# SEC Petition Evaluation Report
# SEC-00012-2

Report Rev # Draft 2 Report Submittal Date __________

| Petition Administrative Summary | | | |
|---|---|---|---|
| **Petition Under Evaluation** | | | |
| Petition # | Petition Type | Submittal Date | DOE/AWE Facility Name |
| SEC-00012 | 83.13 | 07-21-2004 | Mallinckrodt |

| Feasible to Estimate Doses with Sufficient Accuracy? | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Single class | | | | Multiple classes | | | | Determination Established for All Classes? | | | |
| Yes | | No | | Yes | | No | X | Yes | | No | X |

| Initial Class Definition |
|---|
| The entire uranium division of Mallinckrodt Chemical Works (1942-1957) |

| Proposed Class Definitions (Abbreviated) |
|---|
| (1) All Department of Energy (DOE), DOE contractors, or subcontractors, or Atomic Weapons Employer (AWE) employees who worked in the Uranium Division at the Mallinckrodt Destrehan Street facility during the period from 1946 through 1948. (2) All DOE, DOE contractors, or subcontractors, or AWE employees who worked in the Uranium Division at the Mallinckrodt Destrehan Street facility during the period from 1949 through 1957. |

| Related Petition Summary Information | | | |
|---|---|---|---|
| SEC Petition Tracking #(s) | Petition Type | DOE/AWE Facility Name | Petition Status |
| NA | NA | NA | NA |

| Related Evaluation Report Information | |
|---|---|
| Report Title | DOE/AWE Facility Name |
| SEC Petition Evaluation Report SEC-00012-1 | Mallinckrodt |

| | | |
|---|---|---|
| **Lead Technical Evaluator:** | **Signature on File**<br>*LaVon B. Rutherford* | *Date* |
| **Peer Review Completed By:** | **Signature on File**<br>*James W. Neton* | *Date* |
| **SEC Petition Evaluation Approved By:** | **Signature on File**<br>*Larry J. Elliott* | *Date* |

# Evaluation Summary

This evaluation report by the National Institute for Occupational Safety and Health (NIOSH) covers a subset of the employees proposed as a class for addition to the Special Exposure Cohort (SEC) in SEC Petition No. 12, qualified on November 24, 2004. Although the petition requested NIOSH to consider all workers within the Uranium Division at the Mallinckrodt Destrehan Street facility in St. Louis, Missouri, over the entire period of operation from 1942 through 1957, this evaluation is limited to those Uranium Division employees working from 1946 through 1957. An evaluation of workers employed from 1942 through 1945 has been performed and documented in SEC Petition Evaluation Report SEC-00012-1. The current evaluation addresses all Uranium Division workers including those employed directly or under contract by the Manhattan Engineering District /Atomic Energy Commission (MED/AEC) for radioactive material processing or for research.

This evaluation report addresses the feasibility of estimating radiation doses with sufficient accuracy (i.e., the feasibility of dose reconstruction) and the evidence concerning the possible health endangerment for members of two classes that cover the 1946-1957 time period. As discussed below, these two factors, the feasibility of dose reconstruction and health endangerment, govern decisions by the Department of Health and Human Services (HHS) on whether or not to designate a class of employees for addition to the SEC and the definition of such classes.

Feasibility of Dose Reconstruction

The feasibility determination for the class of employees covered by this evaluation report is governed by 42 C.F.R. § 83.13(c)(1). Under this regulation, NIOSH must establish whether or not it has access to sufficient information to either estimate the maximum radiation dose that could have been incurred under plausible circumstances by any member of the class, or to estimate the radiation doses of members of the class more precisely than a maximum dose estimate. If NIOSH were to have access to the information sufficient for either case, then dose reconstruction would be feasible.

NIOSH has established in this evaluation that it does not have access to sufficient information to estimate the maximum radiation doses incurred by employees of Mallinckrodt working during the period from 1946 through 1948. NIOSH has queried all recognized and currently known sources of data concerning the operations at the facility. The majority of the data identified is summarized in NIOSH's Technical Basis Document (TBD) for the facility, *Technical Basis Document: Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site, St. Louis, Missouri, Period of Operation: 1942-1958.* There are limited workplace and worker monitoring data available for the 1946-1948 period, prior to the establishment of a formal health physics program, and some of the worker monitoring data are documented as unreliable. Furthermore, NIOSH has reviewed documents that raise serious questions concerning the integrity of the handling and reporting of monitoring data at Mallinckrodt. These circumstances, taken together, do not provide NIOSH with reasonable means to validate dose estimates based on monitoring data. In addition, although NIOSH has substantial information on radiological sources and processes during this period at Mallinckrodt, the variety of these sources and the diversity of processes involving these sources limit the ability of NIOSH to use this information, independently of monitoring data, to estimate maximum doses for employees who worked during the time period. As a result, NIOSH finds that it is not feasible to estimate doses to employees at Mallinckrodt with sufficient accuracy from 1946 through 1948, and proposes establishing a class comprising employees of this time period.

NIOSH has defined a separate class of employees covering those who worked at Mallinckrodt from 1949 through 1957, for which the scope and variety of monitoring data differ substantially from those of the earlier period. Beginning in 1949, Mallinckrodt established an operational program of radiation monitoring of employees and of work areas. This monitoring program was conducted with oversight from the Atomic Energy Commission's Health and Safety Laboratory (HASL), which possessed recognized expertise in monitoring radiation exposure in the workplace. Moreover, there is sufficient information from the various monitoring activities, together with information on radiological sources and processes, to validate dose estimates. This ability to validate dose estimates using independent data, and the substantial extent of the radiological source, process, and monitoring data available, would ordinarily provide assurance that NIOSH dose reconstructions would provide reasonable estimates of dose for the purposes of the Energy Employees Occupational Illness Compensation Act (EEOICPA), as provided for under 42 C.F.R. pt. 82 and NIOSH internal procedures for implementing its dose reconstruction program. On the other hand, any documentation that raises questions concerning the integrity of data management or reporting at Mallinckrodt helps sustain the lack of credibility accorded by the Mallinckrodt claimant population to the government concerning the employees' radiological exposures at Mallinckrodt and concerning the dose reconstruction program under EEOICPA. For this reason, although NIOSH believes that it has a sufficient scientific and technical basis to estimate radiation doses incurred by employees of Mallinckrodt working from 1949 through 1957, NIOSH has not decided whether or not its basis for dose reconstruction is viable for the purposes of this compensation program. NIOSH will, however, seek advice from the Advisory Board on Radiation and Worker Health ("the Board") concerning this matter. Specifically, NIOSH will ask the Board to provide advice on how to weigh the scientific and technical evidentiary basis in support of a positive feasibility determination against the evidentiary basis for concern about the integrity of the monitoring activities at Mallinckrodt during this late period. The Board's advice concerning this and similar weight-of-the-evidence determinations involving data reliability will also be taken into consideration in light of the potential for such matters to arise in future Cohort petitions.

Health Endangerment

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

The NIOSH evaluation did not identify any evidence from the petitioners or from other resources that would establish that either of the classes defined above were exposed to radiation during a discrete incident likely to have involved exceptionally high level exposures, as described above. NIOSH is not aware of any report of such an occurrence at the facility. Evidence presented by the petitioner and obtained by NIOSH characterizes the hazard as episodic inhalations of radionuclides that cumulatively resulted in chronic exposures. NIOSH has determined that it is reasonably likely that such exposures may have endangered the health of Mallinckrodt workers covered by the proposed class definitions provided in section 9.0 of this evaluation. Consequently, NIOSH has specified that health was endangered for those workers covered by this evaluation who were employed for a number of work days aggregating at least 250 work days within the parameters established for these classes or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

Proposed Class Definitions

This evaluation defines one class of employees for which NIOSH has established that it cannot estimate radiation doses with sufficient accuracy and whose health may have been endangered by such radiation doses. This class includes employees of DOE or DOE contractors or subcontractors employed by the Uranium Division of Mallinckrodt during the period from 1946 through 1948 and whom were employed for a number of work days aggregating at least 250 work days, occurring either solely 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.

The evaluation defines a second class of employees which includes employees of DOE or DOE contractors or subcontractors employed by the Uranium Division of Mallinckrodt during the period from 1949 through 1957 and whom were employed for a number of work days aggregating at least 250 work days, occurring either solely 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. For this class, HHS will obtain the advice of the Board concerning the matter of data reliability, as discussed above, as well as the advice of the Board as generally provided for under 42 C.F.R. § 83.15.

This evaluation, in conjunction with SEC Evaluation Report Petition SEC-00012-1 (1942-1945), completes the NIOSH evaluation of SEC Petition No. 12, which covered all workers within the Uranium Division of the Mallinckrodt Destrehan Street facility in St. Louis, Missouri, over the entire period of operation from 1942 through 1957.

In consultation with the Division of Energy Employees Occupational Illness Compensation, Department of Labor, NIOSH has determined that Plants 1, 2, 4, 6, and 7 are functionally equivalent to that portion of the Mallinckrodt Destrehan Street facility known as the Uranium Division, and has therefore proposed class definitions that utilize that designation.

## 1.0 Purpose

The purpose of this report is to provide an evaluation of the feasibility of reconstructing the doses for a subset of the employees proposed as a class in SEC Petition 00012 at the Mallinckrodt Destrehan Street facility in St. Louis, Missouri. Although the petition requested NIOSH to consider all workers within the Uranium Division at the Mallinckrodt Destrehan Street facility in St. Louis, Missouri, over the entire period of operation from 1942 through 1957, this evaluation is limited to those Uranium Division employees working from 1946 through 1957. An evaluation of workers employed from 1942 through 1945 has been performed and documented in SEC Petition Evaluation Report SEC-00012-1.

This evaluation was conducted in accordance with the requirements of 42 C.F.R. pt. 83 and the guidance contained in NIOSH's Internal Procedures for SEC Evaluations, OCAS-PR-004. It provides information and analyses germane to considering a petition for adding a class of employees to the SEC. It does not provide any determinations concerning the feasibility of dose reconstruction for any individual energy employee who might require a dose reconstruction from NIOSH.

## 2.0 Introduction

Title 42 of the Code of Federal Regulations (C.F.R.), Part 83, *Procedures for Designating Classes of Employees as Members of the Special Exposure Cohort Under the Energy Employees Occupational Illness Compensation Program Act of 2000,* requires NIOSH to evaluate qualified petitions requesting HHS to add a class of employees to the SEC. The evaluation is intended to provide a fair, science-based determination of whether or not it is feasible to estimate with sufficient accuracy the radiation doses of the class of employees through NIOSH dose reconstructions[1]. If it is not feasible, the evaluation is further required to make a determination with respect to the health endangerment of the class of employees.

NIOSH is required to document the evaluation in a report, which is provided to the petitioners and to the Board. The Board will consider the NIOSH evaluation report, together with the petition and any comments of the petitioner(s), to make recommendations to the Secretary of HHS on whether or not to add one or more classes of employees to the SEC. Once NIOSH has received and considered the advice of the Board, the Director of NIOSH will propose decisions on behalf of HHS. The Secretary of HHS will make final decisions, taking into account the NIOSH evaluation, the advice of the Board, and the proposed decision issued by NIOSH. As part of this final decision process, the petitioner(s) may seek a review of certain types of proposed decisions issued by NIOSH.[2]

This NIOSH report provides a summary of the methods and findings of the NIOSH SEC petition evaluation for Uranium Division workers at the Mallinckrodt Destrehan Street facility in St. Louis, Missouri, during the 1946 through 1957 period of operation. The Uranium Division conducted radioactive material processing and related research for the MED/AEC.

[1] NIOSH dose reconstructions under EEOICPA are performed using the methods promulgated under 42 C.F.R. pt. 82 and the detailed implementation guidelines available at www.cdc.gov/niosh/ocas.
[2] See 42 C.F.R. pt. 83 for a full description of the procedures summarized here. Additional internal procedures are available at www.cdc.gov/niosh/ocas.

## 3.0 Initial Class Definition and Petition Basis

A Special Exposure Cohort Petition - Form B (Form B) was received from the petitioners, with attached supporting documentation via fax, on July 15, 2004. A supplemental fax containing four additional items was received on September 30, 2004. Several phone conversations were conducted with the petitioner for clarification purposes to ensure that the correct worker class was evaluated in this petition. An evaluation of the entire set of information provided in Form B and the supplemental fax was conducted by a health physicist assigned to the petition. This evaluation is documented and maintained in the project record. The information supplied by the petitioners that qualified the petition for further evaluation is given here:

- Document A1 (Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site, St. Louis, Missouri, Period of Operation: 1942-1958., ORAUT-TKBS-0005, page 60), monitoring records may be limited or do not exist.
- Document A2 (ORAUT-TKBS-0005, page 58), monitoring records may be limited or do not exist.
- Document A3 (ORAUT-TKBS-0005, page 39-40), monitoring records may be limited or do not exist.
- Document A4 (Mallinckrodt Chemical Works (MCW) document from petitioner's private archive), monitoring records are limited or do not exist.
- Document A6 (ORAUT-TKBS-0005, page 25), monitoring records may be limited or do not exist.
- Document A7 (ORAUT-TKBS-0005, page 41-43), monitoring records may limited or do not exist.
- Document A8 (consisted of two letters associated with Thomas F. Mancuso, MD), medical monitoring records may have been lost or destroyed.
- Document A9 (letter from M. G. Mason to Thomas F. Mancuso, MD), monitoring records may have been falsified.
- Document A11 (document sent to Thomas F. Mancuso, MD), monitoring records may be limited or do not exist.
- First paragraph via fax, September 30, 2004, monitoring records may be limited or do not exist.
- Second paragraph via fax, September 30, 2004, monitoring records may be limited or do not exist.

Based upon the evaluation of the supporting documents, the petitioners for SEC Petition 00012 were notified that the petition "qualified" for formal evaluation on November 24, 2004. [The Federal Register notice was made December 20, 2004 and is located at 69 FR 75984.] The worker class provided by the petitioners included:

> **All employees that worked in the Uranium Division at the Mallinckrodt Destrehan Street facility in St Louis, Missouri from 1942-1957**.

## 4.0 Data Resources

NIOSH identified and reviewed data resources to determine the availability of information relevant to determining the feasibility of dose reconstruction for the class of employees covered by the petition. This included determining the availability of information on personal monitoring, area monitoring, industrial process, and radiation source materials. The following sections identify the resources identified and reviewed.

### Site Profile or Technical Basis Documents

NIOSH reviewed portions of the site profile issued on October 24, 2003 for the facility covered by the petition: *Technical Basis Document: Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site, St. Louis, Missouri, Period of Operation: 1942-1958*. The TBD provides process history information, personal and area monitoring data, radiation source descriptions, references to primary documents relevant to the radiological operations at the facility, and methods to reconstruct dose. An August 2004 draft revision of this TBD has also been utilized to a limited extent in this evaluation. Presentation of material or information from the draft revision will be appropriately cited.

### Previous Dose Reconstructions

NIOSH reviewed its dose reconstruction database, NIOSH OCAS Claims Tracking System (NOCTS), to identify dose reconstruction cases under EEOICPA that might provide information relevant to the petition evaluation. NIOSH reviewed each case to determine whether NIOSH had been able to obtain internal and/or external personal monitoring records on the employee or area monitoring data that could be used in the place of personal data. The following table summarizes the results of that search.

## Summary of NOCTS Claims and Available Monitoring Data Applicable to Mallinckrodt Workers (1946-1957)

| | | Breath Radon | Urinalysis | U Dust Exposure Records[a] | External Monitoring |
|---|---|---|---|---|---|
| Year | Total Number of Claimants[b] | # of Claimants Monitored | # of Claimants Monitored | # of Claimants records | # of Claimants Monitored |
| 1946 | 101 | N/A | N/A | 6 | 9 |
| 1947 | 123 | N/A | N/A | 3 | 33 |
| 1948 | 128 | 25 | 62 | 7 | 70 |
| 1949 | 137 | 29 | 67 | 70 | 71 |
| 1950 | 162 | 32 | 79 | 31 | 84 |
| 1951 | 175 | 74 | 83 | 92 | 93 |
| 1952 | 180 | 53 | 96 | 101 | 101 |
| 1953 | 189 | 72 | 100 | 45 | 104 |
| 1954 | 197 | 75 | 109 | 42 | 108 |
| 1955 | 205 | 38 | 119 | 121 | 123 |
| 1956 | 222 | N/A | 98 | N/A | 136 |
| 1957 | 259 | 1 | 112 | N/A | 136 |

N/A – None Available

[a] Based on breathing zone dust sampling measurements, results were used to calculate time weighted daily average exposure concentrations for all regularly assigned employee job categories. "Number of Claimants Records" data column refers to the number of employees who have been assigned these dust concentration exposure values based on known job duties.

[b] Number of claimants with a work history in this year as of 12/04.

**NIOSH and ORAU Research Documents and Databases**

NIOSH and Oak Ridge Associated Universities (ORAU) site research databases were reviewed for documents to support the evaluation of the petitioning class. The documents identified for review from this search are listed in Attachment 1. They include information on dust studies, radon sampling, dose rate surveys, film badge records, urinalysis data, the radiological control program, medical monitoring, feed materials and process description information. The information from these documents relevant to the petitioning class is summarized in section 5.0 of this report. Monitoring data compiled into databases by ORAU's Center for Epidemiological Research (CER) group were also reviewed. These data are also summarized in section 5.0 of this report.

**Documentation and/or affidavits provided by the Petitioners**

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

1) Letter from Denise Brock (Petitioner) to the Honorable Tommy Thompson, dated July 17, 2004.
2) NIOSH TBD on the facility, issued October 24, 2003: (various sections of the document are referenced in the petition).
3) Mallinckrodt Chemical Works, Subject: Concerning the Grouping of Death Certificate Cards into Exposed vs. Unexposed Groups, M. E. Mason, August 1975.
4) Urine Samples – Mallinckrodt Chemical Works dated September 20, 1951.
5) Letter from Knowlton J. Caplan to W. B. Harris Subject: Techniques of Radon Breath Sampling dated January 8, 1951.
6) Letter from Thomas F. Mancuso to Sidney Marks concerning the possible destruction of Medical Records dated September 12, 1972.
7) Interim Report: MCW Evaluation of Dust Exposure, Plant 4 and Plant 6 dated October 3, 1972.
8) Document untitled, undated, and unknown origin identified as "Gaps in Present State of Knowledge."
9) Mallinckrodt's Uranium Operations for the U.S. Government: MED and AEC unknown date.
10) Memorandum from Merril Eisenbud to W. E. Kelley dated January 31, 1951 (*Cover letter to "An Estimate of Cumulative Multiple Exposures to Radioactive Materials").*
11) Document entitled "An Estimate of Cumulative Multiple Exposures to Radioactive Materials" dated November 20, 1950.
12) Document entitled "Some Observations on Uranium Exposures within the Nuclear Industry," A.F. Becher, Consultant, ERDA Health and Mortality Study, undated.
13) Transcript of the "Oral History of Merril Eisenbud," United States Department of Energy Office of Human Radiation Experiments May 1995.

These documents were reviewed as to the relevance to the petitioning class. The information from these documents relevant to the petitioning class has been summarized in sections 5.0, 6.0, and 7.0 of this report.

## 5.0 Summary of Radiological Operations Relevant to the Class

The following two subsections summarize the radiological operations at the Mallinckrodt facility. The focus is on the processes and source materials utilized from 1946-1957. Some information on earlier plant activities is also provided as an aid to following the transition into the later plant processes. To this end, it should be noted that although the processing history of Plants 1 and 2 have been included in the descriptions, work at both plants reportedly ended in late 1945 or early in 1946 time frame (Mason, 1977). The actual levels of activity occurring within Plants 1 and 2 in early 1946, just prior to their closure are relevant to this petition class but are not discussed. The short period with respect to the class and the activities would not have provided the maximum exposures of concern during this operating period.

The principal source of information for these sections is the Mallinckrodt TBD Rev.0 and information obtained in developing the draft revision to the TBD. This draft revision of the TBD is a significant update to the initial revision and contains more detailed process and source descriptions. It presents available information regarding the identity and quantities of each radionuclide of concern, as well as information describing the process through which the radiation exposures of concern may have occurred and the physical environment in which they may have occurred. A detailed discussion of Mallinckrodt processes is discussed in *Fuel for the Atomic Age – Completion Report on St. Louis Area Uranium Processing Operations, 1942 – 1967*.

### 5.1 Process Description

The following table (from the TBD) presents a summary chronology of the radiological operations at the Mallinckrodt facility from 1942 – 1958. Brief plant-specific process descriptions follow.

## Summary Chronology of Operations at the Mallinckrodt St. Louis Downtown Site

| | |
|---|---|
| April 1942 | Plant 2 was used to develop a batch process using ether to extract uranium as $UO_3$ from milled ore and then to convert the $UO_3$ to $UO_2$. Plant 1 was used for developmental work. |
| October 1942 | Plant 4 was converted for use in the $UO_2 \rightarrow UF_4 \rightarrow U$ metal process. The ore→$UO_2$ operations continued in Plant 2, while miscellaneous activities related to R&D work continued in Plant 1. |
| April 1943 | Production of $UF_4$ from $UO_2$ began in Plant 4. |
| 1944 | Experimental extraction of uranium using pitchblende ores began in Plant 1. |
| 1945 | At some point in 1945 or early 1946, uranium operations at Plant 1 ceased. Plant 2 was apparently still used for some metallurgical-type work. Pitchblende ore began to arrive at the site in greater than research-level quantities in about May 1945. |
| 1946 | Plant 6 began operation in early 1946, with all ore→$UO_2$ production operations shifted there. Uranium operations at Plant 2 ceased in early 1946, the work (including $UO_3$ milling) apparently shifting to Plant 6. Only Plants 4 and 6 were in operation. |
| 1946-1947 | AEC acquires SLAPS in 1946 and Mallinckrodt residues begin to be sent there for storage in about 1947. |
| 1947-1951 | Decontamination of Plants 1 and 2, with unrestricted release to Mallinckrodt in 1951. |
| 1948-1949 | K-65 residue is brought back from SLAPS for reprocessing. After about 1949, no more K-65 residue is sent to SLAPS, only low-radium residues. |
| 1949–1950 | In 1949-1950, major improvements were made in dust control at Plants 4 and 6, with the latter shut down during part of 1949-1950 for this. Ore milling at Plant 6 stopped in 1950. |
| October 1950 | Plant 6E operations began. The $UF_4 \rightarrow U$ metal work shifted there from Plant 4, with the $UO_2 \rightarrow UF_4$ work remaining at Plant 4. Plant 4 was also modified for metallurgical-R&D work and became known as the Pilot Plant; some metal production (derbies, dingots) continued to take place there for experimental purposes. |
| 1951 | Plant 7 operations began in the first half of 1951. At that time, some $UF_4$ production work continued until perhaps 1952 at Plant 4, while the $UO_3$-to-$UO_2$ production at Plant 6 seems to have ended completely. Instead, $UO_3$ was sent to Plant 7 to be converted in a continuous process to $UF_4$. Some recovery and storage operations also shifted to Plant 7. |
| 1952-1953 | At some point, the continuous $UO_3$-to-$UF_4$ process began in Plant 7, after which time Plant 6 made only $UO_3$. |
| 1954 | The Ore Room and K-65 sampling operations in Plant 6 appear to have ended by about August 1954, possibly with the shipment of the last of the pitchblende ore (which would have been processed into at least 1955). It is not clear when the various Plant 6 pilot plant(s) began, but a 1954 start appears reasonable. Also, the Plant 6E Slag Separation Plant started in the first half of 1954. Some reversion of $UF_4$ to $UO_2$ and $UO_3$ was done in Plant 7. |
| 1955 | In 1955, thorium extraction from AM-7 residue began in Plant 7E and slag processing began in the Slag Separation Plant (Bldg. 701, part of Plant 7). Also, processing of residues to extract thorium began in early 1955 and the processing of a small amount of "enriched uranium" was done at Plant 7 early in 1955. Predigestion ore grinding ceased. Processing of high-grade pitchblende ore ceased and concentrates became the principal feed material. |
| 1955 or 1956 | In late 1955 or early 1956, dingots began to be produced in Plant 4, with derby production only intermittent; both were for experimental purposes. |
| Late 1956 | All operations at Plant 4 ceased. |
| 1957–1958 | In 1957, all regular site operations ceased, except for some Plant 7 activities that continued until July 1958. Other post processing and shutdown-related activities may have continued into 1958. |

### Plant 1

Plant 1 conducted laboratory scale developmental work for the operations in Plants 2 and 4. Processes were tested on a pilot scale within Plant 1 prior to the full scale operations in Plants 2 and 4. Research and development work on pitchblende ores (also known as Belgian Congo Ores, which contained high concentrations of uranium and substantial radium content) began in 1944. Related laboratory work that occurred in Building 25-2 and Building K1-E contained the Pilot Plant to test the pitchblende ore extraction methods. Plant 1 also included the engineering and administrative offices for uranium processing operations at the facility. MED/AEC operations in Plant 1 were terminated in the late 1945/early 1946 timeframe and transferred to Plant 6.

Plant 2

Plant 2 began uranium refining operations (production of $UO_2$ from ore concentrates that were originally received from other facilities) in April of 1942, and by July 1942, the Plant attained a production rate of 1 ton of $UO_2$ per day. African and Canadian ores were also milled onsite and converted to black oxides. Most significant with respect to exposures with potential to deliver substantial internal radiation doses, the process in Plant 2 involved batch operations which necessitated bulk transfer of the materials from building to building during the refining process. This process, as tested in Plant 1, required manual scooping of uranium products and waste products, which had potential to produce and aerosolize substantial quantities of radioactive dusts. A continuous flow process to replace this manual batch operation was pilot tested in Plant 2 in 1945, but not implemented for production until operations were transferred to Plant 6 in 1945-1946.

To produce $UO_2$, ore concentrates were digested in nitric acid to produce uranyl nitrate. The uranyl nitrate was purified by using an ether extraction process. The uranyl nitrate was then converted to $UO_3$ through denitrification and oxidized to $UO_2$ using furnaces. Certain locations of Plant 2 served as a warehouse to store incoming feed materials, outgoing product, and tanks of process liquids. In 1945 an annex to one of the buildings in Plant 2 was constructed to serve as a pilot plant for the continuous extraction process that was to replace the manual batch process. All Plant 2 MED/AEC operations were terminated in early 1946 and transferred to Plant 6.

Plant 4

In October 1942, Plant 4 was converted from a lumber sash and door works to a uranium refinery to convert $UO_2$ into uranium tetrafluoride ($UF_4$) and then into uranium metal. In mid-1943, the production of $UF_4$ commenced in Plant 4 using $UO_2$ from Plant 2. The production of $UF_4$ occurred in Building 400 and the conversion of $UF_4$ into uranium metal occurred in Buildings 400 and 401B. Plant 4 operations, similarly to those of Plants 1 and 2, included substantial manual manipulation of radioactive materials with the potential to produce and aerosolize substantial quantities of radioactive dusts.

The principal production of metal moved from Plant 4 to Plant 6E in 1950 although some metal was still produced in Plant 4 and some $UF_4$ was still produced there until perhaps early 1953. After the development of a continuous furnace process, $UO_2$-to-$UF_4$ production moved to Building 705 of Plant 7 in late 1951. In about 1950 or 1951, Plant 4 was refitted as an experimental development and a metallurgical pilot plant processing uranium metal and was then referred to as the “Pilot Plant.” The "dingot" metal production process was developed and conducted at Plant 4 in the mid-1950s along with sporadic ordinary metal "derby" production on a developmental basis. Plant 4 was used until 1956.

Plants 6 and 6E

In 1945-1946, Plant 6 was constructed to increase production and safety in the production process. Plant 6 was referred to as the refinery and contained the laboratories and offices which were relocated from Plant 2. The buildings associated with the Plant 2 operations included Building 110, 110A, 104, and 111. In 1946, the ore to $UO_2$ production was permanently moved to Plant 6. Incoming ore (by rail) was stored in Building 110 prior to processing. Building 104 housed the continuous flow process equipment (which replaced the batch process from Plant 2). Buildings 110A and 111 contained the offices and laboratories where uranium ore assays were performed.

Safety concerns had been recognized by MED and Mallinckrodt as early as 1944 and 1945. Subsequently, Plant 6 was designed for continuous operations with less manual operations as compared to the earlier batch processing. It was felt with this new design exposures would be significantly reduced. However, with the increased production rate and the increased use of the pitchblende ore, workers were exposed to significant dust, radon, and external doses. These safety concerns were identified by MED and Mallinckrodt in 1948 and further engineering controls were implemented in 1949. These improvements were regarded as an interim measure, however. Mallinckrodt and AEC agreed to build a new pair of plants that were located at the Destrehan Street site.

The first was Plant 6E, the new metal plant, which was constructed from early 1948 to June 1950, began startup operations in June 1950, and went into operation in July 1950. Metal production ($UF_4$-to-U metal) operations at Plant 4 moved to Plant 6E, which was from then on referred to in records as "the metal plant." Metal production took place in Building 116.

Plants 7 and 7E

The second new plant was Plant 7, the green salt plant, which was constructed from November 1950 to March 1951 and was turned over to Mallinckrodt for operation in March 1951. At Plant 7, a continuous process replaced the batch-type process used at Plant 4 and the $UO_3$-to-$UO_2$ production process at Plant 6.

Uranium metal recovery and some storage operations were moved to Plant 7 in 1952. Some reversion of $UF_4$ to $UO_2$ or $UO_3$ was done in 1953 and perhaps into 1954. Some time in 1954 or in the late 1950's machining of nuclear reactor core elements was done on a temporary basis in a fabrication facility in Building 700. In 1955, very low enrichment uranium (probably only a small amount) as $UF_4$ was processed at Plant 7 and in August 1956, about 5.5 kg of 20%-enriched uranium was processed, presumably in Plant 7.

Plant 7E, whose sole building (712) was constructed as a temporary facility in 1954-1955 and which was regarded administratively as part of Plant 7, was used from 1955-1957 to process pitchblende raffinate (solids removed during uranium refining by wet filtration) to produce a concentrated thorium solution by an acid digestion process similar to the uranium ore digestion. The concentrate was sent to the Mound site for further processing.

## 5.2 Radiological Source Materials

The following subsections summarize information on source materials with potential to produce radiological exposures. The site TBD provides a significant amount of information concerning the history of radioactive material use at Mallinckrodt and plant operations. Note the information and Table given in Section 5.1 provide approximate time periods and building locations when/where materials were being processed.

### 5.2.1 Uranium Ores

The uranium ores processed at Mallinckrodt came from both domestic and foreign mine/mill sources and uranium content varied significantly, as did other radiologically significant daughter products. Pitchblende ores containing both high levels of uranium and Ra-226 and Th-230 (progeny of uranium) began to be processed in Plant 1 in about July 1944. The laboratory for the testing of radium extraction methods was set up in Building 25-2 and the pilot plant in Building K-1E. By the end of 1944, Mallinckrodt had obtained sufficient data to begin the engineering design of a pitchblende ore refinery. The Ra-226 (in radioactive equilibrium with its progeny) constitutes a significant gamma radiation source and thus produced most of the external whole-body penetrating dose received by the workers, while Th-234 and Pa-234, both beta emitters, would have produced primarily skin and extremity dose. In addition, storage and processing of ores released radon and radioactive dusts, potentially resulting in internal doses to the lung and other tissues due to inhalation. The levels of radon releases would have correlated closely to the radium content of the ore and its derivatives. Radium was removed from the ore during the digestion/dissolution/extraction steps conducted during refinery operations and therefore principal exposures to radium (and radon) occurred in ore and raffinate storage areas and early extraction phases. The concentration of radium and other daughters present at any given time in the ore, the processed uranium, and the processing residue, depended on the initial concentration of uranium in the ore, the levels of radiation doses received by workers would have depended, in part, on the particular uranium ore being processed at a particular time and what process was being conducted.

### 5.2.2 Uranium Products

In 1942, there was potential for workers at the facility to have direct contact with uranium in the form of $U_3O_8$ when mixing it with nitric acid for digestion (MED 1942). When the pitchblende ore processing commenced in Plant 1 in July 1944, it was handled in smaller batch quantities. Due to the higher radium content, Mallinckrodt confined the materials to a limited area to prevent their spread into other plant areas. Plant 6 began operating in 1946 and took over the refining operations and handling of pitchblende ores. Pitchblende ores were processed at the site until sometime in 1955. As discussed in section 4.0, plant 6 was designed for continuous operations with less manual operations as compared to the earlier batch processing. It was felt with this new design exposures would be significantly reduced. However, with the increased production rate and the increased use of the pitchblende ore, workers were exposed to significant levels of dust, radon, and external doses. Additional controls were implemented to minimize direct personal exposure to the pitchblende ore; the ore storage room was divided by brick piers into corridors, with each corridor being wide enough to hold stacks of drums four drums wide and two high (MED 1946c). It was thought that this design would eliminate the need for workers to pass between or close to ore during the ore storage and transfer operations. However, due to the blocking of some corridors and the filling of others with a higher quantity of ore drums, workers had to pass close by the ore drums in the crowded corridors (MED 1946c). In addition, workers had to handle the barrels manually throughout this period of pitchblende operations.

Once the Ra-226 was removed following the digestion step and the vessel(s) had been vented, the gamma dose rates would have been lowered substantially. The radon (which arose from the radium) was no longer an issue from this point forward in processing, except for the presence of radium-bearing waste residues.

There was no information located about processing very low enriched uranium at MCW in the TBD (ORAUT, 2004) except for a reference in an AEC air dust study report for Plant 7. The report stated that the AEC survey covered "health and safety problems existing during production and processing green salt, with the added operation of processing enriched uranium." The panel board operator was said to include among his observed duties "charging enriched $UF_4$ into hopper" and "replacing enriched material drum and sample bottle" (AEC 1955e). Because there was no further mention of any of these activities in later such reports, it appears that this operation may have been performed for only a short period of time, e.g., to use up excess $UF_4$ from another site. There is no indication that Mallinckrodt itself produced the very low enriched $UF_4$.

Starting in 1952, some recycling of uranium was done by the AEC and its contractors nationwide (ORAUT, 2004). Thus the question arises whether this was done at the Mallinckrodt facilities in St. Louis. However, Mallinckrodt (as a company) did not begin to receive recycled uranium until 1962, which was after the St. Louis facilities had been shut down and their work had shifted to Fernald and Weldon Spring (the latter run by Mallinckrodt) (FUSRAP 2003b). ORNL (1981) stated that in its pre-survey review of the site that included interviews with Mallinckrodt old-timers, no indications were found that there had ever been any process conducted under AEC contracts involving highly enriched uranium.

### 5.2.3 Process Residues

African Metals, which supplied the Belgian Congo Ore used by the facility, required that the facility extract and return to it the Ra-226, the Ra-226 progeny, and lead and precious metals (AEC 1967; AEC 1949b). Thus the Mallinckrodt process included steps to extract these materials as a separate residue, called gangue lead cake or GLC.

As much as 100 grams of Ra-226 (approximately 100 curies), contained in the GLC residues, was produced per month at the facility (AEC 1949b). It is also known that quantities of the residues were stored at the site before being transported elsewhere. For example, 200 grams had been transported at one time from the facility to Middlesex (AEC 1949b), meaning that this quantity had been in storage at the Mallinckrodt site and had to be loaded for transport at one time. The residues were stored in drums (FUSRAP 1996). The same storage design and precautions used for the ore were followed for the radium-containing waste (MED 1946c). It is not known, however, how much of the residues were stored at the facility at any given time.

### 5.2.4 Thorium Processing

In late 1954 or early 1955, a new subplant, called Plant 7E, was established. This was part of what was referred to as the Minor Elements Production (ME or MEP) facility that did smaller-scale processing and development in Plant 7. The purpose of 7E was to process some of the AM-7 (pitchblende) residues that had been in storage at the SLAPS site to extract Th-230 (FUSRAP undated a; AEC 1967; FUSRAP undated b; FUSRAP 1996). Starting in 1955, the thorium-bearing AM-7 raffinate residue was brought back from storage at SLAPS, stored at Plant 6, and conveyed by dumpster from Plant 6 to Plant 7E as needed (AEC 1955b). The processing was first done on a crash basis in early 1955, apparently on a laboratory level (AEC 1955c; ORAU 1991), to produce a solution containing several hundred grams of thorium. Mallinckrodt later undertook the process on a pilot scale, but insisted on only a limited number of workers and strict safety precautions (ORAU 1991). The resulting residue, AM-9, was sent back to SLAPS (AEC 1959).

AEC (1955b) described the thorium solution extraction process as follows. The AM-7 was first digested in nitric acid in a tank and filtered. The resulting "liquor" was then processed in a tributyl phosphate (TBP; a solvent) contactor, forming an aqueous phase and a thorium-bearing TBP phase. The TBP phase was treated with hydrofluoric acid, leaving another aqueous phase, a stripped TBP phase, and thorium fluoride (apparently in solution). The thorium fluoride was sent to the Hot Lab in Plant 6, where it was treated with aluminum nitrate ($Al(NO_3)_3$) and a pentaether-ether mixture, forming thorium nitrate ($Th(NO_3)_4$) and impurities. The thorium nitrate was stripped from the impurities, yielding the solution that was sent to Mound. The various waste streams were treated in several ways (e.g., the aqueous fractions were treated with lime). This left various cake, slurry, and water filtrate forms; the first two types were sent to storage and the latter to the sewer. The main residual cake, called AM-9, was sent back to storage at SLAPS. From the beginning of 1955 into 1957, a total of 350 tons of the AM-7 was processed (AEC 1959; AEC 1967; FUSRAP 1996) (ORAU 1991 says the processing was performed in 1958, but this seems unlikely). Note that the Th-230 was also called "ionium" and was referred to that way in Mallinckrodt records.

## 6.0 Summary of Available Monitoring Data

The following table summarizes the types and amounts of monitoring data currently available to NIOSH to support dose reconstructions relevant to the petitioning class. It should be noted that the “number of employees” column refers to the number of available records for white, male employees at Mallinckrodt. It should also be noted that white, male workers accounted for nearly the entire work force in the production areas. According to Mason (1977), no women ever worked in the production areas and very few black employees were employed during the 1946-1957 time frame. All other monitoring record and monitored employee counts shown on the table represent all records contained within the database, regardless of sex or gender.

## Summary of Available Monitoring Data for Mallinckrodt Workers (1946-1957)

| | | Breath Radon | | Urinalysis | | Area Radon | U Dust Exposure Records[a] | | External Monitoring | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Number of Employees[b] | # of Records | # of Employees Monitored | # of Records | # of Employees Monitored | # of Records | # of Records | # of Employees | # of Records[c] | # of Employees Monitored |
| 1946 | 522 | d | d | 0 | 0 | d | | 93 | 171 | 171 |
| 1947 | 587 | d | d | 0 | 0 | d | | 71 | 285 | 285 |
| 1948 | 599 | 118 | 54 | 384 | 319 | 386 | 150 165 | 58 | 485 | 485 |
| 1949 | 676 | 187 | 119 | 835 | 373 | 507 | 146 1268 | 397 | 506 | 506 |
| 1950 | 784 | 175 | 123 | 1092 | 500 | 380 | 564 | 196 | 612 | 612 |
| 1951 | 887 | 469 | 174 | 1284 | 531 | 721 | 2097 | 689 | 730 | 730 |
| 1952 | 883 | 390 | 164 | 1922 | 679 | 708 | 1700 | 728 | 759 | 759 |
| 1953 | 920 | 388 | 212 | 2423 | 715 | 613 | 829 | 311 | 781 | 781 |
| 1954 | 943 | 402 | 238 | 1947 | 741 | 714 | 880 | 323 | 786 | 786 |
| 1955 | 1020 | 240 | 221 | 1905 | 833 | 621 | 1521 | 856 | 947 | 947 |
| 1956 | 1037 | 1 | 1 | 803 | 661 | 215 | 0 | 0 | 1040 | 1040 |
| 1957 | 1227 | 5 | 5 | 1040 | 815 | 210 | 0 | 0 | 1035 | 1035 |

[a] Based on breathing zone dust sampling measurements, results were used to calculate time weighted daily average exposure concentrations for all regularly assigned employee job categories. "Number of Employees" data column refers to the number of employees who have been assigned these dust concentration exposure values based on known job duties.

[b] Total number of employees data currently reflects database records of the white, male population of the Mallinckrodt workforce.

[c] External monitoring record numbers represented are annual exposures, hence the one-to-one correspondence with the number of employees monitored.

[d] Additional hard copy records have been identified but not yet input into the ORAU database nor counted.

It is understood that monitoring was never provided for all Uranium Division workers, but that the initial (and later) site dosimetry and radiological sampling was provided for those areas and individuals with the highest potential for exposure. This conclusion is supported by the review of the data from 1943-1947, as compared to the sample data from 1948-1955. This is also supported by a number of reports from these early years and studies conducted in later years (AEC 1948c, MED 1944j, Rochester 1948a, AEC 1950a, MED 1945e, MCW 1946g, MCW 1950t, MCW 1955d, Mason 1958a, ORAU 1977, ORAU 1980b, and the Mallinckrodt TBD).

The monitoring data that are available include: external dosimetry beginning in late 1945 (with a pilot program commencing in mid-1945 and complete employee monitoring after March 1948), urinalysis beginning in the summer of 1947 with a comprehensive program in 1948, breath radon results that began in 1945, area radon sampling from 1946-1957, and dust monitoring data beginning in 1943 with a formal dust monitoring program including breathing zone measurements starting in 1948. Radiation measurements and evaluations of dust exposure during the earlier years of operation (1943-1947) were performed on an area-wide, episodic basis to determine whether the facility was in compliance with "tolerance" area dose rates. ORAU (1983b) stated that the equipment used to do the air dust surveys during this period (1943-1947) was not very good. HASL had confidence in readings greater than or equal to 25 ug/m$^3$, but has less confidence in readings in the range of 10 ug/m$^3$.

The formal air dust monitoring program resulted in a series of AEC and Mallinckrodt dust study reports (e.g., AEC 1954b, MCW 1949d). The air sampling and report production were at times performed by AEC NYOO, Mallinckrodt, or were joint efforts between the two (ORAU 1983a). Based predominantly on breathing zone dust sampling measurements, time-weighted, daily average exposure averages were calculated for all regularly assigned employee job categories. The data from these studies have been captured in a CER database and are summarized in the following table under "Uranium Dust Exposure Records."

The AEC's HASL staff was committed to the time-weighted average as being most representative of total exposure. As Glauberman and Harris (1958) stated, "HASL has found from experience that the multiple-sample time-weighted average exposure procedure is the most accurate....The GA [general area] sample normally will tend to underestimate an operator's exposure and the BZ [breathing zone] sample to overestimate it, but by time-weighting the average concentrations for both types of samples an operator's exposure may be closely evaluated... [this method] yields reasonably reproducible results."

Review of the individual dust study reports indicates that the sampling procedures and subsequent calculations were consistent. Typical of language found in many of the dust study reports, the following is an excerpt from a report for a Plant 6 study conducted during October and November of 1948:

> "Dust samples were taken in the breathing zone of the operators, either while working on some specific operation or in the general area. A few samples were taken at points other than the breathing zone in order to locate specific dust sources."

An additional excerpt from the same 1948 report (consistent with other reports) describes the overall sampling process:

"Dust samples were collected on 1-1/8 inch diameter Whatman #41 filter paper discs, using a modified Fischer pump. The rate of flow was maintained at 0.50 cubic feet per minute, with the collecting period varying from 45 seconds to 30 minutes depending upon sampling conditions and job time.

The samples were counted in a parallel plate alpha counter for sufficient length of time so that the statistical variations would be no more than +/- 10 % at the 0.9 confidence level. A few samples of low strength may have errors as high as +/- 20 %. The data presented in "Lectures on Radiochemistry, Lecture #9" November 12, 1946 by Alan A. Jarrett, Clinton Laboratories, were used in the error calculations.

The dust concentration in alpha disintegrations per minute per cubic meter (alpha $d/m/m^3$) is determined from the counting rate of the sample as follows:

c/m = c/m of sample – (c/m background + c/m control)

$$d/m/m^3 = \frac{c/m}{(G)\,(1-A)\,(Q)\,(t)}$$

$$d/m/m^3 = \frac{c/m}{(0.52)\,(1-0.30)\,(0.01415)\,(t)}$$

$$= \frac{c/m \times 194}{t}$$

Where c/m = alpha counts per minute, corrected for counter background and controls

G = counter geometry (52 %)

A = filter paper alpha absorption (30%)

Q = rate of sampling (0.50 cfm = 0.01415 cubic meters per minute)

T = sampling time in minutes

$d/m/m^3$ = alpha disintegrations per minute per cubic meter of air

In order to establish the weighted average dust exposure on a given operation, an approximate time study was made in order to determine the appropriate weight factor to assign a given dust concentration."

Section 7.0 of this report describes the practical relevance of data availability and limitations with respect to the feasibility of dose reconstructions.

## 7.0 Evaluation of Feasibility of Dose Reconstruction

The feasibility determination for the class of employees covered by this evaluation report is governed by text within 42 C.F.R. § 83.13(c)(1). Under this regulation, NIOSH must establish whether or not it has access to sufficient information to either estimate the maximum radiation dose that could have been incurred under plausible circumstances by any member of the class or that the information is sufficient to estimate the radiation doses of members of the class more precisely than using a maximum dose exposure scenario for the proposed time period. If NIOSH were to have access to the information sufficient for either of the above cases, then dose reconstruction would be feasible. If NIOSH does not and will not have sufficient information on a timely basis for members of the proposed worker class to reconstruct dose, it is infeasible to conduct dose.

In making determinations of feasibility, NIOSH begins by evaluating whether current or completed NIOSH dose reconstructions demonstrate the feasibility of estimating with sufficient accuracy the potential radiation exposures of the class (identified in section 6.0 of this report). If the evaluation of completed dose reconstructions does not provide necessary information to show feasibility, NIOSH systematically evaluates the sufficiency of different types of available monitoring, process, and source or source term data, which together or individually might assure NIOSH that it can estimate either the maximum doses members of the class might have incurred or more precise quantities that reflect the variability of exposures experienced by groups or individual members of the class. This approach is specified in the SEC Petition Evaluation Internal Procedures (OCAS-PR-004) available at www.cdc.gov/niosh/ocas.

The table below indicates that as of January 25, 2005, there were a total of 246 claims submitted to NIOSH for individuals that worked at the MCW Destrehan Street facility, with dose reconstructions being completed for 51 (or approximately 17%). The table further indicates that 49 of the 51 completed claims have been recommended for compensation.

| DOE Covered Site Information | | | | | | |
|---|---|---|---|---|---|---|
| **Site Name:** | Mallinckrodt Chemical Co., Destrehan St. Plant | | | | | |
| **Number of Cases:** | Active | Pulled | Complete | | | Total |
| | | | GT50% | LT50% | Total | |
| | 246 | 4 | 49 | 5 | 51 | 304 |

A more detailed review of the 49 claims recommended for compensation indicates that 31 (70%) had a lung cancer as a primary cancer; with leukemia, colon, brain, esophageal, bone, skin, and bladder making up the remaining cancers. It is understood that many of these claimants with lung cancers were involved in the handling or storage of uranium ore at the site. An additional Evaluation Report for the MCW site is being submitted concurrently with this report, for individuals that worked during the 1942-1945 period at Mallinckrodt. This proposed worker class for 1942-1945 is known to have conducted much experimental work manually with very limited radiological control mechanisms in place. As a result of this, personal or area monitoring data or information to develop source terms was not available for these early operations and the tasks were much different than those beginning in 1946, it was not feasible to conduct dose reconstructions for that time frame.

Section 6.0 of this Report includes a summary table of the data currently available to NIOSH to support dose reconstructions relevant to this evaluation. A considerable amount of the radiological dosimetry information for the site was obtained in the past to support previous epidemiological studies of the MCW worker population. As discussed in section 6.0, it is understood from the Mallinckrodt TBD and other supporting site records that monitoring was never provided for all Uranium Division workers, but that the initial (and later) limited site dosimetry and radiological sampling was provided for those individuals with the highest potential for exposure. The monitoring data that are available include: external dosimetry beginning in late 1945 (with a pilot program commencing in mid-1945), urinalysis for uranium beginning in the summer of 1948, breath radon results that began in 1945, and air dust monitoring data beginning in 1944 with a formal air dust monitoring program beginning in 1948 (AEC 1950a). Note that though a formal program was not initiated until 1948, air sampling was used in 1943 as a means of indicating process problems. The currently available records could be used to either 1) provide best estimate exposures to individuals or 2) used as surrogate (or co-worker) data to estimate maximum (or plausible) exposure conditions for those claimants who may not have been adequately sampled or monitored at the site.

Note the summary table indicates the trend of available exposure records (external dosimetry and urinalysis data) significantly increases from 1946 through 1957.

The majority of uranium operations were shutdown at the Mallinckrodt Destrehan Street facility in 1957 and were transferred to the Weldon Spring facility (Some Plant 7 activities continued at the Destrehan Street facility until July 1958. Additionally, other post processing and shutdown-related activities may have continued into 1958. These site activities would have been on a smaller scale as compared to production operations.).

The evaluation that follows examines separately the availability of information necessary for reconstructing internal and external radiation doses of members of the proposed worker class.

### 7.1 Internal Radiation Doses

The principal source of internal radiation exposure for members of the proposed class was exposure to radioactive dust particles via direct and indirect handling/processing of ores and other solid compounds or from the drying of liquid radioactive materials and subsequent resuspension of the dried radioactive material into the breathing zone through traffic, housekeeping, and other means of disturbance. The resulting airborne contamination could be inhaled, directly exposing tissues of the respiratory tract and other internal organs.

Exposure to radon and its progeny was another significant internal exposure hazard predominantly in ore handling/storage/processing areas or in areas where individuals worked with waste raffinate materials containing high concentrations of radium. It is known that during times when pitchblende ores (ores that possessed both high uranium and radium concentrations) and their wastes were processed, there was more radium available to parent the radon progeny (and discussed later, to cause elevated external exposure). Radon (and resulting progeny) then became more highly concentrated in the air in those areas. It was noted that even in areas with increased ventilation, concentrations in some cases remained elevated.

Internal exposure to individuals via the ingestion pathway, is accounted for in section 5.3 of the Mallinckrodt TBD, whereas the absorption of radioactive materials into the body through the skin is accounted for by dose reconstructors on a claim specific basis.

Monitoring records are available for all time periods, except for urinalyses and air dust measurements, to conduct dose reconstructions. Operations in Plant 1 and 2 were shutting down and being moved to Plant 6 in the 1945/1946 time frame. Operations in the 1946-1957 time frame were taking place in Plants 4 and 6. Engineering controls were being incorporated within the plants to provide increased ventilation, shielding, and a decrease in direct contact with the radioactive materials (Plant 6 was designed and built in an attempt to reduce personal exposures at the site mainly by using continuous, rather than batch, flow of materials). In 1949 it had become clear to AEC that process improvements to Plants 4 and 6 were not enough to bring about satisfactory control of dust and other hazards (AEC 1949b; AEC 1951b). As Mallinckrodt reminded AEC, Plant 6 had been built as an ordinary processing plant with no special provisions for health hazards because it was not expected to be used more than eight months (AEC 1951b; MCW 1950t). AEC authorized funding for dust control and mechanization improvements, which were installed between 1949-1950. Plant 6 was shut down for a time in late 1949-1950 for this purpose. Due to the following criteria:

- Similar radioisotopes and plant operations during the time frames of 1946 through 1948,
- Quantities of material increased,
- Similar engineering and radiological controls during the time frame,
- Air sample data for 1946 and 1947,
- Personal and Area Monitoring data is present and adequate for 1948 to be used for the years, and 1946 and 1947;

exposures can be “back extrapolated” from time periods where adequate data is available back to time frames that may have gaps in data. This back extrapolation from data available in 1948 can be used to evaluate and reconstruct individual exposures to radiation/radioactive materials at the Mallinckrodt site in 1946 and 1947. Based upon this information, either individual monitoring or surrogate data can be used to reconstruct radiological exposures during the entire 1946 -1957 time frame.

The subsections below summarize the type of data that is available for use in reconstructing doses at Mallinckrodt.

### 7.1.1 Urinalysis Information and Available Data

Mallinckrodt uranium processing workers were given pre-employment physicals that included an initial urinalysis and a blood count (MED 1942) and they were also provided with annual physicals that included a urinalysis and a blood count. These annual physicals were identified as “follow-up” examinations (MED 1942; MCW 1955d; Mason 1958a). Neither of these early urinalyses appears to have included the determination of the presence of radionuclides in the body. Urinalysis results for uranium are available from a routine sampling program that began in the summer of 1948 and from testing performed retrospectively in 1949 to evaluate acute exposures of concern or potential for injury due to chronic exposure to radioactive materials during early site operations.

From about the summer of 1948 (MCW 1950c) through the end of site operations, the annual physical included a measurement of uranium in the urine for all process workers. In addition, up to March 1954 process workers provided urine samples for analysis every 4-6 months depending on their worker class (MCW 1955d; Mason 1958a). After this time period, the sampling frequency was no more than semiannual (MCW 1955d). The earliest site urinalyses appear to have been performed as a means of retroactively checking for acute exposures or for the onset of damage due to chronic exposure rather than for dose measurement purposes.

An increasing number of urine samples were collected from 1948 until the number peaked in 1953. A report (MCW 1955d) noted that NYOO was analyzing a substantial number of urine samples (about 2500 a year) and that the samples were split, with half going to AEC-NYOO for radiological analysis and the other half sent to Barnes Hospital for medical analysis.

Historical site information is provided in Sections 3.0 and 4.0 of the Mallinckrodt TBD. These Sections of the TBD describe the history of site use and operations. The ability to use a surrogate data set to "back extrapolate" exposures to periods where there may be data gaps or where data may not be available is dependant on having the criteria given in Section 7.1 of this Evaluation Report (e.g., similar exposure conditions). Plants 4 and 6 were the primary production facilities operating in 1946 through 1950 (Plant 7 coming online in late 1950) and they had similar exposure conditions until 1949 when upgrades to the dust control and mechanization processes were made to Plant 6. Urinalysis data available for 1948 and 1949 can be used with other internal exposure information to back extrapolate internal dose for 1946 and 1947 where data is not available.

*Other facts related to Mallinckrodt Urine Data*

In addition, much work was conducted on site to determine the solubility classes and effective particle sizes of the materials that individuals were exposed to in an attempt to understand the metabolic properties of the contaminant inside the body. The uranium refining operations at Mallinckrodt produced what was at the time believed to be insoluble uranium compounds, e.g., $UO_2$, $UF_4$, and uranium metal (Lippmann 1958) and no soluble forms, such as $UF_6$, appear to have been produced at the site. Uranium tetrafluoride ($UF_4$) is now considered as being moderately soluble in the body. Further, Eisenbud (1958) reported that, "It has been shown that in these [uranium processing] plants the mass median diameter was about 2 µm." But he also noted that while the peak for alveolar retention is 1-2 µm for dust of unit density (i.e., 1 $g/cm^3$), uranium oxide dust has a density of 9 or 10 g/cc, so that a 1-2 µ particle would behave as though it were a 3-6 µm particle of unit density. This information indicates that the internal dosimetry models given in ICRP Publication 66 (ICRP 1995a) are applicable (e.g., 5 µm sized particle and a solubility class of M for $UF_4$) for conducting internal dose assessments for claimants at Mallinckrodt.

In 1949, AEC compared the Mallinckrodt urinalyses against those for other sites handling similar material and concluded that the results were consistently, inexplicably high (MCW 1950e). Subsequent data analysis showed a gradual precipitation of uranium in the Barnes Hospital (local to St. Louis) standards, which meant that the daily standard curves showed a gradual loss of slope over time, up to 30%. After 1949, only samples taken within one hour of the start of the weekly shift were accepted (ORAU 1983b) for analyses. Because of the questions regarding the validity of the samples, the apparent variations in sample analysis methods, and even who was doing the analyses, the Mallinckrodt urinalysis data should be used with caution, at least when the data was taken by Barnes prior to about 1951. However, the errors, if any, are in the conservative (high) direction and thus are claimant-favorable.

With the processing of waste raffinates (AM-7 residues) in 1955-1957 came an increased level of thorium containing material that was potentially made available for intake by process workers. It does not appear that urine samples were differentiated during urinalysis between uranium (and its daughters) and thorium. Hence in dose reconstruction, urinalysis data from early 1955 on for workers who processed thorium wastes should be examined on a case-by-case basis to see if any special evaluation for thorium was done. If not, then dose estimates from air sampling data may have to be made. Section 6.1 of the TBD indicates a technique to use by dose reconstructors to account for and assess this internal exposure to the isotopes Th-230, Ac-227, and Pa-231. Either uranium urinalysis or air sample results can be used to assess this exposure. These internal assessments can be conducted based upon estimated (claimant favorable) isotopic distributions. For simplification of the dose reconstruction process, the low-contributing isotopes may be conservatively ignored or their contributions may be folded into those of other isotopes when appropriate for the organ type and intake mode.

### 7.1.2 Information and Available Data Regarding Other Types of Bioassay

A program of breath radon measurement began June 1945 (MED 1945e and MCW 1946g) for workers who worked in areas where there was a potential for radium intake. Individuals were categorized into various sampling groups. MCW (MCW 1950i) gives a list of worker sampling groups or occupational areas, along with a rating of the need for workers of each type or in each area to have their exhaled breath sampled for radon content (the radon content in breath was used to determine the amount of radium that was deposited in the body). These sampling groups included: most of the Manufacturing (process), Stores (warehouse), and Maintenance (craft) workers were in the "Definite" category, while most of the Power Plant, Occupancy, Plant Protection (guard), Research, Laboratory, and Laundry workers were in the "Possible" category and most of the Health & Safety, Office & Administration, and Plant 4 workers had most of their people in the "Improbable" category. (Plant 4 was known as the "Metal Plant" and converted $UO_3$ to $UF_4$ and then to metal. Radium bearing materials, and radon, would have been insignificant in the building.) The first breath radon measurements were thought to be worthless by MED because the <u>MED expert concluded that the samples were contaminated at the time they were taken</u> (MED 1945e).

It should be noted here that the measured sample results were biased high (indicating internal radium exposures greater than what was actually present). These samples were considered biased high because individuals left samples after breathing radon contaminated air in their work environment. The workers would subsequently provide samples with radon activity not from radium content in their body, but from the radon in the environment.

As a result, MED directed Mallinckrodt to have breath radon samples taken only in a room away from the plant and only when the employee had not worked for at least 48 hours and while he was still wearing his street clothes (MED 1945e). This would allow the employees to purge their lungs of environmental radon, remove other sources of contaminating the sample and then when samples were pulled the results were indicative to radium content in the body.

Breath radon samples were collected by obtaining one-liter samples of exhaled breath after two days of non-exposure, usually on a Monday morning (AEC 1949g; AEC 1950a; MCW 1950g). The samples were measured at the National Bureau of Standards (AEC 1949g) or at NYOO (AEC 1950a, MCW 1955d) by an "automatically recording pulse-counting device" (AEC 1950a). If a sample was over the "tolerance level" of $1 \times 10^{-10}$ Ci/L, then a recheck (repeat sample) was made, immediately (AEC 1949g). The lower limit (of detection) was 0.1 pCi/L and there was confidence in readings of greater than or equal to 0.5 pCi/L (ORAU 1983b). In 1946, it was reported that of 40 workers tested, the maximum level was the tolerance level of 1 x $10^{-11}$ Ci/L (MCW 1946g). For 1945, few radon breath analyses of employees are available, but began increasing in 1946.

Whole body and lung counts appear to have been performed rarely, if at all, because Mallinckrodt had no invivo examination capability, and workers had to be sent to sites outside Missouri for this to be done or a mobile counter would have had to be brought to St. Louis. Individual whole body and lung count data are not available for the period covered by this evaluation. Air sampling and urinalyses were the predominant internal exposure indicators used at Mallinckrodt.

### 7.1.3 Airborne Dust Levels

Towards the end of 1945, major processes being conducted in Plants 1 and 2 were being transferred to Plants 4 and 6 and later to other site facilities. It is important to indicate that while very little is known regarding the research and laboratory type operations that took place in Plants 1 and 2, handling methods, or even source terms that were present; considerably more information is known about operations in Plants 4, 6, and the subsequent facilities that were used after the 1945 time period.

As discussed in section 5.1, Plant 6 was constructed to increase production and safety in the production process. Safety concerns had been recognized by MED and Mallinckrodt as early as 1944 and 1945. Subsequently, Plant 6 was designed for continuous operations with less manual operations as compared to the earlier batch processing. It was felt with this new design exposures would be significantly reduced. However with the increased production rate and the increased use of the pitchblende ore, workers were exposed to significant dust , radon, and external doses. These safety concerns were identified by MED and Mallinckrodt in 1948 and further engineering controls were implemented in 1949. This is supported by the sample data available for 1946-1948, prior to the engineering controls instituted in 1949.

As mentioned in earlier sections, by 1949 MCW processes had been improved to reduce exposures and formal monitoring programs were being utilized. Regular dust monitoring utilizing extensive breathing zone samples in the calculation of time weighted average dust exposures were initiated in 1948. Details regarding the sampling techniques and calculations used are given in section 6.0. The dust monitoring records available from 1949-1957 are quite extensive and support the feasibility of internal dose reconstruction for that time period.

The ability to assess the affects of contaminated dust on MCW workers from 1946-1948 prior to process improvements and a regular dust sampling program is based on the following available information:

1. Complete dust study time weighted average study reports for Plants 4 and 6 are available (MCW1949c, MCW1949d). These studies were performed in 1948 prior to the major improvements started in 1949,
2. The studies were performed using the same techniques as used in the formal program,
3. Plants 4 and 6 were essentially the only two plants actively engaged in processing operations during the 1946-1948 time frame, and
4. Processes at Plants 4 and 6 remained predominantly unchanged during the 1946–1948 time frame.

The exposure information obtained via the 1948 Plant 4 and 6 dust studies (MCW 1949c, MCW 1949d) therefore support the feasibility of internal dose reconstruction for employees present during the 1946-1948 time period.

### 7.1.4 Radon and Thoron

Radon levels could be substantially elevated in enclosed areas in Plants 1 and 4 where material containing uranium daughter products were stored. It is likely that workers were exposed to short, high level exposures when opening 55 gallon drums of ore, opening storage rooms, and other enclosed equipment containing ore and residues (ORAU 1989a).

Some early radon measurements occurred in 1945 in Plants 1 and 4 using methods developed at the facility. However, routine air sampling for radon did not begin until 1946, when samples were taken once a week in known, high-radon areas (MCW 1950d). Another reference indicated that beginning perhaps in the mid-1940s, radon samples were taken once a week in high-radon areas (MCW 1950e). This included the outdoor yard areas from which measurements indicated that some outdoor area was always downwind and that the Plant 6 outdoor background (based on “ordinary” emissions to the outdoor plant atmosphere) was on the order of $1 \times 10^{-11}$ Ci/l (MCW 1949n). The principal locations which were found in 1946 to be difficult to keep radon concentrations below tolerance levels were the rail cars during unloading of ore drums and in the ore and residue storage area (MED 1946c). In locations affected by the digestion vent exhaust and the residue, the radon levels were likely to have varied depending on the stage and timing of processing. A percentage of the radon produced during decay, which would have varied depending on particulars of the ore and processing conditions, would be adsorbed on the surface of the ore particles. When the ore was digested in acid, the adsorbed radon was released and the gamma activity of the ore slurry would drop. When the radium was subsequently precipitated from the acid solution as a sludge, the precipitate would adsorb some of the radon, resulting in an increase in gamma activity as the precipitate “aged” (AEC 1947e). The high radium content of the sludge also would significantly contribute to elevated radon emanation.

Enclosed spaces in MED/AEC refineries produced radon concentration levels of up to $10^{-7}$ to $10^{-8}$ Ci/L from 1944-1949 (Eisenbud 1975). Improvements in ventilation reduced these exposures, but did not generally control them to within the preferred level of $10^{-10}$ Ci/L until 1949.

With the commencement of radon sampling preceding by some years the processing of high-radium and thus high-radon pitchblende ores and the apparent competence of the Mallinckrodt health and safety and instrument people at developing and using radon-measuring instruments, the radon measurements taken can be regarded as reasonably representative of the conditions.

ORAU (1989a) estimated the radon exposures of approximately 184 Mallinckrodt Plant 6 workers as part of a larger study. They calculated the working level (WL) for each job title using the mean radon concentration value from all available surveys in 1946-1957 for each job title's assigned work area; exposure estimates were then calculated in units of working level months (WLMs) for each job title. It was assumed that an equilibrium factor of 0.25 applied for radium and its daughters was based on plant and memoranda, other documents, and findings from uranium mine and residential radon studies. Their approach of assigning a WLM value for each job title for a single grouped period of years (rather than breaking it down by years) was due to the lack of survey data for many of the years. The “roving operator” and the production/processing/manufacturing operators were assigned the average area radon levels for the entire Plant 6 area and the highest daily work time breakdowns of all the production processes. Weekly rotation as practiced at Mallinckrodt was handled by assigning an average radon level of all available survey data from those work areas in the rotation plan for that job title. Pertinent results are shown in the table below for information. These results are for the years of pitchblende processing and so would presumably be conservative for the pre-pitchblende years. This information is available for the purposes of reconstructing dose to claimants in this proposed class.

**Exposure rates of 184 Mallinckrodt workers, based on surveys done in 1946-1957 (ORAU 1989a)**

| Job title | No. of workers | WLM per month worked | Job title | No. of workers | WLM per month worked |
|---|---|---|---|---|---|
| Manufacturing operator | 3 | .138 | Recovery operator | 13 | .052 |
| Operator, process develop | 1 | .138 | Guard | 3 | .047 |
| Production operator | 2 | .138 | Porter, Lab | 1 | .044 |
| Roving operator | 3 | .138 | Digest operator | 2 | .042 |
| Cleanup operator | 8 | .127 | Pilot Plant operator | 4 | .041 |
| Maintenance (general) | 1 | .111 | Clerk, Manufacturing Office | 1 | .040 |
| K-65/GLC sampler | 1 | .102 | Clerk, Production Office | 8 | .040 |
| Pot Room operator | 14 | .097 | Feed operator | 2 | .038 |
| K-65/AJ-4 sampler | 4 | .096 | Filter press operator | 3 | .038 |
| Raffinate operator | 9 | .092 | Plant monitor | 1 | .030 |
| Barium operator | 6 | .091 | Health office | 2 | .020 |
| C-3 (Centrifuge) operator | 18 | .084 | Engineer, senior mechanical | 1 | .018 |
| Feinc operator | 12 | .084 | Furnace operator | 12 | .010 |
| Director, technical | 1 | .077 | Industrial relations (office) | 1 | .010 |
| Mail boy (office) | 2 | .057 | Ether House operator | 17 | .008 |
| Porter, Production | 6 | .056 | Machinist (instrument) | 2 | .008 |
| Ore Room operator | 16 | .055 | Chemist | 4 | .003 |

During a relatively short contract period between July 1955 and March 1957, the pitchblende raffinate materials were brought back onsite and processed to concentrate Th-230 for the Mound facility. Though not a major contributor to exposure, thoron gas (Rn-220) and its daughters were released during the process and caused additional internal exposure; small in comparison to the radon (Rn-222) progeny that was released (a factor of approximately 200 less). The thoron half-life is 55 seconds, meaning that it is not available in the air long before it decays to a particulate, radioactive daughter. Due to the relatively short half-life, individuals would have to be physically close to the source to incur much exposure. The TBD provides a technique to determine internal exposure due to the inhalation of thoron gas.

## 7.2 External Radiation Doses

As discussed in Section 5.2.1, the pitchblende ores and resulting waste contained high levels of Ra-226. Ra-226 (in equilibrium with its progeny) constitutes a significant gamma radiation source and thus produced most of the external penetrating, whole-body dose received by the workers, while Th-234 and Pa-234m (immediate daughters in the uranium series), both beta emitters, would have produced most of the skin and extremity dose.

The subsections below summarize the extent of information available for reconstructing the external doses of members of the class. Most of the information summarized below is provided in greater detail in the TBD.

It is important to note that limited, external dosimetry commenced at the site in mid-June 1945, with subsequent implementation of individual dosimetry later in the year. Though calendar year 1946 was not included, the following tables are provided to indicate the extent of monitoring and magnitude of measured exposure within the external dosimetry program at MCW. It must be noted here that the reference for these tables was written in 1980 and that number of "workers monitored" does not match with the numbers in the Table given in Section 6.0 of this report. It should also be noted that the era of pitchblende use (early 1945 on) was mostly covered by film badge monitoring, so that the doses characteristic of this work are known.

**Annual gamma exposures, 1947 – June 1957 (ORAU 1980b)**

| | Workers | Annual Gamma Exposure, R | | | | |
|---|---|---|---|---|---|---|
| Year | Monitored | 0 - 1 | 1 - 5 | 5 - 10 | 10 - 15 | >/= 15 |
| 1947 | 253 | 70 | 131 | 27 | 18 | 7 |
| 1948 | 366 | 120 | 171 | 47 | 19 | 9 |
| 1949 | 554 | 370 | 141 | 41 | 2 | 0 |
| 1950 | 615 | 475 | 133 | 7 | 0 | 0 |
| 1951 | 694 | 512 | 171 | 11 | 0 | 0 |
| 1952 | 757 | 659 | 88 | 10 | 0 | 0 |
| 1953 | 763 | 619 | 142 | 2 | 0 | 0 |
| 1954 | 756 | 566 | 188 | 2 | 0 | 0 |
| 1955 | 871 | 766 | 105 | 0 | 0 | 0 |
| 1956 | 958 | 944 | 14 | 0 | 0 | 0 |

**Highest gamma doses to workers, 1947-June 1957 (ORAU 1980b)**

| | Annual Dose, R | | | Weekly Dose, R/week | | |
|---|---|---|---|---|---|---|
| Year | Min | Avg | Max | Min | Avg | Max |
| 1947 | 14.4 | 16.1 | 23.5 | 0.28 | 0.31 | 0.45 |
| 1948 | 14.9 | 17.0 | 20.3 | 0.25 | 0.33 | 0.39 |
| 1949 | 7.7 | 9.0 | 13.3 | 0.15 | 0.17 | 0.26 |
| 1950 | 4.5 | 5.4 | 7.1 | 0.09 | 0.11 | 0.14 |
| 1951 | 5.0 | 5.9 | 7.1 | 0.10 | 0.11 | 0.14 |
| 1952 | 5.1 | 5.9 | 6.6 | 0.10 | 0.12 | 0.13 |
| 1953 | 4.0 | 4.6 | 5.7 | 0.08 | 0.09 | 0.11 |
| 1954 | 3.9 | 4.4 | 5.1 | 0.08 | 0.09 | 0.10 |
| 1955 | 3.9 | 4.4 | 5.1 | 0.08 | 0.09 | 0.10 |
| 1956 | 1.1 | 1.4 | 1.9 | 0.04 | 0.06 | 0.07 |

### 7.2.1 Film Badge Monitoring

Workers were not individually monitored for external dose prior to December 1945, except for a limited pilot program starting around June of 1945. Currently available film badge records indicate monitoring for the weeks ending July 29, August 5, August 12, and August 26 of that year and then there is a gap until the week ending December 9, 1945. Total (accumulated) doses for the period from December 9, 1945 to March 25, 1946 were reported, by individual, in a memorandum from the University of Rochester School of Medicine and Dentistry (Rochester 1950). The same film badge was in use throughout Mallinckrodt uranium operations for AEC (MCW 1961a), i.e., from 1945 through the end of operations. This was a two-element type of dosimeter. The film was a DuPont Type 552 film packet containing two dental-size films wrapped together.

ORAU (1980b) stated that after the start of the film badge monitoring program all Mallinckrodt employees who were cleared to have access to production areas wore film badges at all times, with the purpose being to provide maximum assurance that all exposures were registered. Contemporary references indicate that film badges were issued as a combination security-exposure badge to all employees, except for "office females" who presumably never entered process areas (MCW 1955d, MCW 1955c, MCW 1956i). In addition, workers were directed to wear their badges when they went to the SLAPS or "the Range" (MCW 1949q). The Range appeared to be a firing range (near or at the storage area) where the guards would practice shooting and where some materials were stored (e.g., AEC 1949E reports that some $UO_2$ was drawn from this storage area for use in production). Plant 6 workers were also told to wear their Plant 6 badges when they visited Plant 4, and vice versa for Plant 4 workers, and not to wear a visitors' badge (MCW 1948d).

From April 22, 1946 through the end of MED/AEC work at MCW in 1957 or 1958, film badges were processed on a weekly basis as part of a routine dose monitoring program. Badges for Plant 4 began to be changed only every two weeks in early September 1954 (MCW 1954d); all badges began to be changed every two weeks as of January 30, 1955, because of a shortage of health personnel to read the badges and the comparatively low doses then being recorded on the badges (MCW 1955b, MCW 1956i).

This information indicates that film badging was provided at Mallinckrodt from 1946 through the end of operations and that it is available for use directly, or if needed for surrogate data, to conduct dose reconstructions.

### 7.2.2 Gamma, Beta, and Nonspecific Beta-Gamma Exposures

After high-grade pitchblende ores began to be used, refinery workers were exposed to photons from radionuclides in equilibrium with U-238 and U-235. Ra-226, through its Pb-214 and Bi-214 daughters, contributed gammas to workplaces where ore was stored or processed. Upon removal of the uranium daughters, processed material became radiologically innocuous until the passage of time resulted in the ingrowth of Th-234 and Pa-234m and the consequent domination of the dose profile by electrons. Mallinckrodt worker dose records demonstrate this difference, with significant doses for mixed photons and electrons in the refinery operations and high electron doses with little photon dose in the metal plants.

In 1946 the principal source of significant gamma radiation was said to be the drums of ore as they were stacked in the receiving warehouse (MED 1946c). The gamma dose rate could be as high as 50 mR/hr near stacks of drums of pitchblende ore at 25% concentration and with a radium content of about 100 mg/ton (Eisenbud 1975). A 1958 AEC report documents dose rates of 0.8-8.0 mR/hr, with an average of 3.0 mR/hr, as the gamma dose rate at three feet from bulk ore concentrates (AEC 1958, Table XI), these exposure rates are likely to have been associated with domestic ores. The maximum external gamma radiation doses associated with exposure to ores could be estimated for the class, if necessary, by assuming constant exposure to the ore barrel storage locations. Dose rate survey information is available for this area and dose rates could be modeled assuming maximum concentrations of Ra-226. More detail addressing how these radiation doses could be estimated is provided in the TBD in section 7.4.

In some cases, gamma dose rates from wastes could have been substantially higher than those for the ore. Dose rates at points adjacent to stacks of drums of radium-bearing residues (precipitates) were as high as 100 mR/hr (~ 300 mg Ra/ton) (Eisenbud 1975) and up to 275 mR/hr for direct contact with the drums (MCW 1949g). AEC (1948c) gave the gamma contact dose rate with the radium-containing Feinc filtrate residue under conditions of secular equilibrium (conditions resulting in maximum exposures) as over 300 mR/hr. The highest dose rates would have been associated with operations involving manual transfer and manipulation of the waste materials. These included: 1.) the various dumping, scooping, and scraping operations in which feed, $UO_2$, $UO_3$, $UF_4$, and dust were handled or crucibles and furnaces were cleaned; 2.) the "plowing" (scraping) of the centrifuges; and 3.) the scraping of cake off the Feinc filter cloths (this was the pitchblende cake during the pitchblende years). Maximum external gamma radiation doses associated with exposure to residues could be estimated for the class, if necessary, by assuming a maximum dose rate associated with operations involving the Feinc (rotary vacuum filter) in Plant 6. NIOSH has adequate monitoring data for such operations, which would have produced higher gamma dose rates than those occurring in Plants 1, 2, and 4, because of the higher concentration of radium-bearing materials. More detail addressing how these radiation doses could be estimated is provided in the TBD in section 7.4.

The Th-234/Pa-234m combination (from U-238 and U-234) produced about 1500 alpha dpm/mg U and 1500 beta dpm/mg U when the daughters were in equilibrium, producing 240 mrad/hr at the surface of U metal, 208 mrad/hr at the surface of $UO_3$, and 183 mrem/hr at the surface of $UF_4$. Further, during $UO_3$ prep much of the beta-active material was removed, but built back up to 50-100% by the time it got to the $UF_6$ production facilities (Baker 1958). This suggests that significant buildup could occur before the $UO_3$ left the Mallinckrodt facilities because the storage time might be weeks and the transport time was likely less than a few days. Eisenbud (1975) pointed out that 90% of equilibrium beta activity was restored by 90 days after vacuum casting. Eisenbud (1975) reported high dose rates, up to 1 rad/week to the body and even more to the hands, from loading of $UF_4$ into $UF_6$ reaction vessels. This too implies that if enough time had elapsed, $UF_4$ loaded at Mallinckrodt into the bombs could also produce relatively high beta dose rates. Metallic uranium in equilibrium with Th-234/Pa-234m could produce up to 235 mrad/hr to the basal epithelium when the metal was in contact with bare skin; heavy gloves would significantly reduce this (Eisenbud 1975).

In addition to the beta dose rate from the uranium as natural uranium, uranium oxide, etc., there were two waste concentrates that produced high beta dose rates. First, when ether was used to extract the uranium from uranyl nitrate, Th-234 and Pa-234m were left in the aqueous phase (also called the aqueous uranium tails) (Eisenbud 1975). This aqueous solution was filtered, resulting in a residue (cake) containing the beta emitters. MED (1942) stated that 1942 measurements indicated that the intensity was low and that no precautions needed to be taken for disposal; however, MED/AEC appears to have been more concerned about this later on. Another source of the tails was the $UO_2$-derived shotgun sample, which could have the Th-234 and Pa-234 concentrated to 30-300 times their activity in normal uranium metal in equilibrium, depending on how long the $UO_2$ had stood between production and sampling (MED 1944m). The fourth and final ether extraction performed in processing a shotgun sample produced liquor so concentrated in these beta emitters that it was said that the tolerance dose of beta radiation could be reached by keeping the hands above the liquor for 10 minutes per day. Besides that, the chemist handled the sample for 5-10 minutes from removal from the furnace to bottling, wearing no gloves and directly touching the containers. MED (1944m) advised changing from rubber gloves to leather gloves (to increase the dose rate reduction from a factor of 2 to a factor of 3) and using crucible tongs (to increase the distance to about 10”) for conveying the evaporation dish to the heating areas.

Second, in the vacuum recasting of the uranium metal, impurities in the metal volatilized and condensed on the cooler portions of the furnace, creating spot deposits (AEC 1949b; Eisenbud 1975). The impurities contained Th-234 and Pa-234m, which were concentrated to a significant degree in the deposits (AEC 1949b; Eisenbud 1975). This deposit residue could have "up to 1000 times the beta activity of natural uranium" (AEC 1949b). Manual contact with these deposits during charging, discharging, cleaning, and repair of the furnaces provided "opportunity for hand irradiation of a greater magnitude than whole body" (AEC 1949b), possibly as much as 2-3 rads/week to exposed skin and perhaps to the eyes when the original ore was pitchblende at 25% average enrichment (Eisenbud 1975). Mallinckrodt (MCW 1949a) observed that 25% of Plant 4 workers received over 500 mrep/week beta and 3-6 workers per week received 2000 mrep or more; AEC (1949g) also observed that the beta values (on film badges) from Plant 4 consistently ranged up to 2.7 rep/week.

Because of the high hand doses, the processing of the uranium derbies and billets was studied in 1948 by Mallinckrodt (MCW 1948b). The results of the study were used to reduce skin and extremity doses in the new Plant 6E. This was done by minimizing individual exposure to large bare surfaces of uranium and minimizing the accumulation of scale and powdered residues in which the Th-234 and Pa-234m concentrated, especially in the recasting or metal remelt step.

Maximum external beta doses for the class can be determined from film badge data (section 6.0), dose rate surveys, and data from similar operations at other DOE sites. More detail addressing how these radiation doses could be estimated is provided in the TBD in section 7.4.

### 7.2.3 Neutrons

No neutron exposure measurements are available for the Mallinckrodt site. Neutron exposure could have occurred from the radium-beryllium (Ra-Be) source or neutrons produced by the alpha-neutron reaction in the mixtures of uranium/thorium and fluorine, which occurred after 1954. Maximum neutron doses associated with exposure during this period could be estimated by multiplying the measured or reconstructed gamma exposures at the Mallinckrodt facility by the known ratio of neutron to gamma dose for alpha-neutron reactions in fluorine matrices.

Section 5.4.2 of the MCW TBD discusses the techniques used to estimate neutron exposures to site personnel based on knowledge of the source terms and handling of the alpha-neutron source that was in use at the site.

### 7.2.4 Occupational X-ray Examinations

MED (1944d) stated that the medical program recommended by MED was being followed by Mallinckrodt. This included a routine chest x-ray prior for employment and annually thereafter and a pelvic x-ray for those employees handling fluorides for the time periods of 1942-1944. MED (1944d) thought that the pelvic x-ray could be dispensed with and apparently this was subsequently done. Later documents also indicate that Mallinckrodt uranium processing workers were given a pre-employment physical that included a chest x-ray (MCW 1955d and Mason 1958a). They were also given an annual physical that included a chest x-ray (MCW 1955d and Mason 1958a). That these x-rays were actually given is indicated in the series of Mallinckrodt Health Office and other reports (e.g., MCW 1951b, MCW 1954e, MCW 1955d). Section 7.4 of the TBD indicates the assumptions and techniques available to reconstruct Mallinckrodt workers' exposure to occupational medical X-ray examinations. Both Posterior–Anterior (PA) and Lateral Chest X-ray examinations are assumed to have been conducted for employees at Mallinckrodt on an annual basis for the time period covered by this Petition Evaluation Report (Pelvic examinations were not given to site workers during the time-period covered in this Evaluations Report, they are not discussed in this document).

## 7.3 Petition Basis Evaluation

An evaluation was conducted by the reviewing health physicist early in the process to determine whether the submitted petition and supporting documentation qualified the proposed worker class for formal evaluation. A total of 23 referenced documents (or statements that were provided separately) were received and reviewed during the SEC petition qualification step. Eleven of the 23 documents provided information that qualified the petition for evaluation. [The other twelve (12) documents provided by the petitioner either did not indicate: 1) unmonitored, unrecorded, or inadequately monitored or recorded exposure incidents or 2) exposures were not monitored; were lost, falsified, or destroyed; or information regarding monitoring, source, source term, or processes were unavailable for the site.] Since the release of Rev.0 of the site TBD, new information and data have been retrieved that provides additional site information to support dose reconstruction. The TBD is under revision to include this information. This evaluation report is the result of the formal review of the petition supplied for the Mallinckrodt Destrehan Street site.

The following text presents evaluation summaries of the statements and documents submitted by the petitioners that qualified SEC Petition 00012 for evaluation. (All supporting information that was submitted in the petition was carefully reviewed to determine the extent to which it supported the petition basis and for its usefulness in determining feasibility/infeasibility of performing dose reconstruction.) Only those documents and statements that, to at least some extent, qualified the petition for evaluation have been included in this report. An evaluation of all submittals is available in a "Professional Judgment Document" which is part of the project record. Note that there currently are two evaluation reports for the Mallinckrodt Destrehan Street site (SEC-00012-1 and SEC-00012-2) that take the initially petitioned time frame at the site (1942 – 1957) and split it so that early (1942 – 1945) and later (1946 – 1957) activities are covered separately.

> *1. By virtue of the site profile, conducted by NIOSH/ORAU, there is limited to no individual data from 1942 until 1948 (see Doc A1, A2, and A3).*

For the time frame included in this evaluation report (1946 – 1957), external dosimetry and air sample records are available for the entire period. As discussed in section 6.0, the initial (and later) site dosimetry and radiological sampling was provided for those areas and individuals with the highest potential for exposure. Therefore, using the air monitoring data from 1946 and 1947 and comparing it to the air sample data and urine data from later years, an exposure matrix for 1946 and 1947 could be established. Urine sample results are available for the majority of the time frame, beginning in the summer of 1948. Therefore, though the documents supported qualifying the petition for evaluation, currently available data or techniques given in the TBD indicate that dose reconstructions could be conducted for the 1946-1957 time frame at Mallinckrodt, except for the issues raised in response to #4 below.

*2. In reference to Breath Radon (see Doc A6 and A7, site profile p. 25 and 41) – please see (Doc A4). Very few BR samples were taken and tested in 1946, none before. It didn't get going until 1948 and ended in 1957. Again, the use of 0.000 is misleading.*

For the time frame included in this evaluation report (1946-1957), limited breath radon samples were obtained. Many area radon samples were taken to evaluate internal exposure conditions. The TBD provides a technique to assess internal exposure to individuals to radon. As discussed in the resolution to the initial comment above, urinalysis results were collected at Mallinckrodt and used (with surrogate data) to assess internal exposure to site workers. The TBD also indicates a technique to assess internal exposures to other radioisotopes based upon uranium urinalysis results. Site breath radon results indicated as ".000" will not effect the ability to reconstruct dose to site individuals because surrogate information is available for use. Therefore, though the documents supported qualifying the petition for evaluation, currently available data or techniques given in the TBD indicate that dose reconstructions could be conducted for the 1946-1957 time-frame at Mallinckrodt, with respect to radon exposures.

*3. Possible lost medical records (see Doc A8). Page 3, not one complete set of medical records/files from Weldon Spring. Possible destruction of key records V2161 (see A8, page 4). Cover letter states these were the best records in the world in regard to uranium exposed workers.*

NIOSH searched epidemiology records available at ORAU and extensive research conducted to match employee medical records to employment record lists did not indicate a loss of medical records. Documentation is available in the ORAU Records Storage Vault documenting this research. Therefore, though the document supported qualifying the petition for evaluation, a destruction of medical records was not confirmed and would not limit dose reconstructions from being conducted for the 1946 – 1957 time frame at Mallinckrodt.

*4. Altered illegally/conscious cover-up (see Doc A9). Referencing to a 1949 dust evaluation, records and formal report was never prepared on this study; this was on the advice of MCW attorneys to avoid subpoena. There was a fake benchmark and correspondence on whether one might even consider making this study (by lying) more favorable or even not recording it at all.*

The letter from M. G. Mason, a former health and safety representative at Mallinckrodt, to Thomas F. Mancuso, MD, an AEC research study director at the University of Pittsburgh, contains the statement: "Perhaps they [estimates of worker internal exposures based upon a dust sample result evaluation] could be presented in a more favorable way or not even made a part of your records." This statement could be interpreted as a recommendation by a site safety representative to cover-up a study. Although NIOSH believes that the air sample data from that study were maintained and are available to NIOSH, the fact that personnel responsible for worker protection are documented to have discussed hiding the results of an analysis on worker exposures is profoundly troubling. It raises the question as to whether safety personnel might have taken other, undocumented actions, to obfuscate or change the existing air sample data. If such actions were taken, NIOSH would not be able to detect misleading air monitoring data during the 1946-1948 period because the quality of the urinalysis monitoring data at Mallinckrodt prior to 1949, which provides the best means to validate the air monitoring data, and vice versa, was brought into question in a review by the AEC's Health and Safety Laboratory.

Further, the routine urinalysis program was not fully functional until 1949. Under certain circumstances, NIOSH can substitute radiological source term and process information for both personal and area monitoring data, but the Mallinckrodt operations involved a diversity of source terms and processes, as are briefly summarized in Section 5.0 of this report. This combination of source terms and processes result in too many different plausible exposure scenarios to model with reasonable certainty of identifying and characterizing the highest plausible radiation exposures, as would be needed to estimate maximum radiation doses to members of the class.

The specter of doubt raised by the Mason document also poses added difficulties for dose reconstruction for employees who worked after 1948 because, despite the scientific and technical ability of NIOSH to validate doses from multiple sources of information, such procedures are difficult or impossible for most claimants to comprehend. This may pose a special credibility problem for the NIOSH dose reconstruction program among Mallinckrodt claimants.

Based on the documentation of concern, the limitations of data prior to 1949, and the complexity of plausible exposure scenarios, NIOSH would not have sufficient information to reasonably estimate radiation doses for Mallinckrodt employees prior to 1949. This situation differs substantially from 1949-1957, given the availability of data from a fully operational urinalysis program as well as the added oversight of the radiation monitoring by the Atomic Energy Commission's Health and Safety Laboratory (HASL), which possessed recognized expertise in monitoring radiation exposure in the workplace. The overall extent of monitoring and consistency of radiological practices after 1949 provides a relatively high level of confidence, from a scientific and technical standpoint, concerning the ability to estimate radiation doses with sufficient accuracy for compensation purposes. As discussed above, however, this confidence would be unlikely to be held by Mallinckrodt claimants, given the high level of skepticism among some of their members and advocates, which can only be abetted by the documentation discussed above.

> *5. Letter to Dr. Tom Mancuso, MD stating that the quality of records is much more spotty than those in Hanford and Oak Ridge. Also states that records were incomplete and in many cases, not found at all (see Doc A11).*

The majority of this document is illegible, but two sentences identified by the petitioner indicate "My inspection of the records indicated that many of them were spotty, … much more spotty than those that we have in Hanford or Oak Ridge." As indicated in the response to #3 above, when ORAU obtained the Mallinckrodt records, significant research was conducted to verify the existence of records and assign them to individuals when possible. It has been acknowledged that there are gaps in the data, but the use of air sample data, urinalysis results, and surrogate data will allow internal dose estimates to be conducted. Therefore, though the document supported qualifying the petition for evaluation, currently available data or techniques given in the TBD indicate that dose reconstructions could be conducted for the 1946-1957 time-frame at Mallinckrodt, except for the issues raised under the response to #4 above.

> *6. In addition, the first two statements that were received in a later fax* (20040930\{09516D4D-780C-4113-B16A-91788B35B26D), *indicate that 1) neither actinium, protactinium, nor ionium were monitored and 2) urine sample results were inadequate to assess for actinium or protactinium.*

Both statements that were provided indicated the air or urine samples were not analyzed for Ac-227, protactinium, or ionium. The TBD provides techniques to estimate internal exposures to each of these isotopes based upon the general air or uranium specific urine sample results and estimated (claimant favorable) isotopic distributions. The use of air sample data, urinalysis results, and surrogate data would allow internal dose estimates to be conducted. Therefore, though the document supported qualifying the petition for evaluation, currently available data or techniques given in the TBD indicate that dose reconstructions could be conducted for the 1946 – 1957 time-frame at Mallinckrodt, except for the issues raised under the response to #4 above.

### 7.4 Summary of Feasibility Findings

The information in the previous subsections describes techniques that were used at Mallinckrodt to monitor both internal and external exposures to radioactive materials and direct radiation sources. It appears from historical documentation that individuals were monitored based upon exposure potential. During the early years of operations, the most highly exposed individuals were monitored. Both the number of persons monitored and available monitoring records increased from the commencement of site radiological handling operations (the initial determination was that site activities would not take place for an extended period of time and that the processing of uranium would present an extreme exposure hazard.). An evaluation of whether dose reconstructions could be conducted for claims for the site operational period of 1942 – 1945 time period was addressed in another document (SEC 00012-1).

The four major exposure monitoring techniques in place at Mallinckrodt included: external dosimetry, urinalysis, air dust sampling/analysis, and radon analysis. External exposure records (see section 7.2.1 of this report) indicate weekly and biweekly film badge exchange frequencies beginning April 22, 1946 and extending through the end of site operations. Uranium urinalysis results (see section 7.1.1) are available beginning in the summer of 1948, also extending through the end of site operations. Air dust sampling (see section 7.1.3) began onsite in 1943 to aid in evaluating locations of potential internal exposure and of the need for changes in processes and equipment. It was expanded into a comprehensive program beginning in 1949. Finally, radon analyses (see section 7.1.4) began in 1945 in Plants 1 and 4, using methods developed at the facility. Routine air sampling for radon did not begin until 1946, when samples were taken once a week in known, high-radon areas (a limited number of breath radon samples were also conducted for site workers, but the results can only be used as a qualitative indicator of exposure).

As discussed under item #4 of Section 7.3 of this report, the petitioners have provided documentation that raises concern about the integrity and hence the validity of Mallinckrodt air dust monitoring data in particular. Assuming that the dust monitoring data were not valid, particularly that it might not include the highest measured exposures, NIOSH would not have sufficient information to reliably reconstruct internal doses from radiological dusts for employees who worked prior to 1949. Other exposures could be reconstructed from a scientific and technical standpoint, as indicated in the two tables below:

**The table below summarizes the results of the feasibility findings for each exposure source for the period from 1946-1948**

| Source of Exposure | Maximum or Accurate Exposure can be determined | Maximum or Accurate Exposure cannot be determined. |
|---|---|---|
| Internal | | X |
| - Airborne Dust | | X |
| - Radon | X | |
| External | X | |
| - Gamma | X | |
| - Beta | X | |
| - Neutron | X | |
| - Occupational X rays | X | |

**The table below summarizes the results of the technical feasibility assessment for each exposure source for the period from 1949-1957**

| Source of Exposure | Maximum or Accurate Exposure can be determined | Maximum or Accurate Exposure cannot be determined. |
|---|---|---|
| Internal | X | |
| - Airborne Dust | X | |
| - Radon | X | |
| External | X | |
| - Gamma | X | |
| - Beta | X | |
| - Neutron | X | |
| - Occupational X rays | X | |

This evaluation has attempted to address in reasonable detail the scientific and technical matters concerning the feasibility of completing dose reconstructions. NIOSH has also come to a determination concerning the extent to which the documentation concerning data integrity casts excessive doubt on the validity of data available for dose reconstruction. NIOSH has determined that it cannot provide reasonable assurance of validity for dose reconstructions involving internal exposures of radiological dusts during the 1946-1948 period, which would include all employees working during this time period, because all employees had potential exposure to such dust.

NIOSH has not resolved how to weigh the scientific and technical evidence, which support the feasibility of reconstructing internal as well as external radiation doses incurred during the 1949-1957 period, against the evidence that raises questions about the integrity of monitoring data. In this weight-of-the-evidence test, NIOSH questions whether the data integrity issue outweighs the scientific and technical evidence. NIOSH questions whether its scientific and technical evidence is viable in this particular case, for the purposes of the EEOICPA compensation program because it does not provide a transparent basis by which NIOSH could assure Mallinckrodt claimants that they would receive reasonable estimates of their radiation doses. This is an important issue that NIOSH is likely to encounter in evaluating other SEC petitions in the future. Hence, NIOSH will seek the advice of the Board on the consideration of such issues generally, as well as on this specific weight-of-the-evidence determination with respect to the 1949-1957 period at Mallinckrodt.

In summary, NIOSH has determined that it is not feasible to estimate radiation doses with sufficient accuracy for employees of the Uranium Division at the Mallinckrodt Destrehan Street facility (and associated facilities) during the operating years of 1946-1948. A determination of feasibility concerning a second class employed from 1949-1957 will be made after obtaining the advice of the Board.

### 8.0 Evaluation of Health Endangerment

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

As discussed in section 5.1 of this report and as documented in the dust monitoring results available to NIOSH, Mallinckrodt employees had significant exposures to radiological dusts. On this basis, NIOSH has determined that it is reasonably likely that such exposures to alpha-emitting dust may have endangered the health of the Mallinckrodt workers covered by the two class definitions provided in section 9.0 of this evaluation.

The NIOSH evaluation did not identify any evidence from the petitioners or from other resources that would establish that the classes were exposed to radiation during a discrete incident or similar conditions resulting from the failure of radiation exposure controls and likely to have produced levels of exposure similarly high to those occurring during nuclear criticality incidents. NIOSH is not aware of any report of such an occurrence at the facility. The evidence reviewed in this evaluation indicates that some workers in the classes may have accumulated substantial chronic exposures through repeated, episodic inhalations of radionuclides. Consequently, NIOSH is specifying that health was endangered for those workers covered by this evaluation who were employed for a number of work days aggregating at least 250 work days within the parameters established for these classes or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

## 9.0 Proposed Class Definition

This evaluation defines one class of employees for which NIOSH has established that it cannot estimate radiation doses with sufficient accuracy and whose health may have been endangered by such radiation doses. This class includes employees of DOE or DOE contractors or subcontractors employed by the Uranium Division of Mallinckrodt during the period from 1946 through 1948 and whom were employed for a number of work days aggregating at least 250 work days, occurring either solely 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.

The evaluation defines a second class of employees which includes employees of DOE or DOE contractors or subcontractors employed by the Uranium Division of Mallinckrodt during the period from 1949 through 1957 and whom were employed for a number of work days aggregating at least 250 work days, occurring either solely 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. For this class, the advice of the Board concerning the matter of data reliability, as discussed above, as well as the advice of the Board as generally provided for under 42 C.F.R. pt. 83.15 will be obtained.

This evaluation, in conjunction with SEC Evaluation Report Petition SEC-00012-1 (1942-1945), completes the NIOSH evaluation of SEC Petition No. 12, which covered all workers within the Uranium Division of the Mallinckrodt Destrehan Street facility in St. Louis, Missouri, over the entire period of operation from 1942 through 1957.

In consultation with the Division of Energy Employees Occupational Illness Compensation, Department of Labor, NIOSH has determined that Plants 1, 2, 4, 6, and 7 are functionally equivalent to that portion of the Mallinckrodt Destrehan Street facility known as the Uranium Division, and has therefore proposed class definitions that utilize that designation.

## 10.0 References

**Note:** The reference document identifier matches the references from the Mallinckrodt TBD.


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**Attachment 1**
**Mallinckrodt Documents and Reports**
**From Site Research Database**

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MCW - TLD Reports, Radon Reports Partial License Reports Radiological Surveys
MCW - Urinalysis and Radon Analysis Program Basis 1949 - 1950 Surveys
MCW - Whole Body Exposures for Selected Personnel - 1981 - 1985
MCW - and Weldon Springs Possible Use of Quarry for Contaminated Debris Disposal
United Nuclear Corporation - Mallinckrodt
MCW - Plant Drawings and Maps - 1946 - 1955
Documents Associated With Employees Exposure at MCW
Dust Study of the New K-65 Ledoux Laboratory Installation
Film Badge Data February Wage 1966
Film Badge Program
Employee Job History Sheet
Information on X-ray Film & Procedure
Monitoring Results for Donald L. Harrison
Autopsy Report on OWEN KERSNER
Radiation Exposure of Plant 6 Employees
Radiological Limits for Plant 6 and Other Locations
General Information about Product
This document is a duplicate of another document - Refer to 010002059 for entire document
Mallinckrodt - Fuel for the Atomic Age - Report on St. Louis - Area Uranium Processing Operations, 1942 - 1967
Historical Review of the Mallinckrodt Airport Cake
External Radiation Exposure and Mortality in a Cohort of Uranium Processing Workers
Radiological Survey of the Mallinckrodt Chemical Works, St. Louis
Observation of the Electrolysis of UO2 at Mallinckrodt Chemical Works, Weldon Spring, Missouri from June 1, 1966, to October 7, 1966
Disposal of Destrehan Street Facilities and Restoration of Site
Lowman Mill and Disposal Site, Boise County, Idaho
SLDS Fact Sheet
Sales of Residues at the Airport Site
Radon Breath Analysis (1945 - 1947)
Breathe Samples at MCW (1945, 1946, and 1947)
Utter Principle Potential Radioactive Hazards at Mallinckrodt
X-Ray Examination Frequency Change (1946)
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Mallinckrodt Film Badge Results (1945, 1946, 1947)
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Various Reports on Mallinckrodt Radiation Hazards (1944)
Progress Report of the Special Materials Division of Medical
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Film Badge Results (1945)
Air Samples at Mallinckrodt 1945
Uranium Refining Process
Toxicology of Thorium
Film Badge Results Aug 18 - Aug 25, 1947
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Film Badge Date July 28 to August 4, 1947
Film Badge Date June 2 to July 1947
Film Badge Date Dec 30, 1946 to June 9, 1947
Radiation Injuries from Uranium
Extractions of Uranium Ore from Domestic Uranium Ore Concentrations
Radon Breath Samples
Film Badge Analysis May 27, 1946 - Sept 2, 1946
Mallinckrodt Film Badge Results May 20-27, 1946
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