frequency for any compass point), and K is 1 m. The average wind speed at the WSCP from 1951 to 1970 was 4.2 m/s from the south (Weidner and Boback 1982). The height of effluent release from the acid recovery plant is not known, but is assumed to be 10 m.

The estimate by Meshkov et al. (1986) of an average annual release of radon (^{222}Rn) between 12 and 34 Ci/yr (1.4×10^4 to 4.0×10^4 Bq/s) is based on the following: (1) 5,000 to 14,500 MT of uranium materials were processed per year; (2) 70% of this was uranium; (3) radium activity was 1% of the uranium activity (believed to be an upper end estimate); (4) radon was in equilibrium with radium, and (5) all radon escaped during processing. Using this value in Equation 4-1, the estimated average radon concentration within 100 m of the source is between approximately 30 and 80 Bq/m^3 (0.7 and 2 pCi/L). Because the radon concentrations reported here include background radon contributions, the average value of 11 Bq/m^3 (0.3 pCi/L) for the Weldon Spring area (MK-Ferguson 2001a) is added to the calculated estimates, such that the average concentration ranges from 41 to 91 Bq/m^3. This TBD uses the upper estimate, which is a claimant-favorable assumption.

* A similar estimate for thoron release from the WSCP during the operational period was not made, in part because the type of thorium material processed is not sufficiently described in accessible documentation. DOE (1986) states that "natural thorium was typically received in either a nitrate or oxide form," with no mention of it as a concentrated feed material. In addition, DOE (1986) indicates that the amount of thorium material processed ranged from a low of 0.05% of the natural uranium material processed in 1964 to a high of 7% in 1965. According to Wallo (1981), the ThO_2 mass content, and thus the ^{232}Th content, of natural thorium materials (like monazite sand) is approximately 5%. Assuming this and a secular equilibrium between ^{232}Th and ^{224}Ra and ^{220}Rn, it follows that the estimated release of thoron according to the procedure above for radon is between 0.04% and 5% of the radon release. If, however, the thorium material is assumed to be concentrated similarly to uranium (i.e., 70% ^{232}Th), the thoron release could range from 0.5% and 70% of the radon release. Either way, the estimated dose attributable to thoron and its progeny is insignificant under these assumptions with respect to radon and its progeny because radon progeny have a higher estimated equilibrium factor and higher associated dose factors than thoron progeny (MK-Ferguson 2001b).

This TBD analysis estimated radon concentrations for the WSQ during the operational period from measurements made in the vicinity from 1979 through 1982 (Meshkov et al. 1986; MK-Ferguson 1989a). Because the activities of ^{226}Ra and ^{224}Ra are not significantly depleted in the quarry over time, due to limited leaching and continuous production of these isotopes from precursors present in the waste (Section 4.2.3.1), these years reasonably represent radon emanations for the WSQ during the years of operation of the plant. These measurements are applied to the 1963-1967 period only. Prior to that, drummed thorium waste was probably submerged and no significant source of radon probably existed. Table 4-5 lists the average measured concentrations for this area.

Measurements of radon in 1979 through 1982 did not distinguish between ^{222}Rn and ^{220}Rn. Therefore, the analysis made a dose-maximizing assumption that all the radon measured was ^{222}Rn. Because most of the dose from inhaled radon is due to alpha-emitting, short-lived daughters, the working level month (WLM) unit is often a preferred method of reporting inhalation intake exposure to

Table 5-16. Uranium urine data summary by cost center for 1965.

Cost center	Monday samples (mg/L)			Number of records	Friday samples (mg/L)			Number of records
	Median	95th percentile	Maximum		Median	95th percentile	Maximum	
110	0.018	0.034	0.042	41	0.018	0.094	0.152	19
120	0.011	0.025	0.047	156	0.014	0.072	0.318	102
150	0.011	0.035	0.347	61	0.011	0.036	0.049	35
180	0.020	0.045	0.052	45	0.024	0.102	0.146	26
200	0.015	0.024	0.028	19	0.016	0.069	0.088	16
290	0.010	0.015	0.021	26	0.010	0.025	0.039	19
310-321	0.011	0.042	0.065	29	0.012	0.024	0.024	16
350	0.007	0.018	0.027	36	0.005	0.012	0.024	19
370-379	0.008	0.022	0.045	165	0.010	0.055	0.193	120
380-390	0.010	0.026	0.050	46	0.011	0.026	0.033	27
392	0.004	0.010	0.015	28	0.006	0.015	0.016	18
400-460	0.009	0.039	0.078	85	0.017	0.045	0.068	25
500-510	0.006	0.015	0.016	60	0.005	0.012	0.016	34
520	0.007	0.018	0.020	57	0.008	0.022	0.030	33
530	0.006	0.018	0.022	19	0.012	0.022	0.022	7
550-569	0.007	0.018	0.027	109	0.007	0.014	0.026	73
600-690	0.006	0.014	0.016	65	0.005	0.011	0.011	5
370 Elec	0.008	0.024	0.027	28	0.008	0.027	0.031	22
370 Mill	0.012	0.030	0.048	35	0.012	0.048	0.060	22
370 Misc	0.010	0.024	0.057	88	0.008	0.025	0.039	63
370 Mtns	0.011	0.025	0.069	69	0.012	0.029	0.061	48
370 Pipe	0.012	0.020	0.024	37	0.011	0.027	0.042	26
Other	0.010	0.020	0.075	85	0.009	0.033	0.055	43

Table 5-17. Uranium urine data summary by cost center for 1966.

Cost center	Monday samples (mg/L)			Number of records	Friday samples (mg/L)			Number of records
	Median	95th percentile	Maximum		Median	95th percentile	Maximum	
110	0.015	0.030	0.039	19	0.025	0.053	0.053	12
120	0.009	0.030	0.052	130	0.015	0.048	0.100	83
150	0.006	0.018	0.019	25	0.011	0.054	0.054	13
180	0.012	0.036	0.036	20	0.025	0.048	0.048	9
200	0.006	0.027	0.027	17	0.011	0.024	0.024	9
290	0.006	0.024	0.024	22	0.006	0.036	0.036	12
310-321	0.009	0.021	0.022	20	0.016	0.459	0.459	11
350	0.002	0.008	0.008	13	0.002	0.009	0.009	15
370-379	0.006	0.027	0.046	107	0.008	0.050	0.052	61
380-390	0.007	0.021	0.025	26	0.008	0.029	0.029	13
400-460	0.006	0.025	0.035	53	0.008	0.032	0.045	24
500-510	0.002	0.008	0.011	26	0.004	0.008	0.010	35
520	0.006	0.025	0.018	34	0.004	0.024	0.024	25
530	0.005	0.019	0.021	24	0.004	0.022	0.022	12
550-569	0.005	0.012	0.020	72	0.004	0.012	0.028	38
610-690	0.006	0.011	0.012	18	0.004	0.008	0.008	4
370 Elec	0.012	0.027	0.027	13	0.009	0.036	0.036	10
370 Mill	0.008	0.024	0.027	32	0.008	0.034	0.071	16
370 Misc	0.008	0.021	0.028	53	0.010	0.033	0.036	29
370 Mtns	0.009	0.022	0.066	46	0.009	0.050	0.055	25
370 Pipe	0.006	0.015	0.024	22	0.015	0.088	0.088	13
Other	0.006	0.019	0.027	58	0.004	0.025	0.213	37

5.3.1.2 Thorium

* There is no indication discovered so far that a routine urine-sampling program was implemented for thorium. No urine bioassay data for thorium have been found in the worker files.

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> *The recycled uranium (RU) data are internally inconsistent and also inconsistent with some available DOE documentation. They are incomplete and do not appear to be claimant favorable for many workers and periods, though they are likely to be claimant favorable for many others. The problem in regard to adequacy of RU data is even more difficult for RU raffinate streams, in which the trace radionuclides, notably plutonium-239, thorium-230, and neptunium-237, became concentrated.*

Therefore, basing the WS site dose reconstruction recommendations on the Fernald site profile may lead to claimant-unfavorable assumptions and underestimated doses assigned to some workers.

The statement on page 35 of TBD-5 (ORAUT 2005e) consists of the following:

> ***If specific information is not available** in the worker's file, the DR should consider the following default uranium source terms:*
>
> - *Natural uranium, before 1961*
> - *Natural uranium, recycled, 1961 to 1962*
> - *Enriched (1%) uranium, recycled, 1963 to 1967.* (Emphasis added.)

This recommendation is not conducive to consistency in dose reconstruction and appears to be an over simplification resulting from the lack of sufficient information/data or investigation of the RU issue.

Although RU was a small fraction of the total uranium processed at the WS site, its contribution to external and internal doses, especially to the workers associated with processing it and exposed to it by products, could be of significance in dose reconstruction. Therefore, RU should play a more predominate rôle in the TBDs and in dose reconstruction.

Finding #5: Lack of Accident/Incident Documentation Not Sufficiently Addressed

* The WS site TBDs do not address accidents or incidents at the WS site (or the apparent lack of their documentation being readily available), except for the brief mention of two accidents on page 27 of TBD-2 (ORAUT 2005b). Accidents and incidents that could potentially release material to the operations area and to unmonitored workers onsite are important at the WS site, because the radiological hazards may not have been fully recognized, investigated, or documented at the time of its occurrence. During onsite interviews with former WS site workers, the subject of accidents/incidents was mentioned with the concern that MCW did not identify and document radiological events sufficiently, either through lack of knowledge of the radiological hazards, or as a manner of policy at that time. SC&A's preliminary investigation of several cases indicates that the accidents described by former workers were not evident or were not recorded sufficiently in the workers DOE files. For example, a serious furnace accident occurred in 1960; however, the only mention of it in the worker's DOE records was a couple of brief sentences describing the *medical* aspect of the worker's complaints; no investigation into the radiological aspect of the accident was evident. There was no other documentation of the accident in the worker's files that SC&A could locate. Another serious accident apparently

occurred in 1961; the only reference in the worker's DOE file was an entry in the "PERSONAL MONITORING SUMMARY RECORD," which stated that "*Data included in Feb. Accident File.*" There was no other record of it in the worker's DOE records. Fortunately, this accident was written up in a MCW report (MCW 1961) and the dose reconstructor evaluated the dose received from the accident during the dose reconstruction process. However, this may not always be the case.

* Accounting for accidents and incidents that have the potential to lead to radiation exposures are problematic at a number of DOE and DOE contractor sites. The WS site is no exception; it is especially prone to this problem, because uranium was treated mostly as a chemical rather than a radiological hazard during the plant's operational period. Therefore, occurrences may not have been documented sufficiently or be readily available to the dose reconstructor to allow dose reconstruction by today's standards. Although NIOSH's WS site profile cannot correct the lack of documentation in the workers' DOE files, it can provide information concerning where the dose reconstructor might search to locate any accident or incident files, and outline some of the major occurrences that the dose reconstructor should be aware of to match them to possible exposures for a given case. By the nature of the operations at the WS site, most doses came from chronic low-level exposures; however, unusual occurrences, accidents, and incidents could lead to acute intakes and/or contamination that greatly exceed the normal levels.

3.2 SPECIFIC ISSUES

SC&A reviewed the six TBDs for the WS site and has identified a number of issues that may impact the outcome of dose reconstruction for the WS site workers; these are listed in the following section as findings associated with each specific TBD.

3.2.1 Occupational Medical Dose ORAUT-TKBS-0028-3

Background and Introduction

The current version of the WS site TBD for occupational medical dose (ORAUT 2005c) is a relatively short TBD, and contains some general information and data gathered from DOE site profiles and technical documents. There is very little information available concerning the WS site occupational medical procedures, equipment, x-ray exam frequency, etc. Some references are made to MCW documents associated with the Destrahan Street location. The TBD does present dose conversion factors (DCFs) and organ dose estimates for a number of organs/tissues for the periods prior to 1970 and after 1985 taken from ORAUT-OTIB-0006 (ORAUT 2005g). Because of the lack of WS site documentation in the occupational medical area, this TBD is by nature mostly a genetic document. SC&A has reviewed this TBD and has the following Secondary Findings pertinent to the WS site.

Finding #6: Inconsistence in Frequency of X-ray Exams

TBD-3 (ORAUT 2005c, page 8) assumes annual x-rays for **all periods,** and in Section 3.1.2 (page 7), it recommends annually from **1955 through 1966**. However, in the same paragraph it states, "A review of pre-1970 files indicates that, approximately 30% of the time, workers

In this section, a brief summary of the issues are presented, followed by a summary of the primary findings. (Primary Findings, along with Secondary Findings, are further detailed in Section 3 of this report). SC&A then provides a discussion of the strengths of the TBDs, followed by recommendations for improvement at the end of this section, which are listed as Observations.

Summary of Issues

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SC&A found that detailed documentation of radiation hazards, surveys, and potential exposures were not readily available or do not exist for the WS site, especially for the operational period of 1957–1966 or the maintenance period of 1967–1984. Therefore, the underlying problem with the TBDs for the WS site is that they rely on recent WS site data (1985–2002), recent and some previous era environmental data, and very limited operational-period onsite data. Because of the limited WS site data and documentation, NIOSH also relied heavily on the Fernald site data and extrapolated it to the WS site TBDs. Unfortunately, the data/assumptions used for the Fernald site TBD are frequently estimates, instead of the results of measurements or documented information. Additionally, relatively recent data for the Fernald site was sometimes extrapolated to earlier time periods when sufficient data did not exist. The SC&A review of the Fernald site profile (SC&A 2006) points out the shortcoming of using these assumptions/data at the Fernald site. Understandably, SC&A has reservations concerning applying these questionable concepts/data from the Fernald site to the WS site profile.

*

During the operational period, the WS site had a basic uranium bioassay and beta/photon badging program in place, and a limited site-parameter environmental monitoring program. However, the lack of routine personnel/egress contamination monitoring, consistent and documented badging policy (with geometry correction factors), comprehensive bioassay program that encompassed all the major radioisotopes brought on site, and an onsite environmental monitoring program for unmonitored workers leads to gaps in some of the information and data. NIOSH attempted to fill in some of these gaps with extrapolated operating conditions and data from other DOE sites. SC&A found some of these recommended methods to be uncertain, not sufficiently supported, or in some cases, potentially not claimant favorable. Additionally, a site profile should evaluate the accuracy, adequacy, and representativeness of the workers' recorded internal and external dose data. SC&A could not find that NIOSH had performed a sufficient analysis of this type.

The majority of material handled at the WS site was natural uranium. In addition, some RU, EU, and DU were also handled at the WS site, along with natural thorium. NIOSH acknowledges this in the WS site TBDs and makes some provisions for it, but concludes in general that because uranium is the most prevalent, it will dominate dose reconstruction. However, it cannot be assumed that because the majority of the material handled was natural uranium, then the other radionuclides are of a minor issue. Some workers involved in specific processes that handled these other radionuclides (and workers in the vicinity) had the potential of receiving substantial doses from these other radionuclides.

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1.1 SUMMARY OF PRIMARY FINDINGS

1.1.1 Findings Common to Several TBDs

In reviewing the six site profile documents for the WS site, SC&A found several issues that were common to more than one of the documents. The following is a brief summary of the primary findings that reflect these issues.

Lack of Personnel Contamination and Egress Monitoring

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The WS site TBDs do not mention the lack of monitoring equipment and procedures to check workers for contamination in the work places and upon leaving the controlled areas. During recent worker interviews, SC&A did not find that the workers recalled any regular egress monitoring, either between the operations areas to the non-operations areas (cafeteria, administration offices, labs, maintenance facilities, sidewalks, storage yards, grounds, etc.), or when leaving the plant site (guard shack, parking lots). Workers were apparently allowed to leave the controlled areas and the WS site without confirmation that they were not contaminated. This could have spread contamination to non-controlled areas at the site, creating chronic exposure (internal and external) to unmonitored workers, as well as leaving contamination on the workers that could lead to chronic beta exposure to the skin (especially in the folds of the skin) and internal exposure through ingestion and resuspension/inhalation.

Inadequate Information Concerning Workers Status/Exposures for 1967–1984

The WS site TBDs do not explicitly state when DOE employees and/or DOE contractors were no longer at the WS site after it stopped operations in December of 1966. It has not been determined if DOE employees and/or contractors were present or involved during 1967–1969 when the U.S. Army was attempting to decontaminate and renovate buildings located at the WSCP; during the 1970–1984 monitoring and maintenance period; or during 1983–1984 when there were efforts to remediate leaks at the WSRP. If DOE contract personnel were present at the WS site soon after the shutdown in December 1966, they could have been exposed to numerous radionuclides during decommissioning, clean out, and revamping the facility for a completely different use. This could have lead to incidences of skin contamination, inhalation, and ingestion of radioactive materials (including uranium and thorium, as well as radionuclides contained in the raffinate concentrates and its scale/soil that had been resuspension) that were not monitored and/or recorded or grossly underestimated.

If DOE employees and/or contractors were present at any of DOE's WS facilities during the period 1967–1984, the TBDs need to be revised to include this period of dose evaluation for the site. Therefore, the issue of **legal ownership** of the property (and liability) as a function of time needs to be determined through federal/state/local records to determine if the TBDs should be revised to include additional time periods.

3.0 VERTICAL ISSUES

SC&A developed the issues for the six WS site profile documents using the five objectives defined in SC&A's review procedures (SC&A 2004). Some issues were related to more than one TBD and are covered under Section 3.1, *Common Issues*, and some are related to a specific TBD and are covered under Section 3.2, *Specific Issues*. The issues were identified, consolidated, and grouped into findings. Findings that could substantially impact the results of dose reconstruction for some workers are listed as Primary Findings, and those that are important, but may have less impact on the results of dose reconstruction, are listed as Secondary Findings. SC&A has also identified some areas where changes in the TBDs would be beneficial to the claimant by preventing possible mistakes during dose reconstruction, or where clarification of items would make them less ambiguous. These were listed as *Observations*.

3.1 COMMON ISSUES

In reviewing the six WS site TBDs, SC&A found several issues that were common to more than one of the documents. Therefore, to eliminate repetition, SC&A has consolidated these issues. The following are five areas that SC&A has identified where the present TBDs lacks sufficient information/data that may impact NIOSH's ability to perform claimant-favorable dose reconstructions.

3.1.1 Primary Findings

Finding #1: Lack of Personnel Contamination and Egress Monitoring

* The WS site TBDs do not mention the lack of monitoring equipment and procedures to check workers for contamination in the work places and upon leaving the controlled areas. SC&A could not locate any documentation to verify if such procedures and equipment were used at the WS site during the operating period of 1957–1966. At that time, uranium was considered to be mostly a chemical hazard and control measures were mainly based on chemical toxicity limits, not radiological limits (ORAUT 2005e, page 11). During recent worker interviews, SC&A did not find that the workers recalled any regular egress monitoring, either between the operations areas to the non-operations areas (cafeteria, administration offices, labs, maintenance facilities, sidewalks, storage yards, grounds, etc.) or when leaving the plant site (guard shack, parking lots). Workers did indicate, and documents support, that they were required to change clothing when entering and leaving the operations areas (some workers showered, but this policy does not appear to have been strictly enforced); however, there is no evidence that the workers were checked for contamination before leaving the controlled areas to ascertain that they were not contaminated. Documents indicate that some area monitoring (i.e., with portable survey instruments and swipes) and cleanups were performed to keep some surfaces below certain limits (MCW 1965b, page 20), but there is no indication that survey instruments or hand/foot monitoring stations were available and routinely used to monitor workers as they left the operational areas or the WS site. Contamination was apparently commonplace inside the process * areas as evident by a statement in MCW Uranium Division (MCWUD) *Summary of Health Protection Practices* (MCW 1965b, page 20), which states that "Inside the process locations, surface contamination measurements have little significance." Contamination was apparently common on workers, as described in a 1960 WS site document (Burr 1960):

Individual Exposures versus Average Exposures

The TBDs rely heavily on the fact that mostly natural uranium (>97%) was processed at the WSCP; therefore, the contributions from other forms of uranium (DU, EU, or RU) and other radionuclides (thorium, radium, etc.) are small compared to natural uranium. Whereas the most likely exposures (internal and external) may have been from natural uranium, this does not negate the fact that individuals or certain groups of workers may have been exposed to materials that contained greater concentrations of other forms of uranium and radionuclides, especially in or near plant locations dedicated to the other forms of radioactive material processing and in areas around discharge streams, waste, and raffinate pits.

Assuming that natural uranium predominates as the source of a worker's dose could lead to an underestimate of the worker's correct dose if the worker was exposed to radioactive materials other than natural uranium.

1.1.2 Findings Specific to a TBD

SC&A reviewed the six TBDs for the WS site and has identified a number of issues that may impact the outcome of dose reconstruction for the WS site workers. The following is a brief summary of the primary findings that reflect these issues pertinent to each TBD.

1.1.2.1 Occupational Environmental Dose ORAUT-TKBS-0028-4

Lack of Atmospheric Monitoring Data for Operational Period

* There is no substantial site-wide atmospheric monitoring data available for the operational period to assure an accurate and integrated onsite environmental dose assessment. The TBD recognizes this lack and relied upon the use of dose estimates for the public derived from its reviews of the Fernald plant data to estimate the onsite environmental dose for the WSCP workers. This is problematic, in that raw emissions data from Fernald is not easily converted to environmental dose for the WS site workers when several emission points of varying geographic locations have to be considered, as well as the lack of knowledge that could place workers at specific locations during exposure events. SC&A believes that the limited environmental data presented in the TBD and the lack of environmental surveys of onsite locations over time does not support the supposition and/or conclusion of negligible dose to onsite personnel.

Insufficient Data for Unmonitored Workers' Internal Environmental Dose

The TBD used one series of measurements (decontaminating 5-ton hoppers) and site parameter measurements to determine contributing intakes to non-bioassayed workers during 1957–1967. The hopper dust monitoring experiment consisted of measurements performed on one day under one particular condition, and the parameter measurements contributed very little (<1%) to the final results. This limited (in space, operations, and time) airborne/intake data is not sufficient to construct an adequate intake dose database for unmonitored workers at the WS complex, especially considering that a sizable fraction of the work force was not bioassayed on a routine basis during this period. *

Lack of Validation for Maximum Environmental Dose

The TBD fails to validate the adequacy of estimating the maximum environmental dose due to source terms at differing locations at the Weldon Spring Plant. In the current TBD, NIOSH has offered that existing air monitoring data do not distinguish the source of emissions; therefore, to some measure, it only allows evaluation of cumulative emissions and dose. The estimation of dose methodology currently being applied by NIOSH does not reasonably address maximum dose to workers who are not routinely monitored across the site, which could have been 50% of the site workers.

SC&A believes that the lack of air monitoring stations in general and the overall lack of stations within a particular geographic location at the WSCP (of known higher releases of uranium and thorium) does not readily enable one to accurately estimate environmental dose using only the very limited existing air monitoring data.

1.1.2.2 Internal Dose ORAUT-TKBS-0028-5

Incomplete Assessment of Uranium Decay Products

The TBD recommendations for dose estimate from decay products of U-238 are incomplete, and not always claimant favorable. The dose from **inhaled** Th-234 is not included along with the dose from inhaled U-238 in the dose calculations. What is included is the dose from Th-234 that builds up inside the body after an intake of U-238 takes place. Additionally, the dose contribution due to Pa-234m from the decay of Th-234 in the body also needs to be included in the internal dose calculations. While it is true that the Pa-234m outside the body only contributes to the external dose, the Pa-234m originating inside the body from Th-234 decay must be included in the internal dose calculations.

Incomplete Assessment of Radon Exposure

The TBD describes the potential radionuclide exposure in the different buildings of the WSCP. Radon is listed as a source of exposure inside buildings 101, 103, 105, 403 and 407. However, the recommended approach used in the TBD to estimate radon doses is based on **environmental** radon concentrations for the areas within 100 meters of the assumed release point, which is the acid recovery plant stack. Using this approach requires that several assumptions be made, which results in large uncertainties in the dose estimates for workers located in **indoor** workplaces. For example, documentation shows that indoor radon concentrations averaged four times that of outside radon concentrations.

Therefore, the approach recommend in TBD-5 is not always claimant favorable. NIOSH should propose a more reliable and claimant-favorable approach to the assess radon exposure for WSCP workers.

Different Solubility Classes Listed for the Same Element

The TBD provides a list of solubility classes for uranium and thorium compounds in some of the buildings at the WSCP; however, the TBD lists different solubility classes for the same element. Because there were no means of separating isotopes of a given element at the WSCP, the chemical properties were the same for all uranium isotopes, as well as for all thorium isotopes. According to ICRP Publication 78 (ICRP 1997) the biokinetic behavior is the same for U-234, U-235, and U-238. The same applies for thorium Th-232 and Th-228.

In view of the operations that took place at the WSCP, the TBD should provide justification/clarification concerning the use of different classes of solubility for the same element at the WS site.

Missed Dose and Coworker Data Not Adequately Addressed

The TBD does not address potentially missed internal doses, which should be part of a TBD for internal dose. The limits of detection (LODs) were generally high in the earlier years, which could result in significant missed doses. For the dose reconstructor to assign missed dose, the TBD needs to provide some information concerning the minimum detectable activity (MDA) for given bioassay techniques for the important radionuclides of concern at the WS site as a function of time. Additionally, the TBD provides some coworker internal dose information, but does not provide sufficient instructions for its use or the details of the data, such as the percent of workers bioassayed or the representativeness of the data (especially important at the WS site, because not all workers were bioassayed and none continuously). Also, most internal dose TBDs provide a summary section in the main text or as an appendix with recommendations and procedural steps for using coworker data.

1.1.2.3 External Dose ORAUT-TKBS-0028-6

Shallow and Extremity Doses Not Sufficiently Characterized

The TBD briefly addresses dosimeter quantities, open window (OW), shielded window (SW), etc., and compares beta dose from NU, EU, and DU for shallow doses; additionally, electron dose is listed as >15 keV. But the TBD does not address geometry factors, total shallow dose, or extremity monitoring during the operational period. A geometry factor is needed for adequate dose assessment, because a film badge does not register the same dose as the worker's tissue/organ is receiving from the betas and low-energy photons when handling, machining, scooping, etc., uranium containing materials. No WS site documents have been located that sufficiently address the change in film badge response as a function of radionuclide exposure, especially to low-energy photons and changes in beta energies. Additionally, there is no indication that routine extremity monitoring was performed at WS during the operational period.

Badging Policy Not Consistent

The TBD does not provide sufficient and/or consistent information concerning the badging policies at the WS site. This raises the question of what badging criteria were actually used in practice and if workers not considered at the time to be exposed to radiation were potentially exposed but not monitored because of being in a pre-defined category. The lack of a consistent and documented badging policy may negatively impact dose reconstruction, because the dose reconstructor could assign an unbadged worker only external environmental dose when the worker should have been assigned coworker external dose. Additionally, badging policies could impact the validity of the coworker dose database.

Lack of Sufficient Coworker Data Development for External Dose

The TBD provides annual average gamma and beta exposures. However, the TBD does not provide any information concerning the details of this information, such as the number of data points for each entry, the percent of workers badged, the range of readings, if background was subtracted, if zeroes or outliers were included, if a threshold dose was used, etc. The data presented is a good start in creating a coworker database; however, in order to determine its validity and representativeness, there needs to be additional work performed on the data, as mentioned above. Plus, for internal coworker data, some guidance for use of the data in a summary form would be appropriate.

1.2 SUMMARY OF STRENGTHS

The WS site TBDs were written in six volumes, which assist the reader in accessing and analyzing the information in an orderly fashion. The TBDs addressed the different time periods (operational, shutdown, maintenance, and remediation) relevant to the WS site in a consistent manner. TBD-2 (ORAUT 2005b) provided a sufficient description of the site's history from its origin in 1941 as an ordnance plant to its final state containing the above-ground disposal cell. References were well documented and editorial errors were kept to a minimum. (See Section 1.3, entitled Observations, for some of the errors that were located during this review.)

The various authors were fairly consistent in the information they presented across the six TBDs, and made reasonable attempts to locate substitute data when it was missing for the WS site. This data was sometimes extrapolated from later WS site data, the Fernald site TBDs, or generic DOE documents, and these methods may be appropriate in some situations. However, because of the frequent lack of WS site-specific data/information, SC&A has concerns with using this approach. These concerns are expressed as findings in this report.

NIOSH analyzed some of the environmental, internal (in-vitro bioassays), and external (gamma and beta) dose data and provided summary tables of this information in the appropriate TBDs. Some of this data will be helpful for use by the dose reconstructor for cases where there are gaps in the workers' dose records, or for workers who were unmonitored. SC&A has reviewed this information and included their evaluation in the findings of this report.

With the information available at the time of the writing of the first version of the WS site profile, the TBDs were reasonably well written. However, SC&A suggest that the TBD be revised with any new information NIOSH has acquired since 2005 and address SC&A's concerns expressed in this report.

1.3 OPPORTUNITIES FOR IMPROVEMENT

SC&A has identified some areas where changes in the TBDs would be beneficial to the claimant by preventing possible mistakes during dose reconstruction or clarifying items to make them less ambiguous. These are listed as Observations in this section.

1.3.1 Observations – General

Observation – Lack of Coverage of Offsite Activities

* Apparently, some work was performed by offsite contractors for the WS site, which consisted of inspection of uranium metal samples by cutting of the material and then irradiation using high-energy betatrons. This procedure could induce fission in uranium and create fission products that could emit radiation not normally encountered in a uranium facility, and expose nearby WS workers and transporters who may not have normally been badged; and it could have created inhalable radioactive material for which bioassays were not performed. This subject should be investigated and addressed in the appropriate TBDs.

1.3.2 Observations – Occupational Medical Dose

Equation 3-1, *Dom = SnDi*, is provided on page 6 of TBD-3 (ORAUT 2005c) and the individual terms in the equation are defined, except for the term "S." This may have been meant to be the Greek symbol sigma "Σ" for summing, instead of an "S."

1.3.3 Observations – Environmental Dose

Observation #1 – Application of Environmental Doses

Section 4.1.2 of TBD-4 (ORAUT 2005d, page 6) states the following:

> *The term occupational environmental dose refers to the radiation dose received in the course of work duties outside plant buildings, but on the WSCP site. This TBD considers internal and external exposures to radionuclides in the outdoor environment separately in calculating this dose. Dose reconstructors can use estimated occupational environmental dose to develop a reliable individual dose when a worker was not monitored adequately.*

However, this statement should be qualified to apply only to workers that were **not** routinely exposed and would not be considered a radiation worker by today's standards. If the worker would be considered a radiation worker by today's standard, then the dose reconstruction should be based on coworker dose data, not environmental dose data.

Observation #2 – Special Uranium Curie

The equation for the special uranium curie is correct on page 31 of TBD-5 (ORAUT 2005e), and on page 14 of TBD-4 (ORAUT 2005d), where it is stated that "The original data are reported in

Sections 4.2.2.2 and 4.2.32 of TBD-4 (ORAUT 2005d); Sections 5.3.2, 5.4.2, 5.5.2, 5.5.3, and 5.6.2 of TBD-5 (ORAUT 2005e); and Sections 6.1.3.2 and 6.1.3.3 of TBD-6 (ORAUT 2005f) do not contain sufficient information for the dose reconstructor to be able to assess dose to claimants who may have worked for DOE or its contractors at the WS site during 1967–1984. If DOE contract personnel were present at the WS site soon after the shutdown in December 1966, they could have been exposed to numerous radionuclides during decommissioning, clean out, and revamping the facility for a completely different use. Because uranium was viewed as a chemical rather than a radiological hazard at that time, sufficient controls and monitoring practices may have not have been in place. This was more likely to occur during the time period immediately following plant closure, because the MCW health and safety infrastructure at the WS site was no longer in place. Plant operating protocol would not have been in enforced; buildings and equipment were considered surplus, and supplies/materials (including leftover radioactive material or contaminated material) would have been considered a nuisance and disposable. Working under these conditions could have created a mindset that radiological safety was not an issue (for both the contractor and the workers). This could have lead to incidences of skin contamination, inhalation, and ingestion of radioactive materials (including uranium and thorium, as well as radionuclides contained in the raffinate concentrates and its scale/soil that had been resuspension) that were not monitored or recorded, or grossly underestimated.

It should be determined if there were DOE or DOE contractor shutdown personnel, decontamination and decommissioning workers, or clean-up crews during the years immediately following the 1966 closure, and if there were guards and security staff during the period 1967–1984. If DOE employees and DOE contractors were present at any of DOE's WS facilities during the period 1967–1984, the TBDs need to be revised to include this period of dose evaluation for the site. Therefore, the issue of *legal ownership* of the property (and liability) as a function of time needs to be determine through federal/state/local records to determine if the TBDs should be revised to include additional periods.

Finding #3: Individual Exposures versus Average Exposures

In a number of places (ORAUT 2005d, page 11–12, and ORAUT 2005f, page 23), the TBDs rely on the fact that mostly natural uranium (>97%) was processed at the WS Chemical Plant; therefore, the contributions from other forms of uranium (DU, EU, or RU) and other radionuclides (thorium, radium, etc.) are small compared to natural uranium. Whereas the most likely exposures (internal and external) may have been from natural uranium, this does not negate the fact that individuals or certain groups of workers may have been exposed to materials that contained greater concentrations of other forms of uranium and radionuclides, especially in or near plant locations dedicated to the other forms of radioactive material processing and in discharge streams, waste, and raffinate pits.

Calculating the dose from the radioisotopes that produce 95% or 99% of the dose, as was done in TBD-4 (ORAUT 2005d, pages 11–12), to arrive at the conclusion that natural uranium over-rode all the other radionuclides is not claimant favorable to some workers monitored for only natural uranium who may have received a significant fraction of their internal and/or external doses (either chronic or acute) from other radionuclides. Additionally, non-bioassayed and unbadged workers located near, but not in, a process area may have received unrecorded environmental internal and external doses from sources other than natural uranium.

Likewise, it may not be claimant favorable to assume that all the beta doses were received from natural uranium (as in ORAUT 2005f, page 23), based solely on the fact that 97% of the material processed was natural uranium. Some workers may have received beta doses from other radioisotopes if they were involved in EU, RU, thorium, and other mission-specific projects or processes.

Assuming that natural uranium predominates as the source of a worker's dose could lead to an underestimate of the worker's correct dose if the worker was exposed to radioactive materials other than natural uranium.

3.1.2 Secondary Findings

Finding #4: Recycled Uranium Not Adequately Recognized in the TBDs

Recycled uranium (RU) and its associated radionuclides are one of the major concerns of former WS site workers. During onsite worker interviews, in Computer Assisted Telephone Interview (CATI) reports, and in potential SEC issues, the radionuclides from RU (plutonium, neptunium, U-236, and fission products, such as Tc-99) are listed as foremost concerns and among the items that the workers believe the government did not know, or was not fully disclosing the health hazards of. Therefore, RU should be clearly identified in the TBDs and included in the materials handled at the WS site, such as in the bullet points on page 6 of TBD-1 (ORAUT 2005a) and in Section 2.2.2.2 of TBD-2 (ORAUT 2005b, page 10), with equal importance compared to other materials. TBDs 1, 3, and 6 make no mention of RU; TBD-2 contains one paragraph on page 23, and TBD-5 (ORAUT 2005e) has a short section concerning RU on page 15 and mentions it on page 35, along with enriched (1%) uranium for 1963–1967. Of the six TBDs, the environmental dose TBD-4 (ORAUT 2005d) contains the most material concerning RU. On pages 10–12 of TBD-4, the assumption is made that because the amounts of RU handled at the WS site were a small fraction of the total uranium materials handled, then there is no need to consider RU and its associated contaminants to be potentially significant contributors to onsite environmental dose. This may be true on average or for chronic offsite environmental doses, but this assumption does not consider the fact that some workers or certain groups of workers may have received a substantial portion of their inhalation dose from RU and its associated contaminants for a significant amount of time near an RU-handling process. Although TBD-4 (ORAUT 2005d) did mention RU, it did not address the issue of RU for unmonitored workers environmental dose in sufficient detail.

Not only are the details of the RU at the WS site important, but also the source of the RU is important, because RU from different DOE facilities contained different concentrations of radionuclides (DOE 1985). Therefore, the associated radiation hazards (internal and external) to WS workers would depend on the source of the RU. Defaulting to the Fernald site concerning RU issues [as recommended in WS TBD-5 (ORAUT 2005e, page 15)] may not be technically sound, especially in areas where data for Fernald is uncertain. SC&A's review of the Fernald site profile (SC&A 2006) is summarized as follows:

Additionally, the TBD needs to provide information to assist the dose reconstructor in determining when to assign neutron dose to workers. Information such as job titles, where and when UF_4 and UF_6 materials were present to create potential neutron exposures, etc., would assist the dose reconstructor in determining when to assign neutron dose.

* SC&A has not found any neutron doses recorded or columns labeled for entry of neutron doses in the Center for Epidemiological Research (CER) or DOE databases for neutron doses in the claimant files analyzed to date. From the information contained in the TBD, it cannot be determined if the neutron film badges were issued or read, what the results were, and if they were recorded in the workers' files.

> *The recycled uranium (RU) data are internally inconsistent and also inconsistent with some available DOE documentation. They are incomplete and do not appear to be claimant favorable for many workers and periods, though they are likely to be claimant favorable for many others. The problem in regard to adequacy of RU data is even more difficult for RU raffinate streams, in which the trace radionuclides, notably plutonium-239, thorium-230, and neptunium-237, became concentrated.*

Therefore, basing the WS site dose reconstruction recommendations on the Fernald site profile may lead to claimant-unfavorable assumptions and underestimated doses assigned to some workers.

The statement on page 35 of TBD-5 (ORAUT 2005e) consists of the following:

> ***If specific information is not available** in the worker's file, the DR should consider the following default uranium source terms:*
>
> - *Natural uranium, before 1961*
> - *Natural uranium, recycled, 1961 to 1962*
> - *Enriched (1%) uranium, recycled, 1963 to 1967.* (Emphasis added.)

This recommendation is not conducive to consistency in dose reconstruction and appears to be an over simplification resulting from the lack of sufficient information/data or investigation of the RU issue.

* Although RU was a small fraction of the total uranium processed at the WS site, its contribution to external and internal doses, especially to the workers associated with processing it and exposed to it by products, could be of significance in dose reconstruction. Therefore, RU should play a more predominate role in the TBDs and in dose reconstruction.

Finding #5: Lack of Accident/Incident Documentation Not Sufficiently Addressed

The WS site TBDs do not address accidents or incidents at the WS site (or the apparent lack of their documentation being readily available), except for the brief mention of two accidents on page 27 of TBD-2 (ORAUT 2005b). Accidents and incidents that could potentially release material to the operations area and to unmonitored workers onsite are important at the WS site, because the radiological hazards may not have been fully recognized, investigated, or documented at the time of its occurrence. During onsite interviews with former WS site workers, the subject of accidents/incidents was mentioned with the concern that MCW did not identify and document radiological events sufficiently, either through lack of knowledge of the radiological hazards, or as a manner of policy at that time. SC&A's preliminary investigation of several cases indicates that the accidents described by former workers were not evident or were not recorded sufficiently in the workers DOE files. For example, a serious furnace accident occurred in 1960; however, the only mention of it in the worker's DOE records was a couple of brief sentences describing the *medical* aspect of the worker's complaints; no investigation into the radiological aspect of the accident was evident. There was no other documentation of the accident in the worker's files that SC&A could locate. Another serious accident apparently occurred in 1961; the only reference in the worker's DOE file was an entry in the "PERSONAL MONITORING SUMMARY RECORD," which stated that "*Data included in Feb. Accident File.*" There was no other record of it in the worker's DOE records. Fortunately, this accident was written up in a MCW report (MCW 1961) and the dose reconstructor evaluated the dose received from the accident during the dose reconstruction process. However, this may not always be the case.

Accounting for accidents and incidents that have the potential to lead to radiation exposures are problematic at a number of DOE and DOE contractor sites. The WS site is no exception; it is especially prone to this problem, because uranium was treated mostly as a chemical rather than a radiological hazard during the plant's operational period. Therefore, occurrences may not have been documented sufficiently or be readily available to the dose reconstructor to allow dose reconstruction by today's standards. Although NIOSH's WS site profile cannot correct the lack of documentation in the workers' DOE files, it can provide information concerning where the dose reconstructor might search to locate any accident or incident files, and outline some of the major occurrences that the dose reconstructor should be aware of to match them to possible exposures for a given case. By the nature of the operations at the WS site, most doses came from chronic low-level exposures; however, unusual occurrences, accidents, and incidents could lead to acute intakes and/or contamination that greatly exceed the normal levels.

3.2 SPECIFIC ISSUES

SC&A reviewed the six TBDs for the WS site and has identified a number of issues that may impact the outcome of dose reconstruction for the WS site workers; these are listed in the following section as findings associated with each specific TBD.

3.2.1 Occupational Medical Dose ORAUT-TKBS-0028-3

Background and Introduction

The current version of the WS site TBD for occupational medical dose (ORAUT 2005c) is a relatively short TBD, and contains some general information and data gathered from DOE site profiles and technical documents. There is very little information available concerning the WS site occupational medical procedures, equipment, x-ray exam frequency, etc. Some references are made to MCW documents associated with the Destrahan Street location. The TBD does present dose conversion factors (DCFs) and organ dose estimates for a number of organs/tissues for the periods prior to 1970 and after 1985 taken from ORAUT-OTIB-0006 (ORAUT 2005g). Because of the lack of WS site documentation in the occupational medical area, this TBD is by nature mostly a genetic document. SC&A has reviewed this TBD and has the following Secondary Findings pertinent to the WS site.

Finding #6: Inconsistence in Frequency of X-ray Exams

TBD-3 (ORAUT 2005c, page 8) assumes annual x-rays for **all periods,** and in Section 3.1.2 (page 7), it recommends annually from **1955 through 1966**. However, in the same paragraph it states, "A review of pre-1970 files indicates that, approximately 30% of the time, workers received two sets of chest x-rays in a period of 9 months or less (excluding x-rays for termination of employment);the files do not provide reasons for this." (This would equate to an overall average of 1.25 x-ray exams per worker per year.) In the last paragraph of Section 3.1.2 (page 7), it suggest an x-ray exam was conducted every 2 or 5 years for post-1985 workers. And in the next to the last paragraph on page 13 of the TBD, it recommends annual chest x-rays for **1958–1964**.

While the frequency of x-ray exams are discussed in Section 3.1.2 of TBD-3 (ORAUT 2005c), no mention is made of the frequency of retake exams (because of technical or medical complications) that might add to the total number of x-ray exams performed. ORAUT-OTIB-0006 (ORAUT 2005g, page 14) states, "Retakes should serve as a signal to give special consideration to the evaluation of technique factors, and hence the resultant dose calculations." This indicates that retakes were not an uncommon event.

TBD-3 (ORAUT 2005c) should recommend a defined set of claimant-favorable x-ray exam schedules, so that dose reconstructions can be performed in a consistent manner. It should also be determined if some workers or groups of workers [such as those that wore respirators, were food handlers (tested for tuberculosis), etc.] may have had more frequent x-rays exams; perhaps this was the reason for the increase in frequency as noted in Section 3.1.2 of the TBD.

Finding #7: Photofluorography Exams Not Adequately Addressed

TBD-3 (ORAUT 2005c) mentions photofluorography (PFG) exams on page 7. However, no recommendations to the dose reconstructor are made concerning this type of exam, other than that there had not been any indications that PFG exams were conducted at the WSCP. ORAUT-OTIB-0006 (ORAUT 2005g, page 21) states, "It is reasonable to presume that at least some of the occupational medical diagnostic chest x-rays with the DOE and its predecessor organizations were accomplished by PFG and, in the absence of data to the contrary, the use of PFG should be assumed to ensure claimant-favorable dose reconstructions." Table 7-6 of ORAUT-OTIB-0006 (page 24) also indicates that DOE/AEC facilities used PFG equipment from 1953–1968, which would encompass the 1957–1966 operating period at WSCP. If PGF equipment was not located at the WSCP site, workers may have had occupational PFG exams performed at offsite locations, such as Barnes Hospital Labs, which serviced MCW workers in the earlier years. TBD-3 (ORAUT 2005c) does not show evidence of investigating this subject sufficiently (such as checking Missouri state records, etc.) to justify discounting the possibility that some WS site workers received PGF exams.

Finding #8: Lumbar Spine Exams Not Addressed

TBD-3 (ORAUT 2005c) makes no mention of lumbar spine x-rays and states on page 7 that, "Therefore, the analysis for this TBD assumed annual PA and LAT chest x-ray examinations for all employees, and considered no other view." This excludes both PFG and lumbar spine exams. Lumbar spine exams were sometimes performed for workers that performed heavy and strenuous work, such as laborers and construction workers, or those with back problems. ORAUT-OTIB-0006 (ORAUT 2005g, page 21) states, "However, the possibility of periodic lumbar spine examinations, including an exit employment physical examination should not be precluded." Therefore, TBD-3 should address the issue of lumbar spine exams for WS site workers.

Finding #9: Use of ICRP-34 Instead of ICRP-74

TBD-3 (ORAUT 2005c) utilizes ICRP 34 (ICRP 1982) instead of ICRP 74 (ICRP 1996), which was used in NIOSH's OCAS-IG-001 (NIOSH 2002) to determine absorbed dose from kerma values. Preliminary studies by SC&A indicate that the use of ICRP 34 may tend to underestimate the absorbed dose. ICRP 34 does not have 10 organs that are now in ICRP 74. The use of ICRP 74 is particularly important when the medical examinations included PFG chest x-ray exams, where doses can double or triple based on the differences between ICRP 34 and ICRP 74; for PA and lateral x-rays, the underestimations are not as significant. This issue amplifies the need to ascertain whether WS site workers received PFG exams, as outlined in the previous finding.

3.2.2 Occupational Environmental Dose ORAUT-TKBS-0028-4

Background and Introduction

In TBD-4 (ORAUT 2005d), most of the environmental dose to WSCP workers is attributed to uranium and thorium. Internal dose from exposure outside the process areas is assumed to be due mainly to facility releases and resuspension from contaminated soils, or from waste storage and holding areas (WSQ and WSRP). Source terms are derived mainly from limited process knowledge and calculated or estimated maximum releases from stacks and vents. Because uranium was viewed mainly as a chemical hazard rather than a radiological hazard, little actual onsite environmental measurement data exist for the early years of operations, especially for unmonitored workers on the site premises, but outside the immediate operating areas. Most effluent data utilized in the TBD were derived from several annual environmental reports for the years 1981 to 2002, inclusive. Most releases and subsequent doses were presumed to be primarily from natural uranium (mostly U-238); lesser contributors to environmental dose were Th-232 and Th-230. Notably, the Th-232 was not monitored routinely, as it was believed to be a minor contributor to dose. The TBD concludes that estimates of environmental dose can be derived strictly from uranium air monitoring data, as it should account for resuspension of other radionuclides in soil. Because of the lack of environmental monitoring for unmonitored workers during the operational period, this TBD relies heavily on data obtained during the remedial period, environmental parameter measurements, and the air concentration measurements during a hopper cleaning event.

The current version of TBD-4 (ORAUT 2005d) was published with significant data gaps in the environmental data before 1985. Therefore, the current TBD version already warrants a future revision due to these existing data gaps, especially because of the need for historical data during the operational period (1957–1967). Any revisions should include additional information pertinent to onsite environmental monitoring and effluent data collected, and any applicable information that comes from NIOSH responses to SC&A's site profile review that have occurred since the publication of this TBD.

SC&A has reviewed the TBD, as written, and has identified the following findings.

- There are no indications if this operation (cleaning the hopper) would have constituted a representative source term for all operations over the entire 11-year period.
- There are no other WS site operational measurements to compare these result to in order to assess if they might be at the high, average, or low end of the air concentration range.
- The WS facility was a relatively large complex. Air concentration in one location on a given day most certainly would not be representative of all locations on all days.
- The site environmental parameter measurements had very little influence on the resulting average value (Table 4-5, max = 1.7E-2/4.4 Bq/m^3 = 0.4%; hence, the final values for 1957–1967 were essentially derived from the one hopper monitoring experiment).
- Validating the results of this measurement by comparing it to the average **estimated** value for Fernald (see ORAUT 2005d, page 16) is not supported, because conditions/ operations at the two facilities would not be sufficiently identical on a daily basis; plus the Fernald value was based on an estimated value, not a measured value.

This limited (in space, operations, and time) airborne/intake data is not sufficient to construct an adequate intake database for unmonitored workers at the WS complex; especially considering that a sizable fraction of the work force was not bioassayed on a routine basis during this period.

Finding #12: Lack of Validation for Maximum Environmental Dose

The TBD (ORAUT 2005d) fails to validate the adequacy of estimating the maximum environmental dose due to source terms at differing locations at the WS site. In the current TBD, NIOSH has offered that existing air monitoring data do not distinguish the source of emissions; therefore, to some measure, it only allows evaluation of cumulative emissions and dose. The estimation of dose methodology currently being applied by NIOSH does not reasonably address maximum dose to workers who are not routinely monitored across the site. At WSCP, as many as 50% of the site workers were not routinely monitored.

SC&A believes that the lack of air monitoring stations in general and the overall lack of stations within a particular geographic location at the WSCP (of known higher releases of uranium and thorium) do not readily enable one to accurately estimate environmental dose. It will be difficult for the dose assessor to accurately estimate environmental dose to an individual without more comprehensive air monitoring data, environmental surveys, and substantial knowledge of where workers were located during such episodic and acute releases.

The TBD also does not attribute any significant environmental dose to pre-existing contamination of the environment from plant operations. Very limited environmental analyses of soils are used to suggest that nearly all uranium contamination is attributable to natural causes. The aerial radiological survey referred to in TBD-4 (ORAUT 2005d, page 25) was performed after the WSCP ceased operation by approximately a decade. There is no supporting evidence presented to indicate that the resulting exposure rate (61–88 mrem per year) resulting from this later measurement would have been applicable during the operational period, given the plant has operated for 10 years, had a reasonably high throughput (14,000 tons per year), and experienced numerous incidents and episodes of environmental releases. For monitored workers (nearly

50%) of the population prior to 1992 when restoration commenced, it is assumed that the dosimeters that were provided would reasonably include an environmental dose component. This approach tends to discount any potential dose resulting from inhaled materials that would not be assessed by dosimetry badges that monitored only ambient gamma radiation. Also, some workers were not included in sufficient routine bioassay programs to assess internal dose. For unmonitored workers (nearly 50% of the population), environmental dose is attributed to only ambient (gamma) radiation levels. Similarly, this approach does not consider internal deposition or variations due to spatial locations on the site or episodical releases.

To this extent, NIOSH has recently agreed for other sites that using emissions data alone to estimate air concentrations may not be appropriate. There is a need for more historic environmental data to fill the gaps for sampling and air monitoring for a larger group of radionuclides, such as thorium that was disposed of in the WSQ.

Secondary Findings

Finding #13: The TBD Lacks Sufficient Effluent Data Prior to 1967

The TBD (ORAUT 2005d) has relied, to the extent possible, on data derived from known source terms, yet the validation of that data remains in question. NIOSH/ORAUT should validate this data against any remaining effluent data or reports for the period of 1992 through 2002, when restoration took place and sufficient monitoring data exists.

* NIOSH has indicated that an obstacle to its evaluation is that effluent data back to the 1950s has not been found at the time this TBD was written and approved for dose assessor use. Another source of ongoing controversy involves the development of coworker data that could possibly be used in some instances to address unaccounted for doses from environmental releases. This is particularly important, due to the very large numbers of unmonitored workers at WSCP.

* Another significance of the lack of environmental data is the lack of any early thorium data as there is no basis to estimate thorium releases prior to 1967, even though thorium was first stored and used at WSCP as far back as 1958. Also, significant quantities of thorium in the WSQ were not routinely sampled until after 1985. It would be important to locate any early (1950s and 1960s) air monitoring or soil analyses data to validate the presence or absence of these nuclides in the environs at WSCP.

SC&A believes that the lack of substantial environmental data before 1967 warrants closer scrutiny to effectively assess all doses from environmental sources to ensure claimant favorability.

Finding #14: Stated Uranium/Thorium/Radium/Lead Ratios should be used with Caution

TBD-4 assumes that during the operations period, Th-230 was 5% of the U-238 activity, Ra-226 was 1% of the U-238 activity, and Pb-210 was 1% of the U-238 activity (ORAUT 2005d, page 9). These values may have been applicable for some locations and time periods at the WS site; however, this may not have been true for certain locations, as acknowledged in TBD-5 not to provide estimates of dose, but rather to offer estimates of source terms to be used by dose assessors to estimate the dose to the individual claimant. Effluent data used by dose assessors would often include quantities for both routine and episodic releases; however, NIOSH recognizes that significant current gaps exist in this information.

Episodic releases detailed in the TBD are limited to two events. The most significant event was a spill of uranyl nitrate. Estimated doses to the immediately impacted workers were made; however, no dose to the nearest public member and unmonitored onsite workers are estimated. Because there were no apparent environmental measurements performed during or after the event, it is not possible to validate the level of environmental exposure from the incident. The other event described is the exposure of a worker to soluble uranium in a dust enclosure. This event was also not monitored, and reportedly no environmental samples were taken. SC&A believes this, as well as statements in the TBD, do not seem to support the idea that environmental exposures were necessarily negligible and resulted mostly from incident exposure to resuspended uranium compounds. To the contrary, the lack of sufficient environmental data would suggest the need to develop a maximum exposure scenario for numerous events. Although not all events were recorded, knowledge of potential releases and events at this site could be used to better estimate maximum exposures that are claimant favorable.

3.2.3 Internal Dose ORAUT-TKBS-0028-5

Background and Introduction

TBD-5 (ORAUT 2005e) was written to provide the dose reconstructor with recommendations concerning internal dose reconstruction at the WS site during the operational period of 1957–1966, the monitoring period 1975–1984, and the remediation period 1985–2001 (it does not include the period 1967–1974). The TBD covers the major areas of concern, such as radioactive material source terms, air concentrations, the assessments of intakes, and the in-vitro and in-vivo measurements. During the operational period, 1957–1966, the workers at WS were periodically monitored by urinalysis for uranium, but were not bioassayed for other radionuclides. Some one-time qualitative in-vivo bioassays for thorium were conducted in July 1966. Because there was limited onsite uranium and no thorium or radon air sampling up until 1985, the authors of this TBD relied heavily on the Fernald site internal dose TBD-5 (ORAU 2004b) and WS site environmental and remediation monitoring data, and then applied this data to the WS site during the operating period. Natural, enriched, depleted, and recycled uranium and natural thorium were included as potential internal dose contributors. SC&A reviewed the TBD according to *Site Profile Reviews Procedures* (NIOSH 2004) and has the following findings.

Primary Findings

Finding #18: Incomplete Assessment of Uranium Decay Products

TBD-5 (ORAUT 2005e) recommendations for dose estimates from decay products of U-238 are incomplete, and not always claimant favorable. For example, the following is stated on page 13 of the TBD:

same for all thorium isotopes. According to ICRP Publication 78 (ICRP 1997), the biokinetic behavior is the same for U-234, U-235 and U-238 (see Tables A.10.6, A.10.7 and A.10.8, page 127). The same applies for thorium Th-232 and Th-228 (see Tables A.9.8, A.9.9, and A.9.10, page 107).

Although Table 5-6 of TBD-5 (ORAUT 2005e) was taken directly from the reference DOE/OR/21548-241 (DOE 2001), it does not appear to be applicable here. In view of the operations that took place at the WSCP, TBD-5 (ORAUT 2005e) should provide justification/clarification concerning the use of Table 5-6 and the classes of solubility that should be assumed in the different workplaces at the WS site.

Finding #21: Missed Dose and Coworker Data Not Adequately Addressed

Missed Dose

TBD-5 (ORAUT 2005e) does not address potential internal missed dose, which should be part of the TBD for internal dose, especially considering the complexity of the workplace conditions and the urinalysis techniques applied at the WS site. The urinalysis was based on a photofluorimetric method and reported in units of mg U/liter urine; the isotopic composition of uranium in urine samples was unknown. Additionally, the LOD was generally high in the earlier years, which could result in significant missed doses. For the dose reconstructor to assign missed dose, the TBD needs to provide some information concerning the MDA for given bioassay techniques for the important radionuclides of concern at the WS site as a function of time, and specific radionuclides to assume, or a claimant-favorable default radionuclide. If the MDA values are unknown, the worst-case scenario for a combination of MDA/radionuclide should be provided.

Coworker Dose

If the dose reconstructor needs to apply internal coworker dose, TBD-5 (ORAUT 2005e) does not provide sufficient instructions for the use of Tables 5-8 through Table 5-17, especially in view of the problem with cost-center code listings, as described in a previous finding. Most internal dose TBDs provide a summary section in the main text or as an appendix with recommendations and procedural steps for using coworker data.

* An item of importance that applies to both missed and coworker dose data is the fact that in the everyday operations at the WS site, urine samples were not necessarily collected, as stated in some of the documents. For example, TBD-5 (ORAUT 2005e, page 17) quotes the following from MCW 1965b:

> *The routine sampling program seeks to have one or more persons from each operational group in the plant sample(d) each week. When a person represents his group in the sample, he is asked to give samples on (1) Monday a.m., (2) Friday p.m., and (3) Monday a.m. The Monday sample tends to show the amount semi-fixed in the body, the Friday sample reflects the daily uptake. The sample from each person is analyzed separately and entered in his summary.*

- There is no supporting evidence that the EU received at the WS site was never >1%. A WS document (MCW 1966, page 4) states up to 1.5% enrichment.
- If the EU was received from Fernald, there is no guarantee that it was always <1% enrichment. Fernald's TBD-5 (ORAUT 2004b, page 9) states the following:

  Late in 1964 the Fernald site provided the first production of 1.95% ^{235}U billets for the Hanford Site. During the following production years uranium was processed in a variety of enrichments ranging from depleted to as high as 20%. The quantities of enriched material above 2% was not documented, but was qualitatively reported to be small and/or insignificant in total mass. The reported highest enrichment level processed in quantity was 2%.

- SC&A questioned the validity of the assumption that the Fernald site handled <2% enrichment in their review of the Fernald site profile (SC&A 2006).

TBD-5 (ORAUT 2005e, page 35) recommends that the dose constructor use 1% EU for the period 1963–1967. However, as outlined above, assuming a maximum enrichment of 1% is not supported by the documentation presented.

3.2.4 External Dose ORAUT-TKBS-0028-6

Background and Introduction

The current version of TBD-6 (ORAUT 2005f) covers the operational period 1957–1966, and the remediation period 1985–2000. The TBD provides some information concerning dosimetry records, badge exchanges, missing entries, calibration, and workplace radiation fields as a function of building. Basic coworker gamma and beta dose values as a function of job description are provided, along with LOD/exchange tables for calculation of missed dose. As with the other TBDs for the WS site, this TBD draws on information/data from other DOE sites, such as Fernald, because of the lack of WS site documentation, especially in the area of neutron exposure, dosimeter response, and radiation field characterization. Overall, the TBD addresses external doses from gamma, neutron, and electron radiation, but SC&A has areas of concern as detailed in the findings listed below.

Primary Findings

Finding #25: Shallow and Extremity Doses Not Sufficiently Characterized

Shallow (mainly beta) dose was briefly addressed in TBD-6 (ORAUT 2005f) on pages 12 (dosimeter quantities, OW, SW, etc.) and on pages 20–23 (compared beta dose from NU, EU, and DU). Electron dose is listed as >15 keV in Table 6-10 concerning energy distribution by building or area. Extremity monitoring is addressed briefly for the period 1992–1994 on page 12.

As described in a previous finding, there appears that there was no personal contamination or egress monitoring at WS during the operations period 1957–1966 to detect contamination on the workers after they changed clothes and left the operation areas. Additionally, there is no

* indication that routine extremity monitoring was performed at WS during this period, or that geometry factors were used to correct for the position of the badge versus the radiation source. No WS site documents have been located that address the change in film badge response as a function of radionuclide exposure, especially to low-energy photons and changes in beta energies. Therefore, SC&A has the following areas of concern:

- **No egress monitoring** – Unmonitored external and internal doses from lack of personal contamination and egress monitoring was previously described. The result of this lack of egress monitoring applies to both unmonitored and monitored workers and is especially important for shallow dose exposures.

- **Badge vs. exposure geometry factors** – The problems associated with handling uranium material [contact work as stated on page 20 of TBD-6 (ORAUT 2005f)] close to the body/hands and having the dosimeter badge located on the chest area was not addressed in TBD-6 or other WS site documents. A film badge does not register the same dose as the worker's tissue/organs are receiving from the beta and low-energy photons when handling, machining, scooping, etc., uranium containing materials. For example, a 1958 office memo (MCW 1959) illustrates the fact that the shielding on a lathe greatly affects the beta dose measured; i.e., decreases it from an average of 122 mrep/hr to 0 and Table I of that document lists non-trivial beta doses as high as 10,000 to 35,000 mrep/hr (mrep ~ mrem). Therefore, any material/distance between the beta source and the badge on the worker's chest that is not between the beta source and the worker's trunk area will cause an under-response in the recorded dose. A TIB needs to be developed for the WS site to correct for this underestimate of dose, such as OCAS-TIB-0013 (NIOSH 2005) was for the MCW Destrahan Street site. This is especially important for beta exposures.

- **Total shallow dose** – According to page 16 of TBD-6 (ORAUT 2005f), the dosimeters at the WS site were calibrated using radium photon and uranium beta sources. This is standard practice for uranium processing facilities. However, the WS site also handled other radionuclides, as described in TBD-6 and other WS site documents; these included Th-232 and RU with their associated decay products. Some of these radionuclides have different beta energies than uranium. Additionally, TBD-6 does not address shallow dose from low-energy photons, which may have been more predominate from these radionuclides as compared to uranium. TBD-6 briefly discusses mixed beta-gamma exposures on page 11 and states that they were determined by subtraction; it is assumed that this means that the reading from the portion of the film behind the cadmium shield (called SW) was subtracted from the reading of the film without cadmium shielding (called OW), as indicated in Table 6-2 on page 12. This is not a valid procedure, unless the beta-to-gamma ratio is known and remains constant, because beta and gamma radiation have different darkening effects per unit dose. The response of film to gamma radiation is very energy-dependent because of the photoelectric effect, whereas beta interactions are not subject to this dependence. Shallow doses from both beta and low-energy photons concerning calibration versus workplace radiation fields as a function of location and time needs further investigation and more adequately addressed in this TBD.

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Radiation Protection and Measurements (NCRP) discouraged its use, the *special curie* was commonly employed for natural uranium. The special curie was defined in 1959 as follows (NCRP 1973):

$$\text{Special curie} = 3.7 \times 10^{10}\ \text{d/s}\ ^{238}\text{U} + 3.7 \times 10^{10}\ \text{d/s}\ ^{234}\text{U} + 9 \times 10^{8}\ \text{d/s}\ ^{235}\text{U}$$
$$= 7.49 \times 10^{10}\ \text{d/s}$$

The definition was altered slightly in 1963 to use 1.7×10^9 d/s for ^{235}U. It is important to understand the use of the term special curie when the data are reviewed. In addition, MCW used the ratio between the measured DWA and the guideline or standard as an index of exposure.

5.5.1.3 Dust Exposure Calculation

* The total dust exposure worksheets used to record data for the MCW St. Louis site have a provision for entering the dust concentration, but the applicable worksheet column does not list the units. The values are most likely the index (i.e., the DWA divided by the guideline), and there is no indication of the source of the data. The intake calculated from urine bioassay and the intake calculated from measured dust concentrations were averaged with equal weight given to each source. There is no evidence to show when use of these forms was discontinued and no indication that they were used for WSP employees.

* The Annual Personnel Internal-External Radiation Exposure Report form, apparently in use by 1959 for WSP, includes a section for average dust concentration in disintegrations per minute per cubic meter by calendar quarter. None of the exposure reports reviewed had any data in that section. This indicates that the dust concentration was not routinely recorded. However, because the average dust concentration, when recorded, is in units of disintegrations per minute per cubic meter, the average daily intake can be calculated by assuming a breathing rate of 10 m^3/d for typical light work for an eight-hour work day or by using a job-specific value.

* No specific in-plant air monitoring analysis sheets were found, but samples of the forms for reporting perimeter air sample data were available. These forms could also have been used for in-plant measurements. The forms include information on the sampling rate, time, and the gross alpha activity. The samples were analyzed for alpha and beta activity.

5.5.1.4 Dust Studies

* A study of specific areas and jobs in Building 301 was conducted in 1961 (MCW 1961). Time-weighted average concentrations were calculated based on the number of work hours at various positions. The measured concentrations were reported in microcuries per cubic centimeter using the special curie unit and in micrograms per cubic meter. The data were used primarily as a basis for recommending actions to reduce concentrations. There is no indication that the data were used to assess intake.

An undated document titled *Summaries of Dust Concentrations at Production Jobs* (MCW c. 1966) provides data on time-weighted average dust concentrations for various work areas for the period from 1958 to 1966. The data were summarized for historic use in evaluating worker dust exposures. The dust samples were collected on open-face Whatman No. 41 or membrane filters with areas ranging from 3 to 5 cm^2. The membrane filters had a pore size of 0.8 μm. The flow rate ranged from 10 to 20 L/min. The report notes that the samples were taken either as fixed general air samples or as "hand held breathing zone type."

worst-case assumptions are to be made. And I really want to stress the latter part of this because it's always possible to make worst-case assumptions that are subjective, that you can say well, it can't possibly be bigger than this. But I -- as -- as we look at the situation, the worst-case assumptions do have to have some scientific basis, and that's also how we read the regulations. And I'll come back to that at the end of my presentation because I think there are some quite difficult regulatory issues to be addressed in regard to maximum doses.

But first let me go to the technical issues. Why do we think that reasonable dose estimates are unlikely to be possible. Well, Mont Mason himself said that radon dose data are not sufficient except for minimum and maximum estimates. And it's not simply a question of the number of radon measurements that were taken. We all agree that there were thousands of radon measurements that were taken. It is that the radon exposures were primarily puff exposures. For instance, when the drums of ore were being opened, or when the drums of residues were being opened and so on. And because they were puff exposures and we don't have -- we don't have the data from those puff exposures for the individual workers, you -- you can't make reasonable estimates and the type that I was talking about, but you could make bounding estimates by using distributions and 95 percentiles and so on, but you do have to collect all the data. We discuss that we feel that radon in many areas might be high enough to affect non-respiratory tract organs. The other part that -- that's unclear is what was the history of residue processing in Plant 6, and that's not very clear so it's not -- it'll not be possible, we think, with the existing data to make an accurate assumption about radionuclide ratios in the composition of the air. So some kind of -- if you can't find that history exactly and we -- we didn't see an indication that you could, then you'd have to make some kind of maximizing assumption about that. So a reasonable estimate is not possible -- no distribution, no -- no time period for processing.

Similarly we didn't find Mallinckrodt-based

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ADVISORY BOARD ON RADIATION AND WORKER HEALTH
4676 Columbia Parkway, MS: C-46
Cincinnati, Ohio 45226
(513) 533-6825

September 15, 2005

The Honorable Michael O. Leavitt
Secretary of Health and Human Services
Department of Health and Human Services
200 Independence Avenue, S.W.
Washington, DC 20201

Dear Mr. Secretary:

The Advisory Board on Radiation and Worker Health (The Board) has evaluated SEC Petition -00012-2 concerning workers at the Uranium Division at the Mallinckrodt facility under the statutory requirements established by EEOICPA and incorporated into 42 CFR Sec. 83.13 (c) (1) and 42 CFR Sec. 83.13 (c) (3). The Board respectfully recommends a Special Exposure Cohort be accorded to all Department of Energy (DOE) employees or its contractor or subcontractor employees who worked as at he Uranium Division at the Mallinckrodt Destrehan Street facility from 1949 to1957 and who were employed for a number of work days aggregating at least 250 work days, occurring under this employment or in combination with work days of employment occurring within the parameters (excluding aggregate work day requirements) established for other classes of employees included in the SEC. This recommendation is based on the following factors:

- These workers were employed at a facility that processed materials during the early time period for the production of nuclear weapons. Radiation monitoring methods for all isotopes were under development at that time leading to significant gaps in the monitoring of these workers in comparison to current monitoring programs.

- * There is relatively little information available for estimating thorium, actinium, and protactinium. NIOSH's approach to dose reconstruction no longer relies on individual monitoring but rather plant-wide air monitoring data, which is, itself, not even isotope specific. These data have to be converted into isotope specific activity using residue fraction values which have not been validated. As such, NIOSH has not demonstrated that it can conduct individual dose reconstructions with sufficient accuracy.

5.3.2 Environmental Monitoring Period (1975 to 1984)

No personnel bioassay monitoring appears to have been conducted during this period.

5.3.3 Remediation Period (1985 to 2001)

An extensive, state-of-the-art bioassay monitoring program was conducted during the 1991 to 2001 period to detect intakes greater than 100 mrem committed effective dose equivalent (CEDE). This program is well defined in the WSSRAP Technical Basis Manual revisions (DOE 1991, 1994, 1997, 1998a,b,c, 2000a, 2001). The focus of the program was to conduct bioassay based on workplace action levels for air sampling, nasal wipe analysis, and wipe analysis of the inside of respirators at the end of each day they were used. These action levels triggered fecal sampling, urine sampling, and *in vivo* measurements, as appropriate.

There are no Technical Basis Manuals available to document the bioassay monitoring program during the early part of the remediation period (1985 to 1990). If no individual bioassay data and no applicable co-worker bioassay data are available for a claimant for the 1985 to 1990 time period, the environmental data for 1985 to 1990, described in the Technical Basis Document for the Weldon Spring Plant – Occupational Environmental Dose (ORAU, 2005c) can be used to estimate intake. Alternatively, individual or co-worker bioassay data for the subsequent year (1991) may be used to estimate worker intakes.

Routine uranium urine sampling also occurred monthly for at-risk workers. Uranium MDAs were reported as 1 µg/L in 1991 (DOE 1991) using laser fluorimetry and as 0.1 µg/L in 1994 to 1998 (DOE 1994, 1997, 1998a) and 0.0524 µg/L in September 1998 to 2001 (DOE 1998b,c, 2000a, 2001) using kinetic phosphorescence analysis. Uranium results of 0.2 µg/L or greater were considered positive for occupational uranium intakes in 1997 (DOE 1997), and results of 0.3 µg/L or greater (DOE 1998c, 2000a, 2001) were considered positive for occupational uranium intakes from 1998 through 2001.

5.4 *IN VIVO* MEASUREMENTS

5.4.1 Operational Period (1957 to 1967)

There is no indication that WSP had an *in vivo* measurement program or performed any *in vivo* measurements for uranium, but there is an indication that *in vivo* measurements were performed on some WSP workers for thorium in 1966:

> *From July 11 through July 27, 1966, Y-12 personnel visited the Weldon Spring plant and set up the portable Whole Body Counter for in vivo thorium counting to quantify body burden deposition and the risk inherent with using the current Atomic Energy occupational air concentration limits (3.7E-11 µCi/ml). During this period of testing, 200 measurements were made in the monitoring of 148 persons. The determination of workers to be monitored was done on a strictly voluntary basis. A good cross representation of workers volunteered. The interpretation of the result is as follows:*
>
> 1. *Workers who showed net counts less than 60 counts per 20 minutes had less than detectable amounts of thorium in their lungs and were therefore given a 'negative' result.*
>
> 2. *Workers showing net counts in excess of 60 counts per 20 minutes but less than 204 were interpreted as a 'trace' of thorium.*

> 3. *Net counts in excess of 204 counts for 20 minutes were considered as 'positive' evidence of thorium lung burdens. A person who showed 204 counts for 20 minutes was considered to have at least one lung burden.*
>
> *The overall results showed workers involved in areas 101, 103, 301, 403, Maintenance, and Health and Safety, which were principal exposure positions, had a more frequent occurrence of 'trace' detections. No workers monitored showed a 'positive' designation. (Ingle 1991)*

The reports of these measurements observed in the worker files are titled "Thallium 208 in Vivo Results." This indicates that ^{208}Tl was measured as a marker for thorium. Thallium-208 is in approximate equilibrium (with a branching ratio of 0.337) with ^{228}Th, which might not have been in equilibrium with the thorium series parent ^{232}Th following chemical purification of the natural thorium feed materials. The quantification of thorium depositions from these *in vivo* ^{208}Tl measurements is, therefore, uncertain without knowledge of the degree of equilibrium of the thallium with the ^{232}Th parent. The record only gives a qualitative indication, background or trace, of the detection of ^{208}Tl as a marker for thorium.

5.4.2 Environmental Monitoring Period (1975 to 1984)

No personnel *in vivo* monitoring appears to have been conducted during this period.

5.4.3 Remediation Period (1985 to 2001)

An *in vivo* measurement program was included in the design of the WSSRAP internal dosimetry program to evaluate intakes of ^{238}U and ^{232}Th. Because the number of radiological workers exposed to airborne radioactivity at the WSP site was expected to be small, WSSRAP could not justify the expense of having its own *in vivo* measurement system. Instead, the program was initially based on detection sensitivities provided by the Helgeson Scientific Services mobile counting laboratory. The lower limit of detection cited for that system was 74 Bq (2 nCi) for natural uranium and 37 Bq (1 nCi) for ^{232}Th in the lung (DOE 1991).

Later, the program was based on detection sensitivities of the *in vivo* measurement system at the Fernald Environmental Management Project. The sensitivities (of unstated pedigree) cited for that system were 2.0 nCi for ^{238}U and 1.2 nCi for ^{228}Ac, assumed to be in secular equilibrium with ^{232}Th (DOE 2001). Revision 7 (DOE 2001) of the WSSRAP Technical Basis Manual states:

> *This assumption* [of secular equilibrium] *will not necessarily be true in an actual worker intake.*

and

> *It is important to note that these 'typical' detection limits are highly dependent upon the individual worker's physical features such as height and chest size. The Weldon Spring site has sent individuals to the Fernald site for lung counts, and detection limits were 2.5 times higher than the typical values due to the individual's physical features.*

In vivo lung measurements could have been performed as a special bioassay measurement following a suspected or actual intake. Revision 7 (DOE 2001) states that such measurements were normally reserved for "those incidents where the intake was suspected to exceed 500 mrem CEDE ...."

Table 5-1. History of dust-generating activities.[a]

Period	Activity
1957-1966	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 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
January 1967-?	Site used as interim storage depot for yellowcake later shipped to other plants for refining and processing.
1967	Buildings 103 and 105 transferred from the AEC to the Army for herbicide production
March 1968	Army started decontamination and equipment removal
December 1968	Construction of herbicide facility began; project terminated in early 1969 before renovation was complete.
March 1968-June 1969	Decontamination and equipment removal for Buildings 103 and 105 (see table 5.2 for building operations description) • About 1,000 metric tons rubble removed to the quarry • About 2,000 metric tons scrap moved to Tennessee • About 200 metric tons steel parts moved to Ohio • About 100 metric tons uranium oxide removed from the buildings
1969-1985	Site remained essentially undisturbed
1985	Remediation initiated by DOE – Weldon Spring Site Remedial Action Project (WSSRAP)
October 1986	MK-Ferguson and Jacobs Engineering assumed responsibility for the WSSRAP

a. Adapted from Meshkov (1986) and Lesperance, Siegel, and McKinney (1992).

* Table 5-2. Potential internal radionuclide exposure for production buildings.[a]

Bldg. no.	Building description	Building operations	Potential radionuclide exposures
101	Sampling	Sampling of ore concentrates containing 60 – 70% yellowcake Some material repackaged in drums – some sent to Bldg 103 for processing	U-nat dust, Ra-226, Th-230, Po-210 and Pb-210 Rn-222 and its short-lived decay products Th-232 and decay products in 1966
103	Digestion	Materials digested with nitric acid. Uranium bearing solution sent to Bldg 105 for purification. Materials returned for denitration after purification and sent to Bldg 201.	U-nat dust (as yellowcake and UO_3), Ra-226, Th-230, Po-210 and Pb-210 Rn-222 and its short-lived decay products Th-232 and decay products starting November 1963
105	Purification	Materials were purified by solvent extraction and returned to Bldg 103 for denitration.	Wet process but some potential for uranium or thorium (in 1966) dust exposure. Uranium would have been the major internal exposure component but Rn-222 and decay product exposure possible
108	Acid recovery	Recovering and re-concentrating nitric acid	Radon gas and its decay products
201	Green salt (UF_4) plant	Feed from Bldg 103 (after denitration) converted to UF_4.	Potential for uranium exposure as green salt dust or natural thorium (1965-66). No significant Th-230, Ra-226 or decay product exposure.
301	Metals plant	Mg used to convert UF_4 to U metal. Rotary kiln used to convert U metal chips to U_3O_8. U fuel cores produced; acceptable cores shipped to reactor sites.	Potential for uranium exposure as green salt dust and U_3O_8 or natural thorium (1965-66). No significant Th-230, Ra-226 or decay product exposure. Th-232 and decay products starting November 1963
403	Chemical pilot plant	Small-scale chemical processes	U-nat dust, Ra-226, Th-230, Po-210 and Pb-210 Rn-222 and its short-lived decay products Th-232 and decay products starting November 1963
404	Metallurgical pilot plant	Small-scale metallurgical processes	Potential for uranium exposure as green salt dust and U_3O_8 or natural thorium (1965-66) No significant Th-230, Ra-226 or decay product exposure.
407	Analytical and research labs	Small-scale research and analytical work on products and processes.	U-nat dust, Ra-226, Th-230, Po-210 and Pb-210 Rn-222 and its short-lived decay products Th-232 and decay products from 1965 to 1966

a. Adapted from ORAU (2005b).

background value of 7.4E-04 Bq/m^3 (0.02 pCi/m^3, Meshkov et al. 1986) was subtracted from the values. For 1957 and 1958 at the WSCP, for which measurements are not available, the analysis assumed that perimeter air concentrations were the same as those measured in 1959, the operational year with the highest measured perimeter concentrations. This is probably an overestimate for the first 2 years, when uranium receipts were lower than those during the main production years (1960-1964; Table 2-4 in Part 2 of this Site Profile). Measured concentrations are not available for the WSQ until 1961; until then, only drummed thorium wastes were reportedly stored at the quarry (Section 2.2.3.2 in Part 2 of this Site Profile). Most of the material was dumped at an elevation below the present natural water table of the quarry (*Weldon Spring Raffinate Pits and Quarry Task Force Report* 1967). In 1963 and 1964, an estimated 38,000 m^3 of contaminated rubble, equipment, and soil were placed in the WSQ, and much of this waste was not submerged. Thus, airborne concentrations of uranium and thorium resulting from use of the WSQ were probably negligible before 1963; this observation is supported by the measured concentrations of uranium in air in 1961 and 1962.

The uranium concentrations (Bq/m^3) in Table 4-5 were converted to isotope-specific intakes, in Bq/yr, by assuming the ratio of 1:1:0.05 for ^{238}U:^{234}U:^{230}Th activities and multiplying by an appropriate inhalation rate. For perimeter concentrations, intakes were calculated by multiplying by an inhalation rate of 2400 m^3/yr, representing an assumption of continuous exposure over the work year. To address intakes associated with the localized contaminated dust arising from the reported hopper decontamination operation outside Building 103 (noted above), the analysis assumed that the operation took place for 1 hour per workday (12.5% of the work year) every year during the operational period, and that unmonitored individuals were at a location in which an average concentration of 4.4 Bq/m^3 occurred for 5% of their work year (approximately 24 minutes per day). This corresponds to a yearly inhalation rate of 120 m^3/yr. The resulting average intakes are presented in Table 4-6.

In Table 4-6, the "^{238}U and ^{234}U" columns for the operational period represent the sum of ^{238}U and ^{234}U intakes. Since natural uranium accounted for more than 97% of the nuclear materials throughput (Sect. 2.2.2.2 of this SPD), it is reasonable to assume that the activities of these two isotopes are equal in the measured concentrations, as they are approximately equal in natural uranium ore concentrates. Thorium-230 intake is assumed to be 5% of uranium isotope (in this case, either ^{238}U or ^{234}U) intake, consistent with the assumptions by Meshkov et al. (1986), which are based on estimates for yellowcake composition. During the 10-year operational period, the amount of ^{230}Th likely to be present on contaminated surfaces and in air is more reflective of the amount present in the original material being processed than of the daughter ingrowth due to decay of ^{234}U. This assumption is applicable to post-1962 intakes for the WSQ, although the ratio is less certain for waste deposited in the quarry, which has not been well-characterized radiologically.

Although the intake values in Table 4-6 for the operational period can be attributed largely to the one measured value of uranium downwind of the hopper cleanout operation in 1966, it is notable that the average value of 555 Bq/yr for total uranium intake (corresponding to 277 Bq/yr for ^{234}U intake) compares closely with the average estimated intake of 366 Bq/yr for ^{234}U at the Feed Materials Plant in Fernald, Ohio (ORAU 2004), for the same years of operation. The Fernald plant received yellowcake in similar quantities to those received by the WSP between 1957 and 1966, and used similar operations in processing the receipts for ultimate shipment. Table 4-7 lists site-wide maximum intakes, representing the maximum intake each year for the areas listed in Table 4-6.

Radon

Measured air concentrations of radon during the operational period are not reported in the literature available for this TBD. Therefore, the analysis used a very simplistic screening-level model for estimating air concentrations at the WSCP, the location of the acid recovery plant, to estimate air factor of 0.93. MCW gave as the "tolerance cumulative dose" limits in use in 1955 as beta, 500 mrep per week, whole or part body; gamma, 300 mR per week, whole or part body; sum of beta and gamma, 500 mrep per week whole or part body; and 1500 mrep per week, extremity (MCW 1955).

In 1947, the basic dose limit was 0.1 rep/day and the relative biological effectiveness (RBE) for alphas was 10 (Hursh 1975); probably this was true earlier as well.

In anticipation of the lowering of the radiological dose standards (recommended limits) by the national expert committees such as the National Council on Radiation Protection and Measurements (NCRP), AEC began making changes in the plants in about 1948 to meet new "maximum permissible levels" of 300 mR/week for whole body irradiation and 1500 mrep/week for beta radiation to the hands (AEC 1949). In August 1949, AEC established and circulated to its contractor personnel a tolerance level of 300 mrep per week, which was to be taken as the total gamma plus beta dose to the whole body. However, Mallinckrodt misunderstood that the 300 mrep limit was to be applied to the total of beta and gamma and interpreted it as the limit for either beta or gamma (AEC 1950b). Finally, in January 1950 AEC made it clear to Mallinckrodt that the limit applied to the total beta plus gamma (AEC 1950b)

In mid-1950 AEC agreed to allow Mallinckrodt to interpret the 300 mrep total gamma plus beta whole-body limit as being taken as the average weekly dose over a three-month period, thus allowing the 300 mrep to be exceeded in some weeks (AEC 1950d); this was apparently based on the fact that Mallinckrodt was already using a system of personnel rotation to reduce doses (AEC 1950b). However, AEC at the same time suggested that 150 mrep per week be taken as a recommended limit for most purposes and that a weekly dose of 600 mrep be exceeded only in exceptional cases. It should be noted that in 1953, a design contractor was stating that the design criteria for ventilation and dust control equipment his company had put in at Mallinckrodt and Harshaw included a maximum weekly exposure of 300 mR of gamma radiation, with actual design predicated on half that to allow for a safety factor in unusual circumstances (Miller 1953).

During the early days of wartime uranium processing, AEC/MED's acceptable levels of exposure for the uranium processing plants for dust in air were 500 μg/m^3 for insoluble uranium salts and 150 μg/m^3 for soluble salts (AEC 1949). In 1944 MED determined that a standard was needed for uranium dusts and adopted the air maximum permissible concentration (MPC) level for lead, 150 μg/m^3, as the interim standard (Hursh 1975). In 1949, a University of Rochester scientific group suggested an air MPC of 50 μg/m^3 for soluble uranium forms based on (chemical) injury to the kidney and an air MPC for insoluble forms based on radiation injury to the lung (Hursh 1975). In 1953 the NCRP recommended in National Bureau of Standards Handbook 52 (quoted in Hursh 1975) a limit of 73 μg/m^3 for both soluble and insoluble forms; it was adopted. These were occupational standards that correspond to a 40-hour week (the number of hours that Hursh (1975) uses in conversions in his discussion of the history of standards).

By 1949, AEC had set a "preferred level" of 50 μg/m^3 for uranium dust, assuming a routine exposure of 8 hours a day, 6 days a week (AEC 1949). This was taken to be equivalent to 70 dpm/m^3 for alpha and is based on animal studies (Hursh 1975). For dosimetry reference, Appendix A gives the basis for this figure. This was later referred to as the Maximum Allowable Concentration (MAC) and was still in use as of 1953 (Miller 1953). In early 1955, AEC appears to have adopted a MAC of 100 dpm/m^3 for alpha, as AEC (1955c) stated in an air dust study report. In a 1958 report, AEC gave the limit for natural uranium, either soluble or insoluble, in air as 5×10^{-11} μCi/ml for 40 hours/wk (i.e., occupational) and 1.7×10^{-12} μCi/ml for continuous occupancy (AEC 1958, Table I). In 1959 the AEC also recommended against respirator use except in emergency situations (AEC 1949), suggesting that before the relevant period of Mallinckrodt work, extensive use of respirators was still tolerated as a means of minimizing exposure.

Table 2-10. Estimated annual discharges to raffinate pits (kg).[a]

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

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

Table 2-11. Estimated annual discharges to sewer (kg).[a]

Fiscal year[b]	Natural uranium	Depleted uranium	Slightly enriched uranium	Natural thorium
1958	—c	—	—	—
1959	—	—	–	—
1960	3,472	—	—	—
1961	6,461	0	0	0
1962	4,304	0	0	0
1963	6,374	0	0	0
1964	3,239	0	0	0
1965	1,254	0	979	0
1966	1,411	0	0	0
1967	205	0	0	0
Total	26,720	0	979	0

a. From Table 7 in DOE (1986).
b. Fiscal year begins on July 1 of the previous calendar year and ends on June 30 of the calendar year corresponding to the designated fiscal year.
c. — = no values given for these years.

of groundwater contamination near the WSP site. Ongoing remediation involves active monitoring of the groundwater in this region.

2.4 ACCIDENTS

* No information is currently available about accidental releases of radioactive materials to the environment during operation of the WSP. If additional information becomes available, it will be assessed for value and added to this section as appropriate.

Dupree (1979) cites two accidental exposures of workers which occurred during plant operations and were described by Mason during a visit to ORAU in August 1979. In one instance, a worker overfilled a pot with molten uranyl nitrate solution which spilled onto the floor. While attempting to turn off the valve, he fell into the material on the floor. He was hospitalized and ultimately returned to work approximately 11 weeks after the accident. A full report of the incident was made (MCW 1961). In the other case, a worker inhaled soluble uranium while trapped in a dust enclosure. The notes report that

* the worker suffered from "CNS effect" (presumably central nervous system effect). Mason further speculated that this reaction was due to the chemical toxicity of the uranium exposure. There are no notes about longer-term effects on either employee.

2.5 HEALTH PROTECTION PRACTICES

2.5.1 Operational Period (1957 to 1967)

The health protection program in place when operations began at the WSP in 1957 is not specifically detailed in any of the technical reports available at this time. However, since MCW transferred many of its activities and personnel from the Destrehan Street site in St. Louis at the startup of the WSP, it is likely that the program in place closely resembled that documented by 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 (Fleishman-Hillard 1967), the design of the WSP "took advantage of the Company's and the Atomic Energy Commission's (AEC's) accumulated wealth of experience concerning the handling of health and contamination problems encountered in uranium processing." The WSP layout was planned with the goal of minimizing the spread of contamination; advanced dust-control systems were used, and on-site health facilities were provided. This 1967 document states, "...existing health programs were continued... at the new site, and a number of supplemental programs were initiated at the Weldon Spring plant."

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

Both the 1955 and 1965 documents rely on AEC standards of radiation exposure to the extent that health protection decisions were made about worker rotation based on a comparison of monitored personnel exposures with these standards for radiation workers (i.e., individuals in controlled areas). Table 2-12 summarizes the 1955 document's list of tolerated cumulative doses in use at MCW. In addition, the 1955 document states that the goal was to keep each individual cumulative exposure at no greater than one-half of the tolerance when averaged over 3 months. The methods claimed for controlling exposure are shielding, semi-remote operations, and worker rotation.

Table 2-12. Tolerated dose limits in 1955.

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

a. rep = roentgen-equivalent-physical, an obsolete unit of absorbed dose for types of radiation other than X-rays and gamma rays; replaced by the gray.

Table 2-13 lists the WSP guides for prescribing restricted work so that AEC standards would not be exceeded (MCW 1965). Work restriction involved temporary relocation of the affected personnel from usual duties until the cumulative average was at an acceptable level.

Variation in applied voltage generally falls within ±5% of the machine setting. Beam intensity is approximately proportional to the 1.7 power of the kilovoltage, resulting in an uncertainty of approximately +9% in relation to beam intensity for voltages in the 110- to 120-kVp range. Variations in tube current are normal and generally small. As the tube current drops, beam intensity falls in direct proportion. Large decreases in beam output would be readily detectable and would indicate the need for machine maintenance or, as a temporary measure, an increase in the current or voltage to provide the necessary intensity for proper radiography. ORAU (2005) estimates the variation in tube current to be approximately ± 5% for this parameter.

Exposure time can significantly affect the dose received from radiography (exposure times are a fraction of second). Even a small variation in exposure time due to timer error can significantly change beam output. Because early x-ray machine timers are known to have been inaccurate, ORAU (2003 and 2005) assume uncertainty in beam output due to timers to be ±25%.

SSD can contribute to variability because the entrance skin exposure is determined by this distance. Variations result from accuracy of positioning as well as patient size (thickness). As expressed in ORAU (2003 and 2005), this is generally thought to vary by no more than a few centimeters, with an upper limit of 7.5 cm (±10%).

* A potentially large source of uncertainty for WSP is the number and type of x-rays taken. As noted above, reports indicate the performance of only an annual chest x-ray examination, but no official protocol has been found that would rule out the possibility of other x-ray views or more frequent chest examinations. At this time, dose reconstructors should assume an annual chest x-ray for 1958 through 1964.

Consistent with ORAU (2003 and 2005), the TBD analysis calculated the statistical root mean square to estimate total uncertainty. The root mean square is the square root of the sum of the squares of the individual uncertainty values, and equals 28.9%. An estimate of 30% uncertainty is larger than the default NIOSH guidance standard deviation recommendation of 20% (NIOSH 2002). Therefore, dose reconstructors should multiply all final estimates by 1.3 to account for uncertainty, conservatively assuming that all variables acted to increase dose.

of ^{235}U in natural uranium ore concentrates represents less than 5% of the activity in natural uranium, and because the WSP processed only a small amount of slightly enriched uranium.

Radionuclide concentrations in WSP outdoor areas are based on limited environmental measurements at the site. The total amount of uranium emitted to the atmosphere has been estimated from monitoring data (Meshkov et al. 1986) and from a nuclear materials balance study (DOE 1986). Based on methods and data in these two reports, the estimated uranium activity emitted from the Plant ranged between 1 and 5 Ci/yr. An estimate of radon release, based on the amount of uranium processed during the operational period, ranges from 12 to 34 Ci/yr, assuming radium activity was 1% of uranium activity, radon was in equilibrium with radium, and all radon was released. Beginning in 1981, annual environmental monitoring reports provided estimates of air concentrations of particulate radionuclides and of radon at the WSCP and WSQ. These estimates reflect emissions during the later maintenance period, and throughout remediation activities. The TBD analysis used these data to derive annual estimates of intake for 1957 to 2004.

Measured air concentrations of radon during the operational period are not reported in the literature. Therefore, a simplistic screening-level model was used to estimate air concentrations at the WSCP.

Because no site-specific ambient gamma data were available for the WSCP during the operational period, this analysis evaluated ambient dose rates for the Feed Materials Plant in Fernald, Ohio, as reported in ORAU (2004). The reported net average dose rate for 1956 to 1970 was 0.18 mrem/hr, or 1,576 mrem/yr for continuous exposure. When this dose rate estimate is applied to the WSP operational period, the WSP site background rate of 99 mrem/yr (Bechtel 1986) is added to derive an ambient dose rate of 1,675 mrem/yr for continuous exposure. This corresponds to a 2,000-hr exposure of 382 mrem. Between 1982 and 2000, thermoluminescent dosimeters monitored ambient exposure at many perimeter locations around the WSCP, the WSRP, and the WSQ. These data are summarized in this TBD, which summarizes estimated ambient onsite dose for the WSRP, WSCP, and WSQ for periods between 1957 and 2004.

1.2.4 Occupational Internal Dosimetry

The WSP Occupational Internal Dosimetry TBD (ORAUT-TKBS-0028-5) discusses the internal dosimetry program and develops estimates of potential intakes. Radionuclides of concern at the site include naturally occurring isotopes of uranium (^{234}U, ^{235}U, and ^{238}U) and their decay products (primarily ^{230}Th and ^{226}Ra). Due to the amount of material processed, the primary radionuclides of concern for internal radiation dose are the uranium isotopes. Because WSP processed some natural thorium, dose reconstructors should consider ^{232}Th and its decay products, ^{228}Ra and ^{228}Th.

The primary modes of intake were chronic and acute inhalation. The internal dosimetry program required routine monitoring of environmental radon and thoron and their decay products when an individual was likely to receive an annual intake of 10% or more of the annual limit of intake. According to Revision 7 of the Internal Dosimetry Program Technical Basis Manual (DOE 2001), that threshold was never exceeded. Bioassay (urine) data estimate the activity of the radionuclide excreted in the urine following an inhalation. This TBD discusses these data, including history, sensitivity, and pertinent nuances of methods and data.

* Urine bioassay data represent the primary information available to quantify uranium intake for the worker who is the subject of a claim. However, data are not always available for individual workers. These data can be supplemented by workgroup monitoring data, because essentially continuous bioassay monitoring of a worker was simulated by sampling at least one worker in the group each week, with Monday – Friday – Monday sampling for "exposed" workers.

Table 2-13. Guides for prescribing restricted work based on radiation exposure in 1965.

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

2.5.1.1 Badging

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

The MCW (1965) health protection program document states that personnel in operating areas of the plant and in some laboratories wore badges continuously while at work and exchanged them monthly for processing. Permanent badges were assigned to persons who frequently went into badged areas. Spare badges were available for persons having a casual need to enter badged areas. Badges other than operations badges were exchanged on a 3-month schedule.

2.5.1.2 Radiological Exposure and Access Control

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

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

The sample result (in milligrams per liter) is reported under columns headed by SCHEDULED, RESULTS, or no heading on the original data cards, and under the heading MGUPERL on the computer printouts. On the original data cards, the sample result is frequently followed by two dashes and a number, which has been assumed to be the pH of the urine sample.

Following the sample result on the original data cards or in the column headed by SAMTYPE on the computer printouts, an asterisk indicates a Friday afternoon sample. However, not all Friday samples are flagged by the asterisk. If the sample day is important, the DR could wish to determine the actual day using the Microsoft® Excel WEEKDAY function, which converts a date to a day-of-the-week code where 1 is Sunday, 2 is Monday, and so forth. Written on the original data cards after the result or under SAMTYPE on the computer printouts are notations that indicate pre-employment samples (code P), termination samples (code T), or special samples (code S).

5.3.1.1.6 Work Group Data

Urine bioassays were performed routinely as described in Section 5.3.1.1.1. Urine samples were obtained weekly from representative individuals in areas of WSP where uranium was handled. The data from the representative individuals were intended to be used to assess the intake by coworkers so that the work group was continuously monitored. Individual urine bioassay results supplemented by contemporaneous data from coworkers could provide the best measure of that person's uranium intake because the sampling for an individual worker could have occurred during quiescent operational periods.

Because most of the work group urine data summaries have not been discovered, the data have been recreated. Approximately 28,000 urine bioassay results were recorded during the operational period (1958 to 1966). Tables 5-8 to 5-17 provide median, 95th-percentile, and maximum concentrations for routine urine bioassay samples by year.

The data were analyzed by major work location, cost center or job description, and sample day (Monday or Friday). In some cases cost centers were combined to increase the number of individual analyses. The data set for 1958 includes a mixture of WSP and Destrehan Street workers and was coded in the original records by job description or work location rather than cost center. In cases where there were five or fewer records, the tables contain only the maximum urine bioassay result.

others indicated that people went offsite for lunch or home in their work clothes. The plant did have a laundry service and workers were provided with new clothes the next day. The laundry was found to have radioactive material on it. Workers report that dust would get into their hair.

Use of respiratory protection was intermittent. The primary respiratory protection used included dust masks or half-face masks with removable filters. The type used depended on the area. In pictures from the MCW magazine there appear to be similar to painters masks. Some workers in the green salt processing area remember getting green salt on their face around their mask. Respiratory protection used seemed to be variable for the different operations. The policy was to use respirators for the day and discard them for washing. The lab was responsible for cleaning the respirators and replacing filters. If a worker knew he/she might need it, he/she would carry it with them on their person. One worker indicated he used his until it was worn out. In between, uses he stored it in his locker.

In the 1960's during an OSHA visit, one worker indicated that OSHA directed the plant to dispose of all current respirators as they were not appropriate for the hazard.

Workers report that the uranium compounds at MCW included brown oxide, orange oxide and green salt. Urine samples were collected every six to twelve months starting in the late 1940's. Denise indicated that they recorded a lot of zeros recorded.

Documentation from the production areas was provided to administrative workers for processing. In some cases, the paperwork was returned to the initial organization. In other cases the paperwork was put into a library. The administrative offices were dusted once or twice a day. Some workers recollect that documents were burned.

There were lots of pipes and tanks at the facility. At times maintenance personnel (e.g., pipefitters, welders) had to enter tanks or pipes to work.

Some Radon Breath Analysis was performed for individuals working around Radium. Most of the results were recorded as zero.

Dust control measures at MCW included exhaust systems, used of vacuum, dust collectors, and water. Dust collectors contained dust bags which were monitored by a sensor. When the dust bag became plugged, the dust collector had to be turned off (originally manually) and a ring blower used to loosen the dust. The ring blower was then turned off and the dust collector returned to service. Although the dust collectors reduced dust levels, the dust bags would periodically rupture creating a mess. The plant had some gloveboxes. The level of dust control measures was less in Plant 4, the original production plant. There were wooden floors in Plant 4 and concrete floors in other areas. Plant 5 had a floating foundation. There was also outside storage.

likely the most important contributor to skin dose, because of its frequent high-energy beta emission. Pa-234m also emits higher energy gamma rays, albeit less frequently, than other nuclides of concern at WSP.

Table 6-1. Beta and gamma emissions of primary interest[a]

Radionuclide	Beta energy (MeV, max.)	Gamma energy (MeV)
U-238	None	None
Th-234	0.10 (19%)	0.063 (3.5%)
	0.193 (79%)	0.093 (4%)
Pa-234m	2.28 (99%)	0.766 (0.2%)
		1.00 (0.6%)
U-235	None	0.144 (11%)
		0.163 (5%)
		0.186 (54%)
		0.205 (5%)
Th-231	0.205 (15%)	
	0.287 (49%)	0.026 (15%)
	0.304 (35%)	0.084 (6.5%)
U-234	None	0.053 (0.1%)

a. Source: Shleien, Slaback, and Birky (1998).

Radiation protection practices and exposures at WSP varied over time. There is no comprehensive description of the practices and processes available at this time. Partial descriptions have been discerned from several documents as discussed in the following sections. Though contemporary references at WSP are limited there is dose information for all years discussed.

6.1.3.1 Plant Operations Period (1957 to 1966)

A film badge notification memorandum by the Health and Safety Department (MCW 1958) indicates that the WSP film badge program began on March 1, 1958. Before that time, dosimetry performed at WSP was more than likely provided by the MCW St. Louis plant. A memo from Brandner to Mason (Brandner 1956a) states that some St. Louis employees transferred to the Weldon Spring plant "where they are no longer being monitored for radiation exposure with film badges." This agrees with a footnote from individual film badge data summary sheets in 1966 that states "during start-up at Weldon Spring in 1958 and later, some persons were not badged because [they were] not involved in radiation work" (an example is shown in fig. 6A-7.)

Each employee, with the exception of "office females," (Brandner 1956a) wore a combination film badge and security badge. The film monitors were changed biweekly or more often as necessary. Burr (1959a) indicates that for turret lathe operators, film badges were exchanged weekly on Monday night. However, Burr (1959b) states that "monthly exchange of film badges for all plant personnel is scheduled for January 30, 1959." An undated report entitled "Personnel External Radiation Monitoring Program" (MCW undated) describes the MCW program. It states that "wage personnel film badges are exchanged monthly and salaried personnel film badges quarterly." A 1965 Summary of Health Protection Practices states that "operations badges are exchanged and processed on a calendar month schedule, all others on a three-month schedule." If the exchange frequency cannot be explicitly identified, the dose reconstructor should make the claimant-favorable assumption to use the most frequent exchange frequency for the period.

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Worker Radiation Dose Records Deeply Flawed

By: Arjun Makhijani and Bernd Franke

As part of its responsibility for the production and testing of nuclear weapons, the Department of Energy (DOE) and its predecessor agencies (the Atomic Energy Commission, 1947 -1974; and the Energy Research and Development Administration, 1974-1977) have been responsible for ensuring that workers were not exposed to more than the allowable amounts of radiation. The DOE has also been responsible to adhere to what is called the "ALARA" principle -- the idea that radiation exposures should be kept "As Low As Reasonably Achievable" with available technology.

The goal of setting radiation dose limits and following the ALARA guideline is to protect worker health by limiting exposure. But if exposure is not properly measured, radiation exposure regulations cannot be enforced, nor can guidelines be followed. Health monitoring personnel may not be aware of instances when workers are overexposed. Diseases that workers may be at greater risk of contracting may go undetected, harming them and their families. Health studies based on worker dose data would produce misleading results because dose records would be incomplete and knowledge of doses would be inaccurate.

From the beginning of the nuclear era until 1989, **radiation doses from radioactive materials inhaled or ingested by workers were not calculated or included in worker dose records.** This was revealed by DOE in a background paper sent to IEER on April 7, 1997.[1] DOE and its predecessor agencies did make measurements of internal exposure to radioactive materials, though often sporadic (see below), mainly by taking urine samples. After the mid-to-late 1960s, there was also selective use of more sophisticated counters that directly measure radionuclides in workers' bodies. The DOE was not required by regulations to calculate worker doses, but only to keep records of whether workers were internally exposed to more than certain amounts of radionuclides.

The lack of historical internal dose data in worker dose records has important consequences for public policy on health issues, for scientific investigations of radiation risk, and most of all for the more than half-a-million workers (and their families) who have been involved since the Manhattan Project in making and testing US nuclear warheads. In 1989, DOE began to correct this historical problem by initiating a program of integrating internal and external worker doses.

ears, and have generally
radiation