# SEC Petition Evaluation Report
# Petition SEC-00103

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| Site Expert(s): | N/A |

**Petition Administrative Summary**

**Petition Under Evaluation**

| Petition # | Petition Type | Petition Receipt Date | Qualification Date | DOE/AWE Facility Name |
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| SEC-00103 | 83.13 | Nov. 19, 2007 | March 4, 2008 | Savannah River Site (SRS) |

**Class Evaluated by NIOSH**

All construction workers who worked in any thorium area at the Savannah River Site from January 1, 1953 through December 31, 1972.

**NIOSH-Proposed Class(as) to be Added to the SEC**

All externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1953 through December 31, 1957, and whose records have dosimetry codes A, G, CMX, or TNX; and all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1958 through September 30, 1972, and whose records have dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.

**Related Petition Summary Information**

| SEC Petition Tracking #(s) | Petition Type | DOE/AWE Facility Name | Petition Status |
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| N/A | N/A | N/A | N/A |

**Related Evaluation Report Information**

| Report Title | DOE/AWE Facility Name |
|---|---|
| • SEC Petition Evaluation Report, SEC-00103 | Savannah River Site (SRS) |
| • Addendum to Savannah River Site SEC Petition Evaluation Report | Savannah River Site (SRS) |

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# Addendum 2 to Savannah River Site (SEC-00103) Special Exposure Cohort Evaluation Report

NIOSH presented a Special Exposure Cohort (SEC) evaluation report (NIOSH, 2008) regarding the Savannah River Site (SRS) to the Advisory Board on Radiation and Worker Health (Advisory Board) during the Advisory Board's meeting held from December 16-18, 2008. In its report, NIOSH evaluated the feasibility of reconstructing radiation doses of construction workers who worked in any area at SRS during the time period of January 1, 1950 through December 31, 2007. The feasibility of reconstructing doses received from thorium exposure from the start-up of thorium operations in 1953 through 1959 was reserved in the evaluation report while NIOSH continued to evaluate approaches for bounding doses from thorium exposures during that time period.

NIOSH prepared an addendum to the SEC-00103 Evaluation Report (issued May 4, 2010) in which NIOSH stated that it can complete dose reconstruction for exposure to all site occupational radiation sources for all construction workers who worked in any area at the Savannah River Site during the time period from January 1, 1950 through December 31, 2007 (NIOSH, 2010). Since the publication of that addendum, NIOSH has continued its research, captured additional information, and determined that thorium was used in more locations and operations than had been considered in the 2010 addendum. Furthermore, NIOSH has determined that it lacks the necessary monitoring data or source term data needed to adequately bound internal doses received from exposures to unencapsulated thorium for certain workers at SRS. This Addendum 2 to the SEC-00103 Evaluation Report documents SRS work performed with thorium, locations where these tasks were performed, exposures that may been received from such work, and which exposures cannot be bounded.

***<u>NOTE</u>: This Evaluation Report Addendum 2 only addresses those sections in the Savannah River Site Evaluation Report that require discussion; therefore, the section numbering is not contiguous. The sections requiring additional thorium discussion begin below.***

## Petition Evaluation Report Addendum 2 Summary

<u>Class Evaluated by NIOSH (in Addendum 2)</u>

The feasibility of reconstructing doses received from thorium exposure from the start-up of thorium operations in 1953 through 1959 was reserved for further consideration in the original SEC-00103 Evaluation Report. During this subsequent evaluation, NIOSH has determined that thorium operations were conducted at SRS through 1972, and conducted in locations beyond those considered in the evaluation report (NIOSH, 2008) and the first addendum (NIOSH, 2010); therefore, in Addendum 2, NIOSH addresses the feasibility of bounding doses from thorium exposures received during the expanded time period from January 1, 1953 through December 31, 1972. Thus, the class under evaluation in Addendum 2 is: All construction workers who worked in any thorium area at the Savannah River Site from January 1, 1953 through December 31, 1972.

Addendum 2 addresses thorium operations through 1972 at SRS. The NIOSH research associated with this effort has identified a deficiency resulting in the recommendation of a specific thorium class, and the identification of sufficient information and reconstruction methods to support bounding the thorium dose for all other workers outside of that proposed class. Although there was still thorium on site after 1972, NIOSH has determined a sufficient end point for this thorium evaluation based on D&D of 300 Area thorium operations. NIOSH intends to continue reviewing and assessing any additional thorium documentation and data obtained for the post-1972 period. The findings of this research will be relayed accordingly if the research results require modification of any existing conclusions made in the SRS SEC Evaluation Report/Addendums.

NIOSH-Proposed Class to be added to the SEC

Based on its full research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1953 through December 31, 1957, and whose records have dosimetry codes A, G, CMX, or TNX; and all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1958 through September 30, 1972, and whose records have dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.

The class under evaluation was modified (see Section 3.3 below). The class time period was narrowed to 1953 through 1972 because NIOSH has identified a starting point for thorium being on site and also determined a sufficient end point for this thorium evaluation based on the D&D of 300 Area thorium operations. The class locations were restricted to the 700 Area and the CMX/TNX facility because unencapsulated thorium was used at those locations and NIOSH lacks sufficient documentation to bound potential doses received from thorium exposure at those locations. Class location restrictions also include Central Shops because workers assigned to Central Shops could have entered the other specified thorium areas to perform maintenance, remodeling, and renovation.

Potential radiation doses can be bounded for those employees who worked on the SRS site during the proposed SEC time period (i.e., January 1, 1953 through September 30, 1972) but who did not work in the specified thorium-related locations. Furthermore, the remainder of the class evaluated in the original SEC-00103 SRS Evaluation Report is not part of the SEC class proposed by Addendum 2. Potential radiation doses received during the period preceding the proposed SEC class (January 1, 1950 through December 31, 1952) and during the period after the proposed SEC class (October 1, 1972 through December 31, 2007) can be bounded, as discussed in detail in the SEC-00103 SRS Evaluation Report (NIOSH, 2008).

Feasibility of Dose Reconstruction

NIOSH finds it is not feasible to estimate internal exposures with sufficient accuracy for all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1953 through December 31, 1957, and whose records have dosimetry codes A, G, CMX, or TNX; and all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1958 through September 30, 1972, and whose records have dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z. The finding is based on the lack of internal thorium monitoring data or other data or methods to support bounding internal thorium doses for SRS workers who may have worked with thorium in the designated site areas. With the exception of this class, per EEOICPA and 42 C.F.R. § 83.13(c) (1), NIOSH has established that it has access to sufficient information to: (1) estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class; or (2) estimate radiation doses more precisely than an estimate of maximum dose. Information available from the site profile and additional resources is sufficient to document or estimate the maximum internal and external potential exposure to members of the evaluated class under plausible circumstances during the specified period. The specified period includes: January 1, 1950 through December 31, 1952 (the period preceding the proposed SEC class); January 1, 1953 through September 30, 1972 (for those employees who worked on the SRS site during the proposed SEC class but who did not work in the specified thorium-related locations); and October 1, 1972 through December 31, 2007 (the period after the proposed SEC class). The entire period originally under evaluation is discussed in detail in the SEC-00103 SRS Evaluation Report (NIOSH, 2008).

The NIOSH dose reconstruction feasibility findings are based on the following:

- Principal sources of internal radiation for members of the proposed class included exposures to various radionuclides, including thorium in specified SRS locations. Internal exposure pathways for workers could have included inhalation and ingestion of the unencapsulated radionuclides during fabrication, research and development activities of reactor fuel components, and associated chemical separation operations.

- Based on NIOSH's assessment of SRS thorium exposures, there is a lack of sufficient thorium personnel and area monitoring data from the onset of thorium operations in 1953 through the end of thorium research activities in 1972 (which have been related to the D&D of 300 Area thorium operations). The monitoring data deficiency extends only to the work with unencapsulated thorium in the 700 Area and CMX/TNX Area on site, and is associated with all externally monitored personnel working from January 1, 1953 through December 31, 1957 with dosimetry codes A, G, CMX, or TNX; and all externally monitored personnel working from January 1, 1958 through September 30, 1972 with dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z. NIOSH has identified that it cannot bound, or reconstruct with sufficient accuracy, the internal thorium dose for these identified workers at SRS.

- NIOSH finds it is feasible to reconstruct doses received from potential exposures to thorium (metal) and its progeny for workers assigned to the 300 Area, SRS reactors, and F and H Canyons.

- Principal sources of external radiation for members of the proposed class included exposures to various radionuclides at the SRS site. This could have included beta-gamma and neutron exposures during fabrication, research and development activities of reactor fuel components, and associated chemical separation operations.

- NIOSH has determined that it has access to sufficient external monitoring data, and associated medical monitoring data, for all personnel during all time periods at SRS. NIOSH has identified that it can bound, or reconstruct with sufficient accuracy, the external and occupational medical dose for all SRS workers.

- Pursuant to 42 C.F.R. § 83.13(c)(1), NIOSH determined that there is insufficient information to either: (1) estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred under plausible circumstances by any member of the class; or (2) estimate the radiation doses of members of the class more precisely than a maximum dose estimate.

- Although NIOSH found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any internal and external monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1953 through December 31, 1957, and whose records have dosimetry codes A, G, CMX, or TNX; and all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1958 through September 30, 1972, and whose records have dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

Health Endangerment Determination

Per EEOICPA and 42 C.F.R. § 83.13(c)(3), a health endangerment determination is required because NIOSH has determined that it does not have sufficient information to estimate dose for the members of the proposed class working from January 1, 1953 through December 31, 1957 with dosimetry codes A, G, CMX, or TNX; and from January 1, 1958 through September 30, 1972 with dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z.

NIOSH did not identify any evidence supplied by the petitioners or from other resources that would establish that the proposed class was exposed to radiation during a discrete incident likely to have involved exceptionally high-level exposures. However, evidence indicates that some workers in the proposed class may have accumulated substantial chronic exposures through episodic intakes of thorium materials. Consequently, NIOSH has determined that health was endangered for those workers covered by this evaluation who were employed for at least 250 aggregated work days either solely under their employment or in combination with work days within the parameters established for other SEC classes.

For the periods: January 1, 1950 through December 31, 1952 (the period preceding the proposed SEC class); January 1, 1953 through September 30, 1972 (for those employees who worked on the SRS site during the proposed SEC class but who did not work in the specified thorium-related locations); and October 1, 1972 through December 31, 2007 (the period after the proposed SEC class), a health endangerment determination is not required because NIOSH has determined that it has sufficient information to estimate dose for the members of the evaluated class.

## 3.2 Class Evaluated by NIOSH (in Addendum 2)

The feasibility of reconstructing doses received from thorium exposure from the start-up of thorium operations in 1953 through 1959 was reserved for further consideration in the original SEC-00103 Evaluation Report. During this subsequent evaluation, NIOSH has determined that thorium operations were conducted at SRS through 1972, and conducted in locations beyond those considered in the evaluation report (NIOSH, 2008) and the first addendum (NIOSH, 2010); therefore, in Addendum 2, NIOSH addresses the feasibility of bounding doses from thorium exposures received during the expanded time period from January 1, 1953 through December 31, 1972. Thus, the class under evaluation in Addendum 2 is: All construction workers who worked in any thorium area at the Savannah River Site from January 1, 1953 through December 31, 1972.

## 3.3 NIOSH-Proposed Class to be added to the SEC

Based on its research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class to be added to the SEC includes all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1953 through December 31, 1957, and whose records have dosimetry codes A, G, CMX, or TNX; and all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1958 through September 30, 1972, and whose records have dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort. During this period, employees at this facility were involved with fabrication and testing of reactor fuel components containing thorium and chemical separation of thorium waste in process canyons.

# 4.0 Data Sources Reviewed by NIOSH to Evaluate the Class

*ATTRIBUTION: Section 4.0 and its related subsections were completed by Mike Mahathy, Oak Ridge Associated Universities. These conclusions were peer-reviewed by the individuals listed on the cover page. The rationales for all conclusions in this document are explained in the associated text.*

NIOSH has obtained additional process data and thorium inventory data for SRS since the initial evaluation report was published in November 2008 and the first addendum was published in May 2010. Some of these data have been considered in the performance of this Addendum 2 evaluation and will be cited. NIOSH has also conducted additional interviews of former workers to obtain specific information on the use and monitoring of thorium.

## 4.3 Facility Employees and Experts

NIOSH interviewed former SRS employees in order to learn about thorium work, thorium work locations, health physics practices, internal and external dosimetry programs, and radiological incidents pertinent to thorium use from 1953 through 1972.

- Personal Communication, 2011a, *Personal Communication with Former Health Physics Technician*; Telephone Interview by ORAU Team, March 17, 2011, SRDB Ref ID: 93641; Follow-up interview, June 15, 2011, SRDB Ref ID: 98144

- Personal Communication, 2011b, *Personal Communication with Former Health Physics Technician*; Telephone Interview by ORAU Team, March 17, 2011, SRDB Ref ID: 93642; Follow-up interview, June 15, 2011, SRDB Ref ID: 98145

- Personal Communication, 2011c, *Personal Communication with Former Supervisor of Reactor Support Group*; Telephone Interview by ORAU Team; April 14, 2011; SRDB Ref ID: 94988

- Personal Communication, 2011d, *Personal Communication with Former Process Coordinator*; Telephone Interview by ORAU Team; March 31, 2011; SRDB Ref ID: 95253

- Personal Communication, 2011e, *Personal Communication with Former Lab Worker and QA Employee*; Telephone Interview by ORAU Team; March 31, 2011; SRDB Ref ID: 95254

- Personal Communication, 2011f, *Personal Communication with Former Manager of Plant Facilities and Services*; Telephone Interview by ORAU Team; May 5, 2011, 2:00 PM; SRDB Ref ID: 96050

- Personal Communication, 2011g, *Personal Communication with Former SRS Employee*; Telephone Interview by ORAU Team; May 16, 2011, 11:00 AM; SRDB Ref ID: 96343

- Personal Communication, 2011h, *Personal Communication with Former SRS Employee*; Telephone Interview by ORAU Team; June 15, 2011; SRDB Ref ID: 98144

- Personal Communication, 2011i, *Personal Communication with Former Health Physics Technician*; Telephone Interview by ORAU Team, June 15, 2011, SRDB Ref ID: 98145

## 4.5 NIOSH Site Research Database

NIOSH has performed additional data captures at SRS since the first addendum was published in May 2010. As of June 20, 2011, there were 5,225 documents in the Site Research Database (SRDB) pertaining to SRS; thus, approximately 1,548 additional documents have been captured, reviewed, and uploaded into the SRDB since May 2010.

SRDB documents evaluated for relevance to the thorium issue include: historical background on thorium operations; radiological monitoring data (surface and air concentrations, personnel external and internal exposures); information on the radiological controls program; monthly reports; and incident documentation.

The volumes of the *History of the Savannah River Laboratory* summarize the major activities and accomplishments at the Savannah River Laboratory. As appropriate, their thorium summary information is excerpted in the following sections and then matched with the plants and/or facilities that supported them in order to identify the SRS locations where thorium materials were handled and processed. Details regarding the processes and programmatic progress on the production side of the site can be gleaned from the periodic progress reports from various departments at the SRS (i.e., “Monthly Progress Reports of the Works Technical Department”).

Another source of thorium information is the Thorium Accountability Ledger, which recorded the thorium inventories within the involved SRS facilities from 1952 through 1972 (Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962). The thorium inventory information is included in this addendum in order to associate the quantities of thorium materials to the R&D and production activities. The Addendum 2 effort also considered the potential exposure hazard levels posed by thorium materials in Building 773-A, which were assessed qualitatively in *Charts of Isotope Hazards* (Isotope Charts, 1953-1976). The hazard potential information provides perspective on the type of materials that were handled and processed and the nature of the process activities at the time.

NIOSH captured several radiological control notebooks during a data capture performed in June 2011 (Lab Notes, 1954; Lab Notes, 1955; Lab Notes, 1955-1956; Lab Notes, 1956-1957a; Lab Notes, 1956-1957b; Lab Notes, 1956-1962; Lab Notes, 1960).

# 5.0 Radiological Operations Relevant to the Class Evaluated by NIOSH

The following subsections summarize SRS radiological operations involving thorium from January 1, 1953 through December 31, 1972 as well as the information available to NIOSH for characterizing particular processes and radioactive source materials. From available resources, NIOSH has gathered process and source descriptions, information regarding the identity and quantities of each radionuclide of concern, and information describing both the processes through which radiation exposures to construction workers may have occurred and the physical environment in which they may have occurred. The information NIOSH has included within its initial evaluation report and the report's addendum is intended only to be a summary of the available information.

Thorium was fabricated into reactor fuel and targets that were irradiated in the production reactors to produce U-233 (Personal Communication, 2011d; Personal Communication, 2011f). The U-233 that was created in the irradiated thorium fuel was chemically separated and extracted. Although the primary goal of the thorium programs was to produce U-233, the chemical process developmental work included thorium recovery for reuse.

The Savannah River Laboratory (SRL), located in the 700 Area, provided necessary research and development (R&D) work for the production of U-233 via thorium irradiation (Personal Communication, 2011c). The SRL conducted R&D in reactor physics, fuel technology and fabrication, and separation process development and improvement. The SRL was also committed to solving plant start-up problems, improving production efficiency, developing new production processes, and providing analytical control of supplied chemicals, manufacturing processes, and finished products. Building 773-A served as the main laboratory of SRL and housed much of the process development and experimental research areas. Nearby were the Equipment Engineering Laboratory (Building 723-A) and the Waste Disposal Facility (Building 776-A), which handled the waste created by the laboratory. The Pile Physics Laboratory (Building 777-M) contained experimental reactors used for various lattice and reactivity experiments.

Two other facilities performed SRL work though they were not located in the 700 Area: CMX and TNX, located in Buildings 679-G (also known as 679-T) and 678-G (also known as 678-T), respectively. CMX was designed to conduct long-term flow testing of new fuel and target elements (Personal Communication, 2011f; Swanson, 2006). TNX was used for determination of operational parameters for separations equipment and procedures. Models of SRS reactors to one-sixth scale were located in CMX for testing uncharged fuel assemblies (Personal Communication, 2011f). Maintenance and craft workers were assigned through Central Shops and may have worked in each of these areas, as needed.

A February 6, 1952 memorandum described the thorium requirements for research and development work to be conducted at the Savannah River Plant (SRP) for calendar year 1952-1953 (Montenyohl, 1952):

- Eleven tons of 0.75" slugs for Critical Experiments for two reactor loading configurations. This thorium was requested to be available by June 1953.

- Fourteen tons as ingots for Metallurgical Research which included: (1) evaluation of rolling vs. extrusion; (2) casting research to provide better ingot quality; (3) determination of impurity limits; and (4) alternate methods of fabrication. These ingots were to be supplied at the rate of one ton per month for 14 months.

  (1) Evaluation of Rolling vs. Extrusion
    - Rolling Investigation
      - Effect on quality of varying the rolling temperature
      - The desirability of salt bath heating vs. air heating
      - Selection of the optimum reduction per pass
    - Extrusion Investigation
      - Effect of varying the extrusion temperature
      - Clad extrusions vs. bare extrusion
      - Die materials and contours
      - Reduction ratio
      - The possibility of extruding sponge, without melting and casting to ingot

  (2) Casting Research to Provide Better Ingot Quality
    - Top pouring vs. bottom pouring
    - The effect of casting temperature
    - Mold geometry
    - Mold temperature
    - Materials of construction

  (3) Determination of Impurity Limits
    - As a function of ingot quality (i.e., those which would warrant rejection of the ingot)
    - As a limitation to fabrication. Several of the impurities damage the mechanical properties, causing "hot shortness," brittleness, excessive hardness, or splitting on rolling
    - As a limitation for irradiation
    - As a limitation of separation processes

  (4) Alternate Methods of Fabrication
    - Recasting the zinc-thorium biscuits obtained from the reduction operation to a more usable shape, then de-zincing and extruding
    - Arc melting of thorium

The fuel fabrication for the critical experiment would have been done in the Slug Fabrication and Process Building (Building 313-M); the irradiation would have been conducted with one of the production reactors; and the metallurgical research would have been performed in the metallurgy and the metallurgical laboratories of the Main Laboratory (Building 773-A). A note of interest was that the memorandum expected delivery of the requested thorium by June 1953.

In the 1960s, work with thorium was focused on production of U-233 reactor fuel (Personal Communication, 2011d). This work involved several campaigns. Tasks were performed in Building 773A, Building 723-A, M Area, CMX/TNX, multiple SRS reactors, with dissolution in the F and H Areas.

## 5.1 Savannah River Site Plant and Process Descriptions

*ATTRIBUTION: Section 5.1 and its related subsections were completed by Mike Mahathy, Oak Ridge Associated Universities; and Robert Morris, Mel Chew and Associates, Inc. These conclusions were peer-reviewed by the individuals listed on the cover page. The rationales for all conclusions in this document are explained in the associated text.*

### 5.1.1 K, L, P, C and R Reactors and Associated Facilities

Thorium Operations

In November 1954, 130 low-enriched uranium slugs and 156 thorium slugs were initially weighed and measured in the Assembly Area of Building 105-R for test work during L-2 charge. These slugs would be returned to the hot laboratory of R or P Areas for final examination when L reactor exposure was completed (Progress Report, Nov 1954). These irradiations were completed by December 1954 (Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962). Prior to irradiation in the production reactors, the finished slugs and/or fuel elements were sent to the Graphite Test Pile in the Slug and Rod Testing Building (305-M) for suitability tests. The 305-M Graphite Test Pile was a graphite-moderated zero-power reactor provided primarily for the final assay of reactivity of all fuel and target slugs.

Canned thorium slugs were received from Sylvania Electric Products (SEP) for R-6 and R-7 full-core reactor loadings. In 1955, the slugs were irradiated through August; inventories of R-6 and R-7 slugs remained at the R and L reactors. In February 1955, two quatrefoils containing striped LMF and thorium metal and one quatrefoil containing one channel of all thorium slugs and three channels of aluminum spacers were assembled in the Fuel or Rod Assembly and Disassembly (Building 105-L Hot Shop) and put in L-3 for an irradiation test in the L Reactor. The quatrefoils containing striped LMF and thorium metal were discharged, their fuel column heights measured, and the slugs unloaded for visual inspection in the Building 105-L Hot Shop. Inspection of the slugs indicated erosion or corrosion marks approximately 0.010-inch deep on the side of the thorium slug cans around the cap weld bead (Progress Report, Feb 1955). In September 1955, SRS developed a plan to dispose of the unused inventory by stripping the cans and returning the metal to the Feed Materials Production Center (FMPC) (Progress Report, Sep 1955). However, thorium ledgers show that a constant level of thorium remained at the L reactor through December 1956 and at the R reactor through June 1957 (Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962).

In December 1958, ORNL proposed that pellets of mixed 4% enriched $UO_2$ and $ThO_2$ be irradiated at SRS. Each pellet was to be 0.26 inches diameter and 3.5 inches long and was to be clad in stainless steel, aluminum, or Zircaloy (Progress Report, Dec 1958). It is not known if this occurred; however, in June 1959 a procedure was developed and tested for making a final arc weld on aluminum-canned hot-press bonded slugs containing powdered and compacted thorium oxide. Ten slugs were welded and inspected (Progress Report, Jun 1959).

In 1960, the AEC requested that SRS produce about 130 kilograms of U-233 via irradiation of thorium targets. Sylvania-Corning Nuclear Corporation (Sylcor) prepared a small lot of hollow aluminum-clad thorium slugs by a hot-press bonding process at their facility. Sylcor shipped the slugs to SRS where there were irradiated. However, when these slugs were dissolved and the uranium was recovered and analyzed, SRS determined that the amount of by-product U-232 exceeded the specified maximum. The excessive formation of U-232 was attributed to the fast neutron flux that resulted from the proximity of the target slugs to the fuel. Accordingly, quatrefoil assemblies containing only target slugs were proposed for future irradiations. SRS calculated that this arrangement, which provided a separation of several inches from the fuel, would permit sufficient thermalization of the neutron flux to reduce the formation of U-232 to an acceptable level.

In October 1961, SRS authorized Sylcor to extrude and can 600 hollow thorium metal slugs for use in the Mark IV fuel (Progress Report, Oct 1961). A plan was also prepared for Sylcor to produce 560 slugs for use as non-irradiation quality specimens. The Sylcor cladding process was to be qualified by destructive examination of slugs at SRS. All of the Sylcor pieces were expected for delivery by November 1961 (Progress Report, Oct 1961). Evaluations of thorium slugs that could be used in producing U-233 continued through 1963 with some irradiations in L reactor. Through this program, eighteen kg of U-233 with 3-5 ppm of U-232 was produced from 20 tons of thorium metal.

In 1964, the Sylcor core was redesigned to use thorium oxide ($ThO_2$) rather than thorium metal as the target material with the final core being a mixed lattice of four uranium fuel assemblies and two thorium oxide target assemblies per hex in the controlled zone of the reactor (Du Pont, 1984a). These redesigned assemblies were first stored in 1964 at the C, L, and P reactors; irradiation commenced in 1965. Using the redesigned core, SRS produced one hundred kg U-233 containing less than 5-6 ppm U-232 from 56 tons of thorium dioxide (Du Pont, 1984b).

In addition to the development of uranium fuel elements, some tests of thorium metal were done in 1964 to evaluate the performance of this material for a thorium/U-233 converter cycle. Two thorium-uranium alloy tubes were fabricated and tested in the Heavy Water Components Test reactor (HWCTR) to evaluate the performance of thorium tubes under conditions that would be encountered in $D_2O$-moderated reactor operating on an equilibrium thorium/U-233 fuel cycle. The tubes reached an exposure of about 3,500 MWD/T at peak temperatures of about 485°C (Du Pont, 1984c).

To study the behavior of various alloys in natural uranium, segmented metal tubes (SMT) were fabricated. Several assemblies were irradiated during 1964; however, inspection showed significant vibration damage (Du Pont, 1984c).

Enriched metal tubes (EMT) were fabricated and irradiated to study the characteristics of slightly enriched uranium metal. Fuel from original assemblies, which was housed in stainless steel, was discharged from HWCTR after initial irradiation, placed in Zircaloy housings, and recharged into the reactor (Du Pont, 1984c). A similar assembly was designed and fabricated to study the characteristics of thorium metal. After satisfactory flow testing, two assemblies were charged into HWCTR and performed satisfactorily through the final reactor shutdown (Du Pont, 1984c).

Seventeen different assemblies of test fuel were irradiated in the HWCTR during 1964. Of these, ten were tubes of uranium oxide, four were tubes of uranium metal, two were tubes of thorium, and one was a CANDU prototype consisting of nineteen rods of uranium oxide (Du Pont, 1984c).

In 1965, SRS started development work on mixed lattices consisting of various target assemblies alternating with high-specific-power, three-tube-driver fuel assemblies. These lattices offered the capability of co-producing from the Savannah River reactors almost any variety of products which could have been desired. The first of the mixed lattices to go into the plant was the Mark XIIA-Mark 50A, which was intended to produce U-233 along with lesser amounts of other radioisotope products (Du Pont, 1984a). Lattice testing continued through June 1966 with irradiations performed in the L reactor (Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962).

Another campaign to produce a minimum of 150 kg U-233 began in K-reactor in June 1967. Operation of the four authorized charges (12 target subcycles) continued into 1968 (Du Pont, 1984a). The mixed-lattice charge consisted of 261 Mark XIIA fuel assemblies (three-tube drivers), 255 $ThO_2$ targets, and 84 depleted uranium blanket assemblies. Three thoria target stages (two heavy and one light) were irradiated during each driver cycle. Eight of the twelve authorized target subcycles were completed during 1967; about 125 kg U-233 with a U-232 concentration of about 7.5 ppm were produced (Du Pont, 1984a). Thorium oxide was irradiated in C and K reactors between 1966 and 1969 as part of the Thorex I and Thorex II campaigns. The Thorex II campaign was completed with the recovery of 80 kg of U-233 from thirty-five tons of irradiated $ThO_2$ (Du Pont, 1984b). A final thorex campaign was conducted during 1969 with the recovery of 181 kg of U-233 (Du Pont, 1984b). Irradiation of thorium oxide was performed in the K reactor. Some thoria materials were stored in the K reactor through at least May 1971 (Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962).

A summary of thorium operations at SRS reactors are shown in Table 5-1. NIOSH has not obtained documentation on specific thorium operations conducted at reactors from January 1958 through December 31, 1959.

**Table 5-1: Thorium Operations at SRS Reactors**

| Time Frame | Building | Operation/Process |
|---|---|---|
| 7/1954-12/1955 | 105-R | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| | 105-K | Thorium storage |
| | 105-L | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| 1/1956-12/1957 | 105-R | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| | 105-K | Thorium storage |
| | 105-L | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| 1/1960-12/1963 | 105-R | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| | 105-L | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| 1/1964-12/1964 | HWCTR | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| 1/1964-12/1966 | 105-L | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| | 105-P | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| | 105-K | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| | 105-C | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| 1/1967-12/1968 | 105-K | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage |
| | 105-C | Thorium storage |
| 1/1969-5/1971 | 105-K | Irradiation; non-destructive examination of irradiated thorium slugs and rods; thorium targets and fuel storage; thorium storage |
| | 105-L | Thorium storage |
| | 105-C | Thorium storage |

The maximum thorium inventories for reactor areas in any month for calendar years 1954 through 1972 are listed in Table 5-2. While some irradiations were performed in 1960 and 1961, NIOSH has not identified documentation to quantify the specific thorium inventories at reactors during those years.

**Table 5-2: Maximum Monthly Thorium Inventories at SRS Reactors**
(inventory values in pounds)

| Year | C | K | L | P | R | HWCTR |
|---|---|---|---|---|---|---|
| 1954 | - | - | 500-2000 | - | 50-500 | - |
| 1955 | - | - | 2000-10000 | 50-500 | >10000 | - |
| 1956 | - | - | 2000-10000 | - | >10000 | - |
| 1957 | - | - | - | - | >10000 | - |
| 1958 | - | - | - | - | - | - |
| 1959 | - | - | - | - | - | - |
| 1960 | - | - | - | - | - | - |
| 1961 | - | - | 50-500 | - | - | - |
| 1962 | - | - | 500-200 | - | - | - |
| 1963 | - | - | 500-2000 | - | - | - |
| 1964 | 500-2000 | >10000 | 2000-10000 | >10000 | - | 50-500 |
| 1965 | >10000 | >10000 | >10000 | 2000-10000 | - | - |
| 1966 | 50-500 | 2000-10000 | 2000-10000 | - | - | - |
| 1967 | >10000 | >10000 | - | 500-2000 | - | - |
| 1968 | >10000 | >10000 | - | 500-2000 | - | - |
| 1969 | 500-2000 | 500-2000 | >10000 | - | - | - |
| 1970 | - | 500-2000 | - | - | - | - |
| 1971 | - | 500-2000 | - | - | - | - |
| 1972 | - | 500-2000 | - | - | - | - |

Source: Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962
Note: A table cell with a hyphen (-) indicates No Data Available

### 5.1.6 300 M-Area Fabrication Facilities

Thorium operations conducted at the 300-M Area are presented in the first addendum to the SEC-00103 Evaluation Report issued May 4, 2010 (NIOSH, 2010). As a result of the research conducted since the first addendum, NIOSH has obtained information on additional thorium work performed but not previously discussed. Loadings containing varying mixtures of thorium metal and thorium oxide were irradiated at Subcritical Experiment (SE), Standard Pile (SP) and the Process Development Pile (PDP) (Building 777-M). Testing of thorium oxide intermixed with enriched uranium fuel clusters were tested at 777-M for their power evaluation in the HWCTR. Configurations of fuel rod clusters were tested at SE, SP and PDP (Du Pont, 1984a).

In 1964, SRS installed vibratory-compaction equipment in 313-M to facilitate the production of thorium oxide (thoria) slugs. Subsequently, the use of off-site vendors was discontinued. SRS canned slugs for L-1 and L-2 charge in 313-M. Additional fabrication work to develop, test, and fabricate thorium oxide slugs for thoria targets was performed in the 313-M and 320-M Area from 1964 through 1970 (Du Pont, 1984a). Excess fuel tubes were chopped in Building 321-M to reclaim and consolidate material for use in new tubes. Thorium oxide materials were temporarily stored in 322-M awaiting shipment to 321-M during some of this period.

The quantities of thorium metal slugs handled in the 300-M Area from 1953 through 1964 are provided in the first Addendum to the SEC-00103 Evaluation Report, Table 5-1 (NIOSH, 2010) and in Table 5-3 of this addendum. NIOSH has since obtained additional information and additional source term quantity data from the thorium ledgers. The maximum thorium inventories for 300-M Area in any month for calendar years 1953 through 1972 are listed in Table 5-3.

**Table 5-3: Maximum Monthly Thorium Inventories for 300-M Area**
**(inventory values in pounds)**

| Year | 313-M | 320-M | 321-M/322-M | 305-M | 777-M | Reported Inventory for M Area (# metal slugs) (NIOSH, 2010) |
|---|---|---|---|---|---|---|
| 1953 | - | - | - | - | - | 321 |
| 1954 | 500-2000 | 2000-10000 | - | 10-50 | 2000-10000 | 1,726 |
| 1955 | 2000-10000 | 500-2000 | - | 2000-10000 | >10000 | 26,618 |
| 1956 | 2000-10000 | 0.1-10 | - | 10-50 | >10000 | 0 |
| 1957 | 2000-10000 | 0.1-10 | - | 10-50 | >10000 | 5,200 |
| 1958 | - | - | - | - | - | 0 |
| 1959 | - | - | - | - | - | 0 |
| 1960 | - | - | - | - | - | 0 |
| 1961 | 10-50 | - | 50-500 | 2000-10000 | 2000-10000 | 417 |
| 1962 | 2000-10000 | 10-50 | 50-500 | 50-500 | 50-500 | 14,000 |
| 1963 | >10000 | - | 50-500 | 10-50 | - | 16,500 |
| 1964 | >10000 | - | 50-500 | 10-50 | >10000 | 9,600 |
| 1965 | >10000 | 500-2000 | 500-2000 | 500-2000 | 2000-10000 | - |
| 1966 | - | 50-500 | 50-500 | 500-2000 | >10000 | - |
| 1967 | - | 500-2000 | 50-500 | - | >10000 | - |
| 1968 | - | 500-2000 | 10-50 | 50-500 | >10000 | - |
| 1969 | - | - | 0.1-10 | 50-500 | 2000-10000 | - |
| 1970 | - | - | 10-50 | 50-500 | 2000-10000 | - |
| 1971 | - | - | 0.1-10 | 50-500 | 2000-10000 | - |
| 1972 | - | - | 2000-10000 | 50-500 | 2000-10000 | - |

Source: Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962; NIOSH, 2010
Note: A table cell with a hyphen (-) indicates No Data Available

### 5.1.7 Receiving Basin for Offsite Fuel (RBOF)

The Receiving Basin for Offsite Fuel (RBOF), located in the H Area near the center of the SRS, was a storage pool for research reactor fuels. It became fully operational in 1964. In that same year, thorium ledgers show that 182 pounds of thorium material received from 244-H and HWCTR were stored at the RBOF. At least 170 pounds of thorium remained there until 1968 (Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962).

### 5.1.8 F Canyon

In 1966, SRS considered the possibility of future U-233 campaigns in which large quantities of thoria would be dissolved and processed, requiring high processing rates to reduce the product unit cost. The large mixer-settlers in the 200-F Area had demonstrated a potential capacity of six tons of thoria per day, which was considered adequate for solvent extraction; however, the dissolving capacity was limited to about 0.8 ton per day in the annular dissolver (Du Pont, 1984b). However, NIOSH has not found documentation to show that thorium was processed in the F Canyon.

### 5.1.11 H Canyon

Thorium Operations

Starting in August 1965, U-233 was separated and recovered from irradiated thorium by the Thorex process in H canyon. This process consists of six steps: (1) dissolution; (2) acid reduction in the dissolver solution, if necessary; (3) co-precipitation (head end) of protactinium with manganese dioxide; (4) separation and recovery of thorium and uranium from fission products, protactinium, and aluminum by continuous solvent extraction with tributylphosphate; (5) concentration of purified thorium nitrate by evaporation; and (6) conversion of recovered U-233 to uranium trioxide. Once separated, the U-233 was concentrated and further treated by conversion to oxides suitable for shipment or storage in the H-B Line. This Thorex program was conducted through June 1967 as part of the Thorex I campaign, and from and 1968 through 1970 as part of the Thorex II campaign (Du Pont, 1984b).

Fifteen tons of thoria ($ThO_2$) had been ordered during 1966 to verify the faster dissolution rate of the magnesium oxide (MgO-thoria observed in earlier plant tests at TNX. This MgO-thoria did not have the large particles found in the 600-lb pilot lots of thoria that had been produced previously. Even though the packing density was low, the MgO-thoria was irradiated with dissolution testing conducted in the H canyon (Du Pont, 1984b).

Residual activities and shipment of thorium from the H area to Fernald began in 1971 and was completed in May 1972.

The maximum thorium inventories for the H Area in any month for calendar years 1965 through 1972 are listed in Table 5-4.

**Table 5-4: Maximum Monthly Thorium Inventories at H Area**

| Year | Pounds |
|---|---|
| 1965 | >10000 |
| 1966 | >10000 |
| 1967 | >10000 |
| 1968 | >10000 |
| 1969 | >10000 |
| 1970 | >10000 |
| 1971 | >10000 |
| 1972 | >10000 |

Source: Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962

### 5.1.12 Old HB Line

Thorium operations conducted in the HB line are discussed in Section 5.1.11 above.

### 5.1.15 Building 235-F Plutonium Fuel Fabrication Facility (PUFF)

Thorium Operations

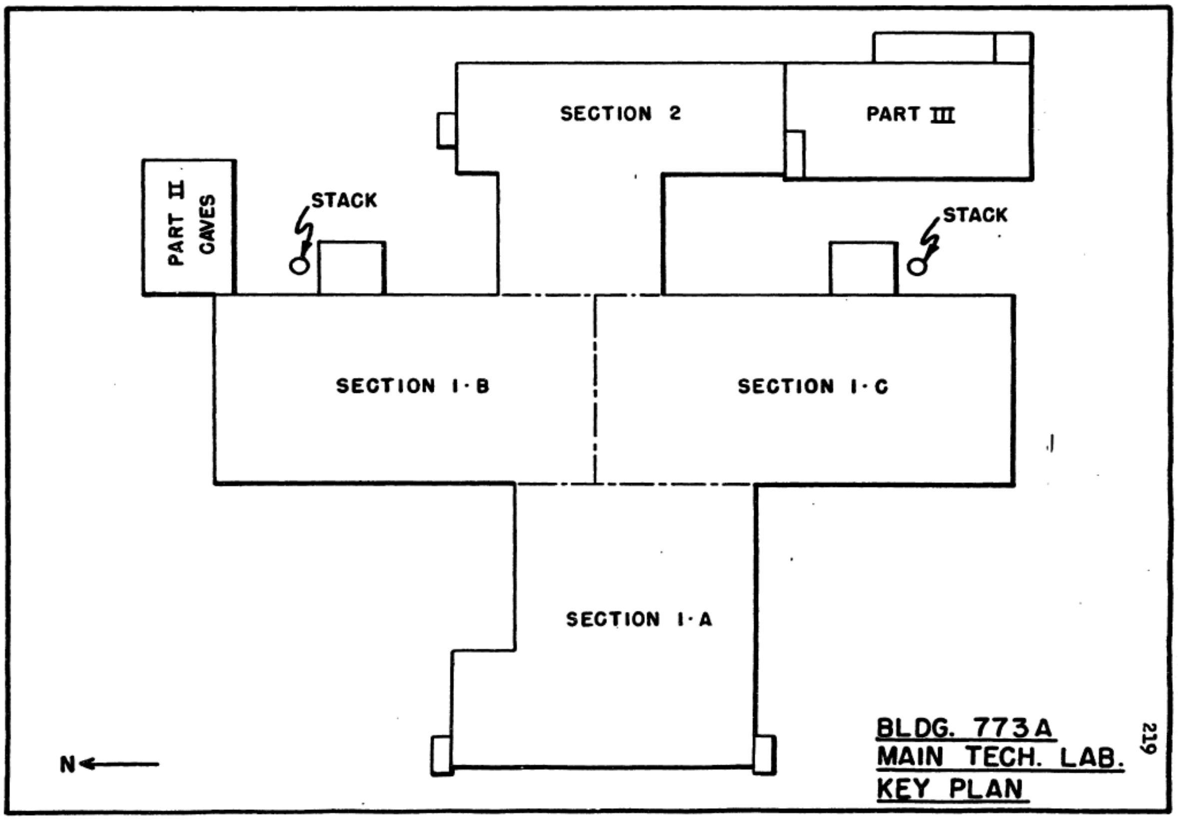
From at least 1961 through 1965, the SRS Works Technical Division operated a portion of Building 235-F for work with thorium oxide. The largest quantity of thorium oxide present in 235-F in any of these months was 500 pounds (Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962).

### 5.1.16 Savannah River Laboratory (SRL)

Thorium Operations

Thorium work at SRL was assessed using SRS thorium ledger data, interviews with former SRS staff, and documents available in the SRDB.

In mid-1953, the Laboratory had started to accumulate a thorium inventory on the order of tons; the inventory steadily increased over the next year and a half to about five tons. It is reasonable to assume that the tons of thorium at the Laboratory were used for the metallurgical research requested by the 1952 memorandum (Montenyohl, 1952) in support of the fuel and target development work. The layout of Building 773-A is shown in Figure 5-1.




Source: Du Pont, 1957

**Figure 5-1: Building 773-A, SRS Main Technical Laboratory Building**

Section 1-A: The front wing of Building 773-A, which contains the administrative and technical services, the change area, and "cold" laboratories.

Sections 1-B and 1-C: The main central portion with laboratory modules were located back-to-back but separated by a utility corridor and flanked on the outside walls by auxiliary modules and personnel corridors. Both of these sections were equipped to handle radioactive materials.

Section 2: Physical property and corrosion testing, metallographic and x-ray diffraction studies, and general physical and chemical studies were conducted in support of the reactor fuel development program.

Part II (Caves): Contained facilities for physical, chemical, and metallurgical work with high-level radioactive materials. By October 1954, a variety of cave apparatus was available, including: dimensioning equipment, contour tracing gauge, weighing scales, analytical balances, binocular periscope, a stage cut-off machine for sectioning irradiated metal, chemical apparatus for dissolving fuel elements, and hardness testers.

Part III, Main Technical Laboratory Metallurgical Extension: Increased space for the Metallurgical Section of the Technical Division. It housed equipment required for the development of new fuel elements. It was divided into the element fabrication area, electroplating and cleaning area, tube-cleaning area, vertical assembly area, nondestructive testing area, machine shop, and storage area. Mock-ups of fuel assemblies were made in this area.

The CMX/TNX facilities (also referred to as Semiworks) were not located in the 700 Area nor were they always part of SRL. Both were located in the T Area (also referred to as CMX/TNX area and the 600 Area). However, discussion of thorium operations at CMX/TNX has been included in this subsection because SRL technical staff were involved in research and development activities conducted there. CMX was constructed in 1951 with the initial mission of performing loop-testing of water as part of researching of SRS reactor cooling. CMX's original scope called for no use of radioactive materials. CMX was also used as the first office of SRS Health Physics. TNX was placed in operation in 1951 with the initial mission of refining the PUREX process and other processes of the large-scale separation process used for separating plutonium and uranium in the 200 Area. In the years that followed, operations at both facilities were expanded to address new issues related to reactors and separations technology. A recent aerial view of the Semiworks is shown in Figure 5-2 (Swanson, 2006).


Source: Swanson, 2006

**Figure 5-2: Aerial View of SRS Semiworks (CMX/TNX)**

In 1953, Savannah River was requested to produce limited quantities of U-233 by thorium irradiation. The slug geometry was chosen for initial development of enriched uranium-aluminum alloy fuel and metallic thorium target elements. The R&D efforts were underway to: (1) produce and encapsulate [can] thorium metal slugs for the inclusion in reactor fuel rods and targets and subsequent irradiation in the reactors; (2) start development work to provide basic data on chemical processes for the separation of U-233 from irradiated thorium and for the recovery of thorium for reuse; and (3) evaluate the physics parameters of reactor loadings of enriched uranium-aluminum alloy fuel slugs intermixed with thorium target slugs (Du Pont, 1984a).

The slug geometry was chosen for initial development of enriched uranium-aluminum alloy fuel and metallic thorium target elements for the U-233 program. For the fuel assembly design, the initial emphasis was placed on the development of an assembly comprising a fuel tube that contained a column of solid thorium slugs. Because of increasing interest in U-233, more efficient fuel assembly design was investigated by the SRL. The investigation found that a more efficient fuel assembly design can be achieved by replacing the solid thorium slugs with hollow slugs (Du Pont, 1984a).

SRL participated in research and testing of two processes to can thorium slugs: AlSi bath at different temperatures and hot die-size bonding. Some cans were removed to study interface wetting (Progress Report, Jul 1954; Progress Report, Aug 1954; Progress Report, Oct 1954; Progress Report, Nov 1954; Progress Report, Dec 1954). The AlSi canning was found to produce a hard, brittle layer between the thorium and the AlSi that interfered with the subsequent separations process. Hot die-size bonded slugs did not have the deleterious layer formed by the AISi, and they allowed superior bond strength and resistance to thermal shock. Therefore, the hot die-size bonded process was selected for future production use (Du Pont, 1984a). In December 1954, a total of 1,166 hot die-size bonded thorium slugs, about 6-1/2 inches in length and 1.085 inches in diameter, were received at SRL from Sylvania Electric Products Company. SRL performed other work to refine the thorium canning process. For example, the mechanical properties of irradiated thorium were studied (i.e., stress responses that could counteract the canning process). These stress tests were performed in the machine shop portion of the Metallurgical Lab (in Section II) without hood ventilation (Personal Communication, 2011e). Other such work, such as etching of the can cladding, was performed in Building 773 hot cells (Personal Communication, 2011e).

NIOSH has found limited documentation on the receipt and transfer of individual shipments of thorium at the SRL; however, one document shows that nine wooden boxes of thorium were received from National Lead of Ohio and delivered to Building 773A (Log Sheets, 1955). At about that time, development work was started to provide basic data on chemical processes for the separation of U-233 from irradiated thorium and for the recovery of thorium for reuse. Bench-scale research was performed in Building 773A in glove boxes; however, up to 1 kg of thorium was dissolved during these experiments (Personal Communication, 2011d). Thorium slugs were cut in a cut-off machine in one of the high-level caves and also in junior caves in 773-A in 1955. These cut pieces were then dissolved with small aliquots sent to B-103 for analysis (Slug, 1955). Uranium recovery equipment including an ion exchanger for the concentration of U-235 and a prototype critically-safe dissolver (of the ORNL "trickle type") were installed at TNX (Building 678-G). During late 1955, some of the development work on the recovery of U-235 was moved to ORNL in order to concentrate the SRL effort on U-233 production from irradiated thorium (Du Pont, 1984b). A workable process was developed that was very similar to the PUREX process and which used 30% tributylphosphate solvent for extraction. The process entailed: (1) dissolving the irradiated metal with nitric acid containing a hydrofluoric acid catalyst; (2) head-end scavenging with manganese dioxide to clarify and to begin the decontamination of the dissolver solution; and (3) solvent extracting of thorium and uranium to separate them from fission products and protactinium, and subsequently, from each other. Problems of particular concern were the corrosion of the dissolver and the adequate separation of thorium from the fission products and protactinium (Du Pont, 1984b).

Work performed in both Building 773A and TNX resulted in a method that appeared to be feasible for producing thorium metal by electrolytic reduction of thorium oxides in a molten salt bath. The best system studied was thorium oxide in potassium thorium fluoride ($KThF_5$), which was quite similar to the Hall Process for the production of aluminum by the electrolysis of aluminum oxide in cryolite (Du Pont, 1984b). SRL used both metal and oxide forms of thorium in this early time period.

Physics parameters of reactor loadings of enriched uranium-aluminum alloy fuel slugs intermixed with thorium target slugs from experiments done in the Subcritical Experiment (SE) and the Process Development Pile (PDP) (Building 777-M) were determined in the intermediate and high-level caves at Building 773-A (Du Pont, 1984a). Thorium oxide dummy slugs prepared by the University of California Radiation Laboratory were used in test irradiations as surrogates for irradiation of neptunium slugs. SRL removed welds from these thorium oxide slugs and fitted new end caps (Dummy Slugs, 1958). Starting in early 1959, thorium was used as a surrogate for neptunium in recovery and separation process development conducted in the Building 773-A, and later, in pilot plant tests in the TNX. A test involving two consecutive loading and elution operations was performed at TNX in August 1960 as part of a test of equipment used to separate neptunium from the PUREX high-activity waste. The test showed that the anion exchange column also had excellent thorium absorption characteristics (Progress Report, Aug 1960).

Development work on hot die-size bonding continued through 1963, with the objective of reducing the cost of the fuel canning, particularly the cost of hot die-size bonding the inner Mark VB tubes in cans with integral ribs (Du Pont, 1984a). Building 774-A was a hot die size bonding facility equipped with a high-pressure autoclave, centrifugal extractors, and a miniature centrifugal extractor facility (Du Pont, 1984d).

Development work on U-233 production performed in 1962 centered on the Mark VIB-VIIIT lattice. The U-232 contamination considered permissible at that time was on the order of 50 ppm. In 1963, theoretical studies were initiated to examine various methods of producing U-233 with U-232 contents ranging from 10 ppm down to less than 1 ppm. These studies were intended to define the mode of operation, cost, and required modification in the reactor, fuel fabrication, and separation areas (Du Pont, 1984a). A general study was made of the production of high-purity U-233 low in U-232 content. Fabrication and testing was performed in the Metallurgical Laboratory (aka Fabrication Laboratory) and the high-level caves at Building 773-A (Personal Communication, 2011c). Subsequently, a charge was designed and a program formulated to produce 100 kg of U-233 at 5 to 6 ppm U-232. For this study, $ThO_2$, rather than thorium metal, was chosen as target material and the final core design was a mixed lattice of four uranium fuel assemblies and two thorium oxide target assemblies per hex in the controlled zone of the reactor (Du Pont, 1984a). Material and fabrication development were required for the thorium targets. $ThO_2$ used in the development programs was produced by Mallinckrodt Chemical Works in a cooperative program aimed at developing specifications that could be used to obtain $ThO_2$ from a commercial supplier (Du Pont, 1984a).

In 1964, Procedures were developed by the Laboratory for processing irradiated thorium and thorium dioxide to separate U-233 and recover thorium for recycle. These procedures would be applied to two irradiation programs in progress: (1) 18 kg of U-233 with 3-5 ppm of U-232 was to be produced from 20 tons of thorium metal; (2) 100 kg U-233 containing less than 65 ppm U-232 was to be produced from 56 tons of thorium dioxide (Du Pont, 1984b).

SRL conducted laboratory studies of the dissolution of "sol gel" thorium oxide, a dissolvent consisting of nitric acid and hydrogen fluoride. Optimum dissolving rates were produced in 1964. However, these rates were sufficient for plant scale use only if moderate agitation was applied (e.g., vigorous boiling obtained by strongly heating the bottom of the vessel). This dissolvent solution attacked aluminum fast enough to de-clad the thoria in 10 to 15 hours, which made a separate de-cladding step unnecessary (Du Pont, 1984b). Laboratory tests were made of a number of materials for the “head end” co-precipitation and removal of Pa-233 from the acid-adjusted Thorex dissolver solution. This step was necessary to decontaminate thorium and U-233 from protactinium, and was desirable for the production of U-233 free from U-232. Carrying agents tested included gelatin, niobium pentoxide, zirconium phosphate, thorium phosphate, thorium iodate, and manganese dioxide. Of these, manganese dioxide ($MnO_2$) produced the best results. While the resulting cake was sensitive to radiation, tests with actual dissolver solutions showed that the cake could be centrifuged and separated under process conditions without appreciable loss of protactinium (Du Pont, 1984b). Tests with aluminum-canned thorium dioxide in the 6-foot-diameter dissolver at TNX demonstrated that the processing capacity of the H Area for the U-233 separations campaign could be increased from 1,000 to 3,000 lb of thorium per day by installing horizontal heating coils at the bottom of the dissolver. Installation of the horizontal coils in an “extra machinery” dissolver was recommended (Du Pont, 1984b).

In 1964, all the equipment for one of the cells in the intermediate level caves at Building 773-A were redesigned, rebuilt, and replaced for use with the Thorex Process (Du Pont, 1984d). Additional pilot plant testing carried out at TNX with simulated aqueous waste from a first cycle extraction in the thorium process showed that the neutralized waste could be transferred through the plant waste header by gravity flow if it is diluted to a final volume five times the volume of the original acidic waste stream. If the volume resulting from this dilution was considered excessive for plant operation, the acidic waste could be transferred to the pump tank in Building 241-H for neutralization before the waste was pumped to a waste storage tank. Further tests showed that it was not necessary to flush the waste header after each gravity flow transfer of the diluted neutralized waste. Plant waste from the processing of irradiated thorium was successfully transferred to the waste tanks for storage (Du Pont, 1984b).

During the first half of 1964, the Experimental Physics Division conducted a number of studies in support of the power reactor evaluations performed at SRL and Oak Ridge. A program on thorium use in $D_2O$ reactors was pursued on an off-and-on basis due to changing program authorizations. A set of $ThO_2$-U-235 fuel assemblies was procured from the Argonne National Laboratory, and the necessary hardware was designed and fabricated for testing this fuel in rod clusters in the SE and PDP. Negotiations were also underway with Nuclear Metals, Inc., to obtain fabricated thorium metal/U-235 fuel assemblies for possible use in a cooperative program with the Babcock and Wilcox Company. Other work included the development of measurement techniques for determining thorium fast fissions and the production of U-232 from Th-232 captures (Du Pont, 1984c).

In addition to the development of uranium fuel elements, a limited number of tests of thorium metal were undertaken to evaluate the performance of this material for a thorium/U-233 converter cycle. Two thorium-uranium alloy tubes were constructed in the Fabrication Laboratory and tested in the HWCTR to evaluate the performance of thorium tubes under conditions that would be encountered in a $D_2O$-moderated reactor operating on an equilibrium thorium/U-233 fuel cycle. These tubes reached an exposure of about 3,500 MWD/T at peak temperatures of about 485°C (Du Pont, 1984c).

To study the behavior of various alloys in natural uranium, segmented metal tubes (SMT) were constructed in the Fabrication Laboratory. Several assemblies were irradiated during 1964; however, inspection showed significant vibration damage. Similar damage also occurred during extended flow testing in the Power Flow Loop (Du Pont, 1984c). Enriched metal tubes (EMT) were fabricated and irradiated to study the characteristics of slightly enriched uranium metal. Fuel from original assemblies, which was housed in stainless steel, was discharged from HWCTR after initial irradiation, placed in Zircaloy housings, and recharged into the reactor (Du Pont, 1984c).

The handling of large quantities of short-cooled thorium oxide ($ThO_2$) and uranium oxide ($UO_2$) caused radiation problems in high level caves. Relatively large quantities of curium were extensively handled throughout the laboratory with excellent contamination control but with some exposure problems (Du Pont, 1984d). The procedures for processing irradiated thorium and thorium dioxide (thoria) to separate U-233 and recover thorium for recycle were demonstrated in the laboratory, tested at TNX, and successfully applied to two plant irradiation programs (Du Pont, 1984b).

In 1965, SRL provided further and extensive technical support for the thorium program (Du Pont, 1984b). A Thorex-type process compatible with existing process equipment in H Area was developed for processing irradiated thorium and thorium dioxide to separate U-233 and to recover thorium for recycle. After dissolution of the irradiated thorium, the product solution required a sorption or "head-end" treatment in which most of the Pa-233 and some of the fission products were co-precipitated with manganese dioxide to separate them from U-233 and thorium. Bench-scale testing was performed in Building 773-A. Prototype testing was performed at TNX (Du Pont, 1984b). The TNX laboratory reported analyzing 6241 samples in 1965, an increase of 9.1% over the 5,718 reported in 1964 (Du Pont, 1984d).

In 1967, process development for thoria slug canning continued with analytical and metallurgical support being performed in Building 773-A. Other analytical support provided by SRL in 1967-68 at Building 773-A included thermogravimetric analysis and in-line mass spectrometry of released gas (Du Pont, 1984b). Pilot scale tests to support Thorex programs were conducted at TNX through 1968 (Du Pont, 1984b).

In 1968, compaction of mixed powders for co-extrusion billet cores was investigated. Evaluation of tubes made with compacted cores using several grades of $U_3O_8$, $UO_2$, $ThO_2$, and Al powders was completed (Du Pont, 1984a). Work may have been performed in Buildings 723-A,-773-A, and TNX.

One of the Thorex campaigns, Thorex IIB, was completed with the recovery of 181 kg of U-233. About 2.65 g of Pa-231 resulting from the decay of Th-232 in a former Thorex campaign was also recovered and purified (Du Pont, 1984b). SRL provided support to the Thorex program through 1970.

NIOSH has not found documentation on processes and operations that may have involved thorium in Building 773-A in 1971 though inventory ledgers show that there were residual thorium processing and handling activities occurring during this time (Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962).

A summary of thorium operations in the 700 Area is shown in Table 5-5 (Progress Report, Aug 1960; Du Pont, 1957; Du Pont, 1984d; Du Pont, 1984b; Du Pont, 1984c; Swanson, 2006).

**Table 5-5: Thorium Operations in SRS 700 Area**
(This table spans two pages)

| Time Frame | Building | Operation/Process |
|---|---|---|
| 7/1953-12/1955 | 773-A | Metallurgical research; fabrication; analytical control of supplied materials, manufacturing processes and finished products; research to find more efficient fuel design (hollow slugs); cut irradiated slugs underwater. Thorex process development work including: (1) dissolution, (2) head-end decontamination of dissolver solution, and (3) solvent extraction |
| | CMX | Flow testing of new fuel and target elements |
| | TNX | Testing of non-charged fuel assemblies; determination of operational parameters for separations equipment and procedures |
| 1/1956-12/1957 | 773-A | Analytical control of supplied materials, manufacturing processes and finished products; slug fabrication; continued research of Thorex process |
| | CMX | Flow testing of new fuel and target elements |
| | TNX | Testing of non-charged fuel assemblies; determination of operational parameters for separations equipment and procedures |
| 1/1958-12/1959 | 773-A | Analytical control of supplied materials, manufacturing processes and finished products; thorium used as surrogate for neptunium recovery and separation process development |
| | TNX | Testing of non-charged fuel assemblies; determination of operational parameters for separations equipment and procedures |
| 1/1960-12/1960 | 773-A | Dissolved Sylcor slugs, recovered some U-233 |
| | TNX | Testing of non-charged fuel assemblies; pilot-scale development of Thorex process |
| 1/1961-12/1961 | 773-A | Analytical control of supplied materials, manufacturing processes and finished products; dissolving Sylcor slugs, recovering some U-233; destructive testing of slug welds; waste collected from high level caves, encased in concrete, and sent to 643-G |
| | TNX | Testing of non-charged fuel assemblies |
| 1/1962-12/1962 | 773-A | Analytical control of supplied materials, manufacturing processes and finished products |
| | TNX | Testing of non-charged fuel assemblies; pilot-scale development of Thorex process |

| **Table 5-5: Thorium Operations in SRS 700 Area** (This table spans two pages) | | |
|---|---|---|
| **Time Frame** | **Building** | **Operation/Process** |
| 1/1963-12/1966 | 773-A | Analytical control of supplied materials, manufacturing processes and finished products; development work on “hot die-size bonding” process; material development for thoria targets; laboratory studies of the dissolution of “sol gel” thorium oxide; support for Thorex process for the recovery of U-233 in the 200 Area (Building 221-H); handle large quantities of short-cooled $ThO_2$ and $UO_2$ (gram quantities were handled in Intermediate Level Cells and up to 250 mg were routinely handled in glove boxes in Separations Chemistry); Cell 1 of the Intermediate Level Cells redesigned, rebuilt, and replaced for use with the Thorex process; assay irradiated thorium targets in both metal and oxide form; test various materials for the “head end” co-precipitation and removal of Pa-233 from the acid-adjusted Thorex dissolver solution |
| | CMX | Flow testing of new fuel and target elements |
| | TNX | Testing of non-charged fuel assemblies; pilot-scale development of Thorex process |
| 1/1967-12/1969 | 773-A | Analytical control of supplied materials, manufacturing processes and finished products; laboratory studies of the dissolution of “sol gel” thorium oxide; support Thorex process (Thorex I, IIA and IIB) for the recovery of U-233 in the 200 Area (Building 221-H); Handle large quantities of short-cooled $ThO_2$ and $UO_2$ (gram quantities were handled in Intermediate Level Cells and up to 250 mg were routinely handled in glove boxes in Separations Chemistry); assay irradiated thorium targets in both metal and oxide form; Removal of thorium from building |
| | CMX | Flow testing of new fuel and target elements |
| | TNX | Pilot-scale development of Thorex process |
| 1/1970-12/1972 | 773-A | Removal of any remaining thorium |

The maximum thorium inventories in any month for calendar years 1953 through 1972 for 700 Area buildings (as recorded on ledger sheets) are listed in Table 5-6. Inventories for Buildings 723-A are included, although NIOSH has obtained no documentation on the processes in which these inventories were employed.

**Table 5-6: Maximum Monthly Thorium Inventories, SRS 700 Area**
(inventory values in pounds)

| Year | 773-A | 723-A | CMX | TNX |
|---|---|---|---|---|
| 1953 | 500-2000 | - | - | - |
| 1954 | 2000-10000 | - | 50-500 | 500-2000 |
| 1955 | >10000 | - | 50-500 | 2000-10000 |
| 1956 | 2000-10000 | - | - | 2000-10000 |
| 1957 | 2000-10000 | - | - | - |
| 1958 | - | - | - | - |
| 1959 | - | - | - | - |
| 1960 | 50-500 | 10-50 | - | - |
| 1961 | 50-500 | 10-50 | 50-500 | - |
| 1962 | 50-500 | 10-50 | - | - |
| 1963 | - | 0.1-10 | - | - |
| 1964 | 2000-10000 | 0.1-10 | 500-2000 | >10000 |
| 1965 | 2000-10000 | 10-50 | 10-50 | >10000 |
| 1966 | 2000-10000 | 10-50 | 500-2000 | >10000 |
| 1967 | 500-2000 | 50-500 | 500-2000 | >10000 |
| 1968 | 500-2000 | 0.1-10 | 500-2000 | >10000 |
| 1969 | 500-2000 | 0.1-10 | - | - |
| 1970 | 500-2000 | - | - | - |
| 1971 | 500-2000 | - | - | - |
| 1972 | - | - | - | - |

Source: Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962
Note: A table cell with a hyphen (-) indicates No Data Available

# 6.0 Pedigree of Savannah River Site Data

The following statements apply to the thorium exposure analysis in this SEC Evaluation Report Addendum 2:

- All air monitoring data used in this analysis came from official SRS primary source documents (i.e., handwritten logs) obtained during NIOSH data captures.

- Thorium bioassay data used in this evaluation came from official SRS bioassay record books. Uranium bioassay data recorded in the record books through 1965 were entered into spreadsheets for use in the statistical analyses.

- Thorium inventories used in this evaluation were recorded in SRS thorium inventory ledgers.

- Work locations specified in the proposed SEC class were derived from external dosimetry codes that indicate where dosimeters were issued. Use of the code set published in this addendum ceased on September 30, 1972; a new set of codes were implemented on October 1, 1972. The codes were used to limit entry to the 700 Area regulated areas and the CMX/TNX regulated areas. While it was possible for someone from another area to have picked up a badge and gone to the 700 Area and/or the CMX/TNX regulated areas, it is not feasible that they would have worked 250 days there without ever having a dosimeter code from that area. Most SRS workers were monitored for external radiation and therefore have a dosimeter code location. In fact, based on the NOCTS claims to date, 80% of SRS claimants have some external monitoring records during their SRS employment. The remaining 20% are a mix of clerical staff, cafeteria staff, coal power plant operators, and construction trades workers. The construction trades workers who were not monitored did not enter a regulated area and were typically involved in new construction activities.

- Information given in thorium ledger documents (Thorium Ledger, 1952-1972) were entered into Microsoft Excel spreadsheet files before being assessed for inclusion in this addendum to the evaluation report. Additional thorium inventory data for 1959 through 1962 are available (Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962).

- All other documents and data used in this analysis were addressed in the original data pedigree analysis provided in *SEC Petition Evaluation Report for Savannah River Site* (NIOSH, 2008).

## 7.1 Evaluation of Bounding Internal Radiation Doses at Savannah River Site

*ATTRIBUTION: Section 7.1 and its related subsections were completed by Mike Mahathy, Oak Ridge Associated Universities; Sam Chu, Mel Chew and Associates, Inc.; Billy Smith, Mel Chew and Associates, Inc.; Robert Morris, Mel Chew and Associates, Inc; and Elizabeth Brackett, MJW Corporation. These conclusions were peer-reviewed by the individuals listed on the cover page. The rationales for all conclusions in this document are explained in the associated text.*

In its SRS evaluation report (NIOSH, 2008), NIOSH reserved for future consideration the feasibility determination for thorium exposures from January 1, 1950 through December 31, 1959. Since the publication of that SRS report, NIOSH has evaluated and quantified thorium operations conducted at SRS from 1950 through 1959. During that evaluation, NIOSH determined that the period of thorium metal work for which a common feasibility decision should be applied extended through 1965. NIOSH published that evaluation in 2010 (NIOSH, 2010). Subsequently, NIOSH conducted additional document captures and interviews with former SRS workers, further extending its evaluation of SRS thorium work through 1972. This section provides further discussion of thorium operations by SRS area and discusses the feasibility of bounding thorium doses in each of those areas.

7.1.1.8 Thorium (Th-228, Th-232)

300 Area

In the first Addendum to the SEC-00103 Evaluation Report, NIOSH stated that under the conditions of use of natural thorium metal at SRS for the period 1953 through 1965, uranium bioassay data can be used to support thorium intake modeling. In order to demonstrate how thorium operations compared to uranium operations, NIOSH analyzed air monitoring data (results in mass) obtained during sampling of thorium and uranium work performed on the same days in the 300 Area. Further, NIOSH tested the hypothesis that the mean of the natural log of the mass air concentrations of thorium was less than or equal to the mean of the natural log of the mass air concentrations obtained for uranium. The hypothesis could not be rejected (NIOSH, 2010).

After publication of first Addendum to the SEC-00103 Evaluation Report, a critique of the air concentration statistical test stated that NIOSH matched thorium sample results to uranium sample results based on date, but should assess the comparison based on similar operations between thorium and uranium. The critique postulated that the selected uranium results may have represented processes that did not have the same potential for airborne contamination as did the selected thorium operations. To address the critique NIOSH re-performed its original analysis selecting uranium and thorium results based on comparable operations (e.g., lathing). For this latter analysis, NIOSH has eliminated one of the thirty thorium results used in the original statistical analysis published in the addendum. NIOSH selected thirty-two uranium results taken during cutting, lathing, machining, and drill operations. The thorium and uranium air sampling results used for this evaluation are shown in Appendix A, Tables A-1 and A-2. The location where the sample was collected and the associated operation are provided for each result.

Air concentrations (pCi/$m^3$) of total thorium were calculated using the raw count data, combined assumed counting and collection efficiencies[1], collection time, and sampler flow rate. The airborne thorium activity is assumed to be fully equilibrated between Th-232 and Th-228. This assumption that the isotopes generally exist in a 1-to-1 ratio maximizes the activity per unit mass collected on a filter. However, due to the extremely long half-life (and therefore, low specific activity) of Th-232, the mass remaining at the time of the air sample is counted is assumed to be essentially all associated with Th-232. Conversely, the mass of Th-228 is assumed to be immeasurably small (as compared to the Th-232) and is assumed to be zero for the purposes of this assessment. Therefore, thorium mass concentrations for the purpose of this mass comparison were derived using a Th-232 specific activity of 0.111 pCi/µg; uranium mass concentrations were derived using a specific activity of 0.672 pCi/µg. The mass concentrations (µg/$m^3$) for Th-232 and natural uranium are included in Appendix A, Tables A-1 and A-2, respectively.

Descriptive statistics were generated for the thorium dataset and the uranium dataset using mass concentrations; these are shown in Table 7-1.

**Table 7-1: Descriptive Statistics for SRS Thorium and Uranium Air Monitoring Data (µg/$m^3$)**

| Statistic | Th-232 | Uranium |
|---|---|---|
| number of results | 28 | 31 |
| minimum | 0.49 | 0.87 |
| lower quartile | 1.86 | 2.96 |
| mean | 6.15 | 13.91 |
| median | 3.42 | 6.33 |
| standard deviation | 6.21 | 21.80 |
| upper quartile | 8.15 | 12.76 |
| Maximum | 25.46 | 112.27 |
| geometric mean | 3.77 | 0.87 |

The descriptive statistics were used to generate the box-and-whisker plots in Figure 7-1. When two box-and-whisker plots are displayed on the same scale, as in Figure 7-1, key features of the data can be graphically compared. The minimum values of both distributions are as close to zero as can be measured with the selected technology. The box portion of the plot is bounded by the lower quartile and upper quartile values and the median is between those two values (represented by the horizontal solid line inside the box). The box defines the range of the middle 50% of the data, which is also called the interquartile distance. Whiskers on each side of the box represent the 10th and 90th percentiles; the black dots represent the 5th and 95th percentiles. The conclusion drawn from this figure is that the thorium distribution median values are generally less than the uranium distribution.

[1] Attribution: Robert Morris, Mel Chew and Associates, Inc. These assumptions are based on extensive experience with alpha counter and air sampling equipment. Several of these assumptions can be substantiated in the Air Force Institute of Operational Health consultative letter, *Alpha Correction Factor for New Bioenvironmental Engineering Radiological Air Sampling Equipment – RADeCO® Model H-809VII* (Correction Factor, 2005).

Thus, the plots support the hypothesis that the thorium concentrations are in the same airborne concentration range (by mass) as the uranium values and the internal exposure profiles for uranium and thorium are similar.

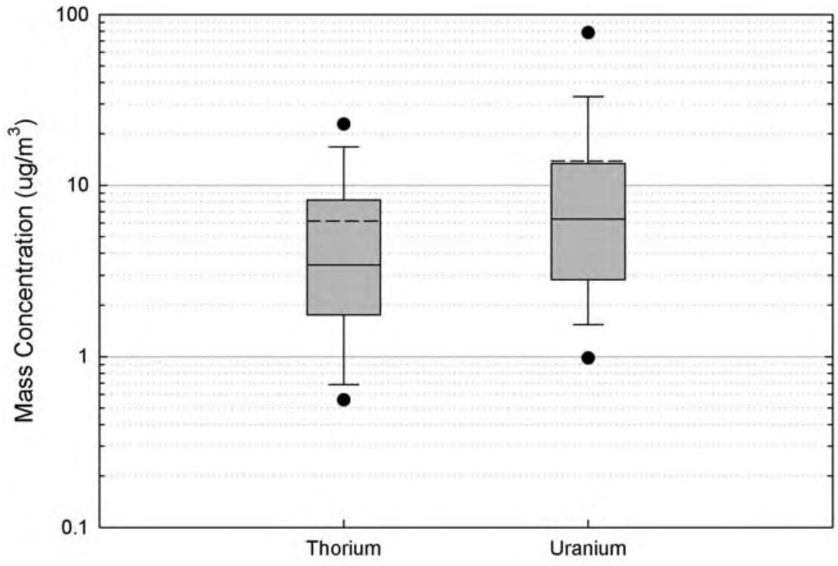



**Figure 7-1: Comparison of SRS Thorium and Uranium Air Sample Data**

NIOSH performed a one-tail t-Test analysis (two-sample assuming unequal variances) to test the hypothesis that the mean of the natural log of the mass concentrations of thorium was less than or equal to the mean of the natural log of the mass concentrations obtained for uranium using α= 0.05 (H0 : µt = µu) with the alternate hypothesis H1 : µt > µu. In order for the hypothesis to be true, $P_{(t)} \leq t_{critical}$ must be true. Results of the hypothesis test are shown in Table 7-2.

**Table 7-2: t-Test Analysis**

| Statistic | Thorium | Uranium |
|---|---|---|
| mean | 1.35 | 1.94 |
| variance | 1.10 | 1.33 |
| observations | 29 | 31 |
| hypothesized mean difference | 0 | --- |
| degrees of freedom | 58 | --- |
| t Stat | -2.08 | --- |
| P(T<=t) one-tail | 0.02 | --- |
| t Critical one-tail | 1.67 | --- |

Note: Data values used in the analysis are log transformations of the mass concentrations.

With a p value of 0.02, there is not sufficient statistical evidence to reject the null hypothesis ($\mu t = \mu u$) in favor of the alternate hypothesis ($\mu t > \mu u$). Since the specific activity of thorium is less than that of uranium, small errors in mass intake would result in less of an effect compared to uranium. Therefore, NIOSH concludes that uranium and thorium operations are sufficiently comparable that uranium bioassay assigned as thorium data can be used to bound doses received from exposures to thorium metal and to thoron from 1953 through 1965 in the 300 Area using the guidance and intake rates provided in the Addendum to the SEC-00103 Evaluation Report (NIOSH, 2010, Section 7.1.1.8).

In ORAUT-RPRT-0046, NIOSH published an analysis of thoria air sample data obtained during periods of thoria work conducted in Building 313-M. The air samples were collected during thoria production operations. An interview with a former Health Physics technician who monitored the operations indicates that the thoria production operations were well-controlled and the intake potential was low (Personal Communication, 2009). The data and interviews show that during the periods when thoria processing campaigns were being conducted, a bounding thorium intake rate can be established based on the lognormally-fitted air sample data and assumptions regarding breathing rate. The interview with the former Health Physics technician suggested that exposure potential was equally low during periods of maintenance and decommissioning. This was confirmed by review of routine contamination survey data for that period data (Sawyer, 1966a; Sawyer 1966b; Sawyer 1966c; Sawyer 1966d; Sawyer, 1966e). NIOSH has more uranium air sample results that could be used to support assessing/bounding the thoron exposures because uranium canning was conducted at the same time as the thorium operations. Intake rates of Th-232 and thoron were derived from the air monitoring data and are available in ORAUT-RPRT-0046.

A critique of ORAUT-RPRT-0046 inquired whether the analysis considered work with recycled thorium at 313-M. NIOSH's response is that personnel working with thorium were much more likely to be exposed to uranium and, consequently, were bioassayed for uranium. Analyses of thorium nitrate stored in five railcars in 1966 showed U-233 contamination ranging from 0.5 to 1.3 ppm and total U ranging from 0.9 to 9.5 ppm (Maher, 1966).

K, L, P, C and R Reactors and Associated Facilities

NIOSH has not identified specific air monitoring data obtained in reactor facilities for monitoring the release of irradiated thorium. Thorium work at reactor facilities included assembly of encapsulated thorium slugs into target core assemblies, and irradiation of assemblies for varying but specified times. Once irradiation was completed, assemblies were stored in a cooling pool to permit decay ("cooling") of mixed fission product activities. Analytical work conducted on irradiated thorium slugs was performed in hot caves with monitoring by Health Physics. An examination of the Special Hazards Database identified no incidents involving release of thorium contamination during handling or pre-irradiated or post-irradiated thorium slugs at reactor facilities. NIOSH finds that operations at reactor facilities were adequately controlled, and because the work was performed with encapsulated thorium in shielded contained environments, thorium exposures were controlled such that they can be bounded by the same methods used for the 300 Area.

F Canyon (Area)

For Building 235-F from 1961 through 1965, the largest monthly quantity of thorium oxide present per available inventory reports was 50 to 500 pounds. NIOSH has not discovered documentation or information that would support a significant exposure potential to thorium in Building 235-F; however, based on the materials and quantities of thorium that existed in this location, NIOSH finds that potential doses from such exposures may be bounded using guidance in ORAUT-RPRT-0046.

H Canyon (Area)

NIOSH has not identified specific air monitoring data obtained in H Canyon or thorium bioassay data for workers in H Area. However, HIOSH has captured information on the handling of irradiated thorium and thorium by-products in H Canyon. SRS thorium wastes generated through 1964 were encased in concrete and shipped to either ORNL or to the 643-G burial ground (Progress Report, Sep 1955; Progress Report, Oct 1961).

As a result of the research and development work performed in Building 773-A and the TNX facility, a process to separate U-233 from irradiated thorium was well developed by 1965 when the first Thorex campaign began. Irradiated thorium was transported to the H Canyon. Dissolution was performed in an enclosed canyon to separate and recover the U-233. Once separated, the U-233 was concentrated and further treated by conversion to oxides suitable for shipment or storage in the H-B Line. Mixed fission products removed from the stream were sent to the tank farms. Separated thorium nitrate was stored in the canyon and in the HB Line and, after storage for a minimum of 231 days, transported through pipe ($\geq$ 2" diameter) to railcars where the $ThNO_2$ was stored for up to one year. Railroad cars were equipped with 4" x 4" x 6" CWS filters with a rating of 10 cfm of air at 0.8" differential pressure to prevent particulate contamination during filling or from thermal expansion of the tank. Health Physics personnel monitored the loading of the cars. The cars were roped off to denote radiation control boundaries and the cars were inspected frequently (at least weekly) with binoculars to look for any leakage. An emergency procedure was in place to move the contents of a leaking railroad car to a stand-by car; the stand-by car, pump, and hose were readily available (Hobert, 1965). NIOSH has found no documentation that shows that SRS ever encountered a railroad car leaking thorium nitrate. All $ThNO_2$ was shipped to Fernald between 1966 and June 1972 (Maher, 1966; Thorium Ledger, 1952-1972; Thorium CEVs, 1955-1962; Thorium JEVs, 1961-1962).

NIOSH has determined there was a low risk of exposure to thorium nitrate in the process of pumping wastes to railcars and from railcar venting. Considering this information, NIOSH has determined that any doses resulting from potential thorium exposures associated with the operations in the H Canyon (Area) can be bounded using the associated thorium intake rates for the 300 Area for 1965 through 1971 (ORAUT-RPRT-0046).

Savannah River Laboratory

Section 5.1.16 discusses the significant work that was performed in Building 773-A. Thorium inventory data shows significant quantities of "unencapsulated" thorium recorded for many of the years from 1953 through 1972. However, there is no breakdown on where in Building 773-A thorium was used. In summary, chemical analysis and chemical engineering studies for the support of plant operation activities were performed in Section 1, Wings B and C. Interviews with former engineers and scientists confirmed that these types of tasks were performed in Section 1 (Personal Communication, 2011c; Personal Communication, 2011d; Personal Communication, 2011e; Personal Communication, 2011f).

Six steel "junior" caves complete with viewers and manipulators were equipped in some of the labs, including LB-106, LB-107, and LB-142 (Lab Notes, 1955; Lab Notes, 1955-1956). Some of the equipment in the junior caves included scale-downs of the separations equipment used in the 200 Area. Although documented for use with plutonium, there was also a glove box facility located on the centerline of the wall dividing LB-126 and LB-130, which documentation shows to have had some thorium work (Data Capture, 2011). Physical property and corrosion testing, metallography and x-ray diffraction studies, and general physical and chemical studies in support of the reactor fuel development program were performed in laboratories in Section 1, Wing C, and Section 2. Physical, chemical engineering, and metallurgical work with high-level radioactive materials was performed in the 773-A Caves (also referred to as Part II of 773-A). By October 1954, a variety of cave apparatus was available, including: dimensioning equipment, contour tracing gauge, weighing scales, analytical balances, binocular periscope, stage cut-off machine for sectioning irradiated metal, chemical apparatus for dissolving fuel elements, and hardness testers. Fuel element fabrication testing and manufacture were performed in Part III of 773-A (also referred to as the Metallurgical Extension). It contained a laboratory, foundry, welding lab, and development office that provided for full-size metallurgical development work with capabilities for melting, vacuum melting, forging, rolling, heat-treating, machining, welding, and pickling various metals (Du Pont, 1957).

Figure 7-2 shows layout of Building 773-A (Building 773-A Layout, 2010). Grey-shaded areas show where thorium work was performed; yellow-shaded areas show change rooms and Health Physics offices. Change rooms were located next to building exits. At least one office (SRS engineer) was located in Part III of the building, which was a controlled area (Personal Communication, 2011g). No thorium work was conducted in Section 1, Wing A (Personal Communication, 2011b).


**Figure 7-2: Building 773-A Thorium Operations Locations**

Health Physics actively monitored locations where thorium operations were conducted. During its June 2011 review of the SRS notebooks (Lab Notes, 1955; Lab Notes, 1955-1956, Lab Notes, 1956-1957b), NIOSH identified hundreds of radiological surveys made within the Savannah River Laboratory (773A). Health Physics surveyed and tagged material before it was transferred out of 773A; this practice was extensively documented. NIOSH noted specific surveys of thorium materials which indicate “No Smearable Contamination Detected.” NIOSH also noted routine surveys performed in the hallways and change rooms looking for contamination with most indicating “no contamination detected.” Such records indicate an active program of contamination control dating back to the early 1950s (Lab Notes, 1954; Lab Notes, 1955; Lab Notes, 1955-1956; Lab Notes, 1956-1957b).

One 1955 notebook mentions that a list of persons who had worked with thorium at SRL and TNX had been compiled for inclusion on a roster for follow-up bioassay (Lab Notes, 1954; Lab Notes, 1955-1956). It is likely that bioassay results obtained by NIOSH pertain to some of those workers. NIOSH noted that some air sampling was conducted in the metallurgical extension (Part III) during an operation that involved grinding of thorium. That particular job was covered by a Special Work Permit (SWP). The SWP stated that the individual doing the grinding was wearing an “assault mask” (respirator). This information illustrates that during high-risk operations that could involve significant inhalations, the radiation control organization took care to prevent the internal exposures (Lab Notes, 1954; Lab Notes, 1955; Lab Notes, 1955-1956; Lab Notes, 1956-1957b).

The Health Physics group provided training on all health physics topics to maintenance workers entering the 700 Area (Misc. Areas, 1955). At least some of the work with radioactive materials performed by SRL maintenance workers was done by SWP (Lab Notes, 1955; Lab Notes, 1956-1957b). Maintenance and construction workers were consulted by Health Physics before and during operations involving contaminated areas or equipment (Lab Notes, 1956-1957b).

Based on this Addendum 2 evaluation, there is clear indication that there was some potential for radiological exposure to “unencapsulated” thorium in 773A. Since equipment for small-scale canyon and “junior cave” experiments had been installed in Section I, it is reasonable to assume that work with thorium was conducted beyond bench-scale chemical analysis. The SRS notebooks reviewed in June 2011 (Lab Notes, 1954; Lab Notes, 1955; Lab Notes, 1955-1956; Lab Notes, 1956-1957b) noted thorium spills that resulted in contamination on the order of a few thousand dpm and that required clean-up of the labs before they could continue operating. One of the documented spills indicated that the highest smearable contamination was 37cpm which translated to about 105 dpm. Thus, spills of even low-level contamination were monitored by Health Physics. In addition, the notebooks discussed hand and foot monitors alarming due to metal chips embedded in the soles of worker’s shoes who had traveled through Part III of 773-A; this indicates there was some radioactive material in the form of chips on the floors in the Metallurgical Extension. NIOSH has made a qualitative evaluation of worker exposure potential for 773-A workers by year, as shown in Table 7-3 (Isotope Charts, 1953-1976).

| **Table 7-3: Worker Exposure Potential in SRS Building 773-A** | |
|---|---|
| **Year** | **Exposure Potential** |
| 1953 | Low |
| 1954 | High |
| 1955 | Medium |
| 1956 | Medium |
| 1957 | Low |
| 1958 | Low |
| 1959 | Low |
| 1960 | Low |
| 1961 | Low |
| 1962 | Low |
| 1963 | Low |
| 1964 | High |
| 1965 | High |
| 1966 | High |
| 1967 | High |
| 1968 | Low |
| 1969 | Medium |
| 1970 | Medium |
| 1971 | Medium |
| 1972 | Low |

Source: Isotope Charts, 1953-1976

In several notebooks, radiation control technicians identified procedural violations by operations personnel. Specifically, there were times when the operations personnel were doing work outside the scope of a special work permit and the radiation control technicians would observe the action, reporting the workers to Health Physics supervisors. There were also some examples of construction workers who violated the work permit conduct of operations requirements. In one case, two electricians were potentially exposed when they inappropriately accessed a fume hood that contained radioactive materials to work on an electrical device. The violation was observed by radiation control technicians who stopped the work and reported it to supervision. Another instance involved the use of hand and foot monitors. Some individuals set off monitor alarms due to metal chips being embedded in the soles of their shoes. Radiation control technicians proceeded to survey all of the workers shoes in the locker room and found additional instances of shoes with radioactive metal chips embedded in them (apparently because the workers were not surveying themselves prior to exiting the work area using the hand and foot monitors). The radiation control technicians began observing workers exiting the Metallurgical Lab.

NIOSH believes that actual exposures to thorium in Building 773-A were minimal due to the radiological control operations within the facility. However, there are some documented lapses that resulted in contamination incidents (Lab Notes, 1954; Lab Notes, 1955; Lab Notes, 1955-1956; Lab Notes, 1956-1957b). In most instances, the radiation control lapses and the less-than- formal conduct of operations generally do not present a problem for dose reconstruction because there was a routine bioassay program that provided data that can be used to assess doses.

At SRL, NIOSH has obtained bioassay for the most dosimetrically-significant radionuclides. However, NIOSH has not discovered a sufficient amount of bioassay data for thorium over the period under evaluation in this ER Addendum 2, other than the period 1955-1956 for which NIOSH has obtained 225 thorium bioassay results for 175 workers (in NOCTS) (Thorium Records, 1956). Those bioassayed workers represented the following nineteen job titles (including Not Found).

- Chemist
- Chemist Trainee
- Clerk
- Engineer
- Engineer Trainee
- Engineering Assistant
- Foreman
- Helper
- Junior Chemist
- Maintenance Foreman
- Mechanic
- Metallurgist
- Not Found
- Operator
- Physicist
- Research Supervisor
- Supervisor
- Technical Assistant
- Technician

Some of these data indicate positive intakes of thorium from unencapsulated sources for some monitored workers; however, it is not known if this set of bioassay data represents all SRL workers exposed to thorium. Therefore, the data may be used to assess an individual's dose but cannot be used to bound thorium doses of unmonitored SRL workers. NIOSH believes that no thorium urinalysis data exist for the period 1957 through 1972. While NIOSH does have the aforementioned thorium bioassay data, NIOSH cannot be certain that the bioassay program covered all workers who had a potential for exposure. Although NIOSH found notations indicating some air sampling had been done in Building 773-A, NIOSH has not captured actual air monitoring results for Building 773-A sufficient to model potential worker thorium intakes.

Interviews with two former SRS Health Physics technicians established that only monitored personnel entered regulated areas (Personal Communication, 2011h, Personal Communication, 2011i); Part I, Sections IB and C and Part I, Sections II and III of Building 773-A were regulated. As shown in Figure 7-2, Building 773-A, Section 1A was an administrative area with Health Physics offices, change/shower rooms, and hand and foot monitors separating it from the radiological areas of Sections IB and IC and farther back. One of the technicians stated that all workers who worked in regulated areas had to wear film badges. He indicated that all workers, including visitors, were required to wear film badge dosimeters if entering or working in any radiological (regulated) areas. He indicated that supplemental pencil dosimeters (ion chambers) were also used to track exposures when working on some high-level jobs. Film badge dosimeters were stored in an administrative area on a board and were usually picked up every morning and returned to the storage board as the end of the shift. The technician indicated that there were no exceptions to workers having to wear dosimeters in regulated areas (Personal Communication, 2011h).

#### 7.2.3.1 Methods for Bounding Operational Period Internal Dose

Internal doses from potential exposure to thorium and thoron may be bounded for monitored workers in the 300 Area, the SRS reactors, and F and H canyons using:

- Guidance and intake rates using the (first) Addendum to SEC-00103 Evaluation Report for exposure to metals during the period 1953-1965 (NIOSH, 2010).

- Guidance and intake rates using ORAUT-RPRT-0046 for exposure to oxides during the period 1964-1972.

Personnel who worked in the 300 Area in 1964 and/or 1965 should be assigned the maximum dose derived from the two models.

NIOSH has determined that it cannot estimate with sufficient accuracy internal radiation doses resulting from exposure to unencapsulated thorium at two SRS locations: 773A and the CMX/TNX facility from 1953 through September 1972. Due to the inability to estimate internal thorium doses in these two areas, NIOSH is recommending adding a class of workers to the SEC. NIOSH has developed dose reconstruction methodologies to estimate with sufficient accuracy internal and external doses incurred in all other SRS areas where thorium work was conducted.

In order to identify members of the proposed SEC class, NIOSH proposes to use SRS external dosimetry records to identify the location where an energy employee picked up their dosimeter badge. The proposed class will be based on the SRS requirement that all workers entering a regulated area wear a dosimeter badge. External dose records identify the location where the energy employee picked up their dosimeter badge for a given period of time (typically a month or a quarter). There are two types of records that document these locations during the time period 1953 through September 1972. The first is an “annual personnel meters card” used at the site until 1958. Table 7-4 lists the dosimeter codes pertaining to the areas covered in the evaluation where thorium was used and specifies the dosimeter codes that should be included in the NIOSH-proposed SEC class.

*Note: This is a new table that is not in either the original ER or the first addendum. This table does not replace an existing table in either of those documents.*

**Table 7-4: Summary of Dosimeter Locations and Their Inclusion in the SEC**

| Functional Designation | Alpha-Numeric Designation | Area Designation | Unencapsulated Thorium? | Encapsulated Thorium? | Inclusion in SEC? |
|---|---|---|---|---|---|
| Separations | 200F | F | No | No | No |
| | 200H | H | No | No[(a)] | No |
| Manufacturing | 300M | M | Yes | Yes | No[(b)] |
| Heavy Water | 400D | D | No | No | No |
| Technical Semi-works | 773A | A | Yes | Yes | Yes |
| | 777M | M | Yes | Yes | No[(c)] |
| | CMX/TNX | A,G, CMX, or TNX | Yes | Yes | Yes |
| A Area Support | A Area | A | - | - | Yes[(d)] |
| Reactors | 100R | R | No | Yes | No |
| | 100P | P | No | Yes | No |
| | 100L | L | No | Yes | No |
| | 100K | K | No | Yes | No |
| | 100C | C | No | Yes | No |
| Central Shops | CS | G | | | Yes[(e)] |

(a) Unencapsulated thorium was not present in the H area prior to 1964.

(b) Internal doses from potential exposure to thorium and thoron may be bounded for monitored 300M area workers using: (1) guidance and intake rates specified in the (first) Addendum to SEC-00103 Evaluation Report (NIOSH, 2010) for exposure to metals during the period 1953-1965; (2) guidance and intake rates specified in ORAUT-RPRT-0046 for exposure to oxides during the period 1964-1972; and (3) the maximum dose derived from the preceding two models for personnel who worked in the 300M area in 1964 and/or 1965.

(c) The 777M area conducted reactivity measurements on mostly encapsulated thorium. Any exposure to unencapsulated thorium can be estimated using the methods developed for the 300M area. Therefore, the 777M workers are not recommended for inclusion in the SEC.

(d) The A Area includes other support facilities for which unencapsulated thorium was not typically present; however, workers in this area could have worked for extended periods of time in 773A and therefore are recommended for inclusion in the SEC.

(e) Although thorium was not present in the Central Shops area, construction trades workers could work in areas where unencapsulated thorium was present for extended periods of time and therefore are recommended for inclusion in the SEC.

In general, these early dosimeter cards indicate a wearer's work location; however, there are occasions where the area designation is blank (i.e., not filled out or unknown). When a card is blank for a worker, that individual should be included in the SEC because this circumstance is effectively equivalent to a missing record (i.e., NIOSH cannot state with certainty that the individual was or was not conducting work in either the 773A building or the CMX/TNX facilities).

The second type of record is the personnel dosimetry printouts, also called "personnel meters." Post-1957, the work designation and time resolution improved significantly; they were reported on a biweekly basis from 1958 through 1962, and on a quarterly basis from 1963 through September 1972. During this same period, there was greater location definition within areas. Table 7-5 lists the designation codes for each of the areas and some sub-areas. The last column identifies workers who should be considered part of the NIOSH-proposed SEC class (i.e., they have a code for an area with the potential for exposure to unmonitored unencapsulated thorium).

*Note: This is a new table that is not in either the original ER or the first addendum. This table does not replace an existing table in either of those documents.*

**Table 7-5: Location Designations from 1958 through September 1972**

| Functional Designation | Alpha-Numeric Designation | HP Area Code | Unencapsulated Thorium? | Encapsulated Thorium? | Inclusion in SEC? |
|---|---|---|---|---|---|
| Separations | 200F | 1A | No | No | No |
| | 200H | 2A | No | Yes | No |
| Manufacturing | 300M | 3A | Yes | Yes | No[(a)] |
| Heavy Water | 400D | 4A | No | No | No |
| Technical Semi-works | 773A | 5A | Yes | Yes | Yes |
| | 777M | 5B | Yes | Yes | No[(b)] |
| | CMX/TNX | 5C | Yes | Yes | Yes |
| A Area Support | A Area | 6B-6Z[(b)] | | | Yes[(c)] |
| Reactors | 100R | 7A | No | Yes | No |
| | 100P | 8A | No | Yes | No |
| | 100L | 9A | No | Yes | No |
| | 100K | 10A | No | Yes | No |
| | 100C | 11A | No | Yes | No |
| Central Shops | CS | 12D-12H[(d)] and 12J-12Z[(e)] | | | Yes[(f)] |

(a) Internal doses from potential exposure to thorium and thoron may be bounded for monitored 300M area workers using: (1) guidance and intake rates specified in the (first) Addendum to SEC-00103 Evaluation Report (NIOSH, 2010) for exposure to metals during the period 1953-1965; (2) guidance and intake rates specified in ORAUT-RPRT-0046 for exposure to oxides during the period 1964-1972; and (3) the maximum dose derived from the preceding two models for personnel who worked in the 300M area in 1964 and/or 1965.

(b) The 777M area conducted reactivity measurements on mostly encapsulated thorium. Any exposure to unencapsulated thorium can be estimated using the methods developed for the 300M area. Therefore, the 777M workers are not recommended for inclusion in the SEC.

(c) The main administration building 703A should not be included in the recommended SEC class. The designation for this building was 6A. This was an office building that managers and program directors worked from and were generally issued badges so that they could move throughout the site. It is improbable that these individuals would work hands-on with radioactive materials, and therefore, be exposed to unencapsulated thorium for extended periods of time. All other A Aarea workers could have spent extended periods of time in 773A and therefore are recommended for inclusion in the SEC.

(d) This is constructions trades worker codes that operated out of the Central Shops area. The first three sub-shops relate to transportation. Workers from these three shops would only have been exposed to encapsulated thorium; thus, there was no potential for internal exposure and therefore they are not recommended for inclusion in the SEC. The three transportations shops were:
- 618G (12A) = Locomotive Shop
- 705G (12B) = Traffic and Transportation Shop
- 706G (12C) = Traffic and Transportation Office

(e) The "temporary construction" or TC area, later known as B Area, should not be included in the recommended SEC class. The designation for this area was 12I. This area housed the offices for procurement, payroll, accounting, medical, timekeeping as well as management offices for the construction division. The actual construction trades workers worked out of the main portion of the Central Shops area designated by the selected codes.

(f) Although thorium was not present in the Central Shops area, construction trades workers could work in areas where unencapsulated thorium was present for extended periods of time and therefore are recommended for inclusion in the SEC.

### 7.2.4 Internal Dose Reconstruction Feasibility Conclusion

NIOSH lacks sufficient bioassay, air monitoring data, and source term data necessary to bound thorium doses for monitored personnel who worked in the Building 773A or TNX. Although NIOSH found that it is not possible to completely reconstruct internal radiation doses for the period from January 1, 1953 through September 30, 1972 for this group of workers, NIOSH intends to use any internal monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Dose reconstructions for individuals employed at the Savannah River Site during the period from January 1, 1953 through September 30, 1972, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

NIOSH can bound internal doses received from potential exposure to thorium metals using bioassay data and to thoron using available air monitoring data for monitored personnel who worked in the 300 Area, SRS reactors, F canyon and/or H canyon.

## 7.6 Summary of Feasibility Findings for Petition SEC-00103

This report evaluates the feasibility for completing dose reconstructions for all construction workers who worked in any thorium area at the Savannah River Site from January 1, 1953 through December 31, 1972. NIOSH found that the available monitoring records, process descriptions and source term data available are not sufficient to complete dose reconstructions for all members of the evaluated class, specifically: All externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1953 through December 31, 1957, and whose records have dosimetry codes A, G, CMX, or TNX; and all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1958 through September 30, 1972, and whose records have dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z.

Potential radiation doses can be bounded for those employees who worked during the proposed SEC time period but who did not work in the specified thorium-related locations. The remainder of the class evaluated in the original SEC-00103 SRS Evaluation Report can be bounded, specifically: (1) the period before the proposed SEC class (January 1, 1950 through December 31, 1952); and (2) the period after the proposed SEC class (October 1, 1972 through December 31, 2007). Table 7-5 summarizes the results of the feasibility findings at Savannah River Site for each exposure source during the time periods specified above.

**Table 7-6: Summary of Feasibility Findings for SEC-00103**

January 1, 1950 through December 31, 1952 (before proposed SEC class period)
January 1, 1953 through September 30, 1972 (proposed SEC class period)
October 1, 1972 through December 31, 2007 (after proposed SEC class period)

| **Source of Exposure** | **Designated Codes (1953-Sep 1972):** **Jan. 1, 1953 through Dec. 31, 1957: A, G, CMX, or TNX** **Jan. 1, 1958 through Sep. 30, 1972: 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z** | | **Sitewide - Non-designated Codes:** **Jan. 1, 1953 through Sep. 30, 1972** **Sitewide – All Codes:** **Jan. 1, 1950 through Dec. 31, 1952** **Oct. 1, 1972 through Dec. 31, 2007** | |
|---|---|---|---|---|
| | **Reconstruction Feasible** | **Reconstruction Not Feasible** | **Reconstruction Feasible** | **Reconstruction Not Feasible** |
| **Internal**[1] | | **X** | **X** | |
| - Thorium/Thoron | | X | X[2] | |
| **External** | **X** | | **X** | |
| - Gamma | X | | X | |
| - Beta | X | | X | |
| - Neutron | X | | X | |
| - Occupational Medical X-ray | X | | X | |

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

[2] There was no thorium on site during the period January 1, 1950 through December 31, 1952. Internal doses from potential exposures to thorium metals can be bounded using bioassay data, and thoron doses can be bounded using available air monitoring data for monitored personnel who worked in the 300 Area, SRS reactors, F canyon and/or H canyon from January 1, 1953 through September 30, 1972. Although thorium was still on site after September 1972, NIOSH has determined a sufficient end point for this thorium evaluation based on the D&D of 300 Area thorium operations. NIOSH intends to continue reviewing and assessing any additional thorium documentation and data obtained for the post-September 1972 period. The findings of this research will be relayed accordingly if the research results require modification of any existing conclusions made in the SRS SEC Evaluation Report/Addendums.

Although NIOSH found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any internal and external monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at the Savannah River Site during the period from January 1, 1953 through September 30, 1972, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

# 8.0 Evaluation of Health Endangerment for Petition SEC-00103

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

In its evaluation NIOSH found that it does have sufficient bioassay and air monitoring data to bound thorium doses for some members of the evaluated class. Chiefly, NIOSH can bound thorium doses for monitored workers who worked in the 300 Area, SRS reactors, F canyon and/or H canyon. Based on the sum of information available from available resources, NIOSH's evaluation determined that it is not feasible to estimate radiation dose with sufficient accuracy for a group of members of the NIOSH-evaluated class for the time period January 1, 1953 through September 30, 1972. Therefore, the resulting NIOSH-proposed SEC class must include a minimum required employment period as a basis for specifying that health was endangered for this time period. NIOSH further determined that it is feasible to estimate radiation dose with sufficient accuracy for members of the NIOSH-evaluated class for the time periods: (1) January 1, 1950 through December 31, 1952; and (2) October 1, 1972 through December 31, 2007. Therefore, a health endangerment determination is not required for these two time periods.

# 9.0 Class Conclusion for Petition SEC-00103

Based on its full research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class to be added to the SEC includes all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1953 through December 31, 1957, and whose records have dosimetry codes A, G, CMX, or TNX; and all externally monitored employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Savannah River Site from January 1, 1958 through September 30, 1972, and whose records have dosimetry codes 5A, 5C, 6B through 6Z, 12D through 12H, or 12J through 12Z.

NIOSH has carefully reviewed all material sent in by the petitioner, including the specific assertions stated in the petition, and has responded herein (see Section 7.4). NIOSH has also reviewed available technical resources and many other references, including the Site Research Database (SRDB), for information relevant to SEC-00103. In addition, NIOSH reviewed its NOCTS dose reconstruction database to identify EEOICPA-related dose reconstructions that might provide information relevant to the petition evaluation.

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

# 10.0 References (for Addendum 2)

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# Appendix A: SRS Thorium and Uranium Air Sample Results

**Table A-1: SRS Thorium Air Sample Results**

| Sampled for | Building | Location | Comment | Collection Date | cpm | Derived Concentration Th-232 (pCi/m³) | Mass/volume Th-232 (µg/m³)† |
|---|---|---|---|---|---|---|---|
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/22/1954 | 14.3 | 0.37 | 3.37 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/22/1954 | 12.0 | 0.30 | 2.74 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/23/1954 | 28.0 | 0.69 | 6.26 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/23/1954 | 56.7 | 1.34 | 12.03 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/25/1954 | 4.0 | 0.07 | 0.64 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/25/1954 | 7.7 | 0.16 | 1.41 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/25/1954 | 36.3 | 0.47 | 4.28 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/28/1954 | 31.0 | 0.37 | 3.29 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/29/1954 | 44.0 | 0.90 | 8.12 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/29/1954 | 42.8 | 0.92 | 8.25 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/29/1954 | 38.3 | 0.62 | 5.60 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/30/1954 | 35.0 | 0.78 | 7.07 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 6/30/1954 | 30.0 | 2.83 | 25.46 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 7/1/1954 | 10.0 | 0.26 | 2.36 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 7/2/1954 | 4.7 | 0.10 | 0.87 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 7/2/1954 | 3.7 | 0.32 | 2.88 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 7/6/1954 | 46.6 | 1.83 | 16.48 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 7/7/1954 | 55.3 | 2.17 | 19.55 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 7/8/1954 | 37.3 | 1.46 | 13.19 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 7/9/1954 | 8.0 | 0.19 | 1.70 |
| thorium | 320M | Lathe Room | Cutting and machining rods | 7/9/1954 | 26.1 | 0.61 | 5.54 |

**Table A-1: SRS Thorium Air Sample Results**

| Sampled for | Building | Location | Comment | Collection Date | cpm | Derived Concentration Th-232 (pCi/m³) | Mass/volume Th-232 (μg/m³)† |
|---|---|---|---|---|---|---|---|
| thorium | 320M | Spectro-Chem Lab | Grinding | 7/30/1954 | 28.0 | 1.10 | 9.90 |
| thorium | 320M | Swagging Area | Swagging of rods | 8/11/1954 | 9.0 | 0.21 | 1.91 |
| thorium | 320M | Swagging Area | Swagging of rods | 8/12/1954 | 3.0 | 0.05 | 0.49 |
| thorium | 313M | Special Process | Handling Thorium | 4/15/1955 | 3.8 | 0.15 | 1.34 |
| thorium | 313M | Special Process | One foot from welding of slugs | 4/15/1955 | 2.6 | 0.08 | 0.69 |
| thorium | 313M | Special Process | Two feet from welding of slugs | 4/15/1955 | 3.6 | 0.38 | 3.41 |
| thorium | 313M | Special Process | Thorium in room | 5/3/1955 | 12.9 | 0.38 | 3.43 |

**Table A-2: SRS Uranium Air Sample Results**

| Sampled for | Building | Location | Comment | Collection Date | cpm | Derived Concentration Th-232 (pCi/m³) | Mass/volume U-nat (μg/m³)† |
|---|---|---|---|---|---|---|---|
| uranium | 320M | Special Metal Prep Lab | Cutting | 7/17/1957 | 7.0 | 0.58 | 0.87 |
| uranium | 321M | Special Lathe | Machining | 11/21/1957 | 281.0 | 37.33 | 55.54 |
| uranium | 321M | Lathe Room | Cutting Natural Uranium | 11/7/1957 | 7.0 | 1.86 | 2.77 |
| uranium | 321M | Lathe Room | Cutting Billets | 12/30/1957 | 32.0 | 4.25 | 6.33 |
| uranium | 321M | Lathe Room | Cutting and Machining | 10/6/1957 | 31.0 | 2.75 | 4.09 |
| uranium | 321M | Lathe Room | Cutting and Machining | 12/27/1957 | 28.0 | 3.72 | 5.53 |
| uranium | 321M | Lathe Room | Cutting Billets | 12/19/1957 | 11.0 | 1.46 | 2.17 |
| uranium | 321M | Sanding Hood | Sanding | 12/31/1957 | 8.0 | 0.71 | 1.05 |
| uranium | 321M | Lathe Room | Cutting and Machining | 11/14/1957 | 17.0 | 1.51 | 2.24 |
| uranium | 321M | Press | Drilling Billet | 12/6/1957 | 199.0 | 22.03 | 32.78 |

| Table A-2: SRS Uranium Air Sample Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Sampled for** | **Building** | **Location** | **Comment** | **Collection Date** | **cpm** | **Derived Concentration Th-232 (pCi/$m^3$)** | **Mass/volume U-nat (µg/$m^3$)†** |
| uranium | 313M | MarkVI Lathe Room | Cutting and Machining | 12/19/1956 | 114.2 | 17.83 | 26.52 |
| uranium | 313M | MarkVI Lathe Room | Cutting and Machining | 11/3/1956 | 10.0 | 1.89 | 2.82 |
| uranium | 313M | MarkVI Lathe Room | Cutting and Machining | 11/4/1956 | 8.6 | 1.63 | 2.42 |
| uranium | 313M | MarkVI Lathe Room | Cutting and Machining | 12/19/1956 | 16.3 | 6.78 | 10.10 |
| uranium | 313M | MarkVI Lathe Room | Cutting and Machining | 12/21/1956 | 40.6 | 6.34 | 9.43 |
| uranium | 313M | MarkVI Lathe Room | Cutting and Machining | 12/20/1956 | 74.3 | 11.82 | 17.59 |
| uranium | 313M | Mark III Lathe Room | Cutting and Machining | 12/7/1956 | 30.7 | 9.58 | 14.26 |
| uranium | 313M | Mark III Lathe Room | Cutting and Machining | 11/6/1956 | 20.8 | 8.12 | 12.08 |
| uranium | 313M | Mark III Lathe Room | Cutting and Machining | 11/11/1956 | 11.8 | 2.23 | 3.32 |
| uranium | 313M | Mark III Lathe Room | Cutting and Machining | 8/31/1956 | 10.7 | 2.23 | 3.31 |
| uranium | 313M | Mark VI Lathe Room | Cutting and Machining | 12/10/1956 | 10.7 | 2.09 | 3.11 |
| uranium | 313M | Mark VI Lathe Room | Cutting and Machining | 12/20/1956 | 36.8 | 7.66 | 11.40 |
| uranium | 313M | Mark VI Lathe Room | Cutting and Machining | 12/19/1956 | 23.1 | 5.15 | 7.66 |
| uranium | 320M | Mark VI Lathe Room | Cutting and Machining | 4/2/1957 | 15.0 | 4.26 | 6.33 |
| uranium | 313M | Lathe Room | Cutting and Machining | 12/16/1956 | 50.0 | 7.80 | 11.61 |
| uranium | 321M | Lathe Room | Cutting and Machining | 9/24/1957 | 168.0 | 22.32 | 33.21 |
| uranium | 321M | Lathe Room | Cutting and Machining | 10/24/1957 | 7.0 | 0.93 | 1.38 |
| uranium | 313M | Lathe Room | Cutting Billets | 12/11/1956 | 69.0 | 7.18 | 10.68 |
| uranium | 321M | Lathe Room | Cutting Billets | 11/29/1957 | 24.0 | 3.19 | 4.74 |
| uranium | 321M | Press | Drilling | 12/12/1957 | 568.0 | 75.45 | 112.27 |
| uranium | 321M | Lathe Room | Cleaning up Chips | 10/26/1957 | 68.0 | 9.03 | 13.44 |