SEC Petition Evaluation Report
Petition SEC-00103

Report Rev #: Addendum 3 Report Submittal Date: November 20, 2012

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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
SEC-00103	83.13	Nov. 19, 2007	March 4, 2008	Savannah River Site (SRS)

Class Evaluated by NIOSH

All workers who worked in any thorium area at the Savannah River Site from October 1, 1972 through December 31, 2007.

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

None

Related Petition Summary Information

SEC Petition Tracking #(s)	Petition Type	DOE/AWE Facility Name	Petition Status
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)
• Addendum 2 to Savannah River Site SEC Petition Evaluation Report	Savannah River Site (SRS)

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Addendum 3 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 December 16-18, 2008, Advisory Board meeting. 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 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.

On May 4, 2010, NIOSH issued an addendum to the SEC-00103 Evaluation Report. In that report, NIOSH concluded 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).

NIOSH issued a second addendum to the SEC-00103 Evaluation Report on August 9, 2011. In that report, NIOSH proposed an SEC class for some SRS workers that included: “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 Advisory Board discussed NIOSH’s proposed class during its December 7-8, 2011, meeting in Tampa, Florida. The Advisory Board subsequently voted to recommend a revised class definition. The Board’s revised class definition was “All 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 September 30, 1972, 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" (NIOSH, 2011). The class designation became effective on March 3, 2012, as provided for under 42 U.S.C. § 7384*l* (14)(C).

Since the publication of the second addendum, NIOSH has continued its research, captured additional information, and determined that thorium was used in SRS locations and operations from October 1972 through December 2007. Furthermore, NIOSH has determined that it has the necessary monitoring data and source term data needed to adequately bound internal doses received from exposures to unencapsulated thorium for SRS workers during this period. This Addendum 3 to the SEC-00103 Evaluation Report documents post-September 30, 1972 SRS work performed with thorium, locations where these tasks were performed, and exposures that may been received from such work.

NOTE: This Evaluation Report Addendum 3 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 3 Summary

Class Evaluated by NIOSH (in Addendum 3)

The feasibility of reconstructing doses received from thorium exposure from October 1, 1972 through December 31, 2007 was reserved for further consideration in the original SEC-00103 Evaluation Report. During this subsequent review, NIOSH has determined that thorium operations were conducted at SRS through 2007, and conducted in locations beyond those considered in the original evaluation report (NIOSH, 2008) and the first and second addendums (NIOSH, 2010; NIOSH, 2011); therefore, in Addendum 3, NIOSH addressed the feasibility of bounding doses from thorium exposures received during the expanded time period from October 1, 1972 through December 31, 2007.

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

Based on its full research of the class under evaluation, NIOSH has obtained additional process and thorium inventory data and has conducted additional interviews with former workers on the use and monitoring of thorium. Based on its analysis of these available resources, NIOSH found no part of the class under evaluation for which it cannot estimate radiation doses with sufficient accuracy.

Feasibility of Dose Reconstruction

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

Health Endangerment Determination

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

3.2 Class Evaluated by NIOSH

The feasibility of reconstructing doses received from thorium exposure from October 1, 1972 through December 31, 2007 was reserved for further consideration in Addendum 2 of the SEC-00103 Evaluation Report (NIOSH, 2011). That class is further evaluated in this Addendum 3 of the SEC-00103 Evaluation Report.

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

Based on its research, NIOSH has obtained additional process and thorium inventory data and has conducted additional interviews with former workers on the use and monitoring of thorium. These resources allow dose reconstruction to be performed with sufficient accuracy. Based on its analysis of these available resources, NIOSH found no part of the class under evaluation for which it cannot estimate radiation doses with sufficient accuracy.

4.0 Data Sources Reviewed by NIOSH to Evaluate the Class

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 Addendum 2 to the SEC-00103 Evaluation Report was published in August 2011. Some of these data have been considered in this Addendum 3 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 four former SRS employees to learn about thorium work performed at SRS from 1952 through 1992.

- Personal Communication, 2012a, *Personal Communication with Former Nuclear Physicist*; Telephone Interview by ORAU Team, February 2, 2012, SRDB Ref ID: 107510

- Personal Communication, 2012b, *Personal Communication with Former Chemist*; Telephone Interview by ORAU Team, February 2, 2012, SRDB Ref ID: 107512

- Personal Communication, 2012c, *Personal Communication with Former Senior Chemist*; Telephone Interview by ORAU Team, February 3, 2012, SRDB Ref ID: 107515

- Personal Communication, 2012d, *Personal Communication with Former Senior Fellow Scientist*; Telephone Interview by ORAU Team, February 10, 2012, SRDB Ref ID: 108605

4.5 NIOSH Site Research Database

NIOSH has performed additional data captures at SRS since the Addendum 2 was published in August 2011. As of May 17, 2012, there were 6,815 documents in the Site Research Database (SRDB) pertaining to SRS; thus, approximately 1,600 additional documents have been captured, reviewed, and uploaded into the SRDB since August 2011.

SRDB documents evaluated for relevance to the thorium issue include: historical background on thorium operations and thorium material inventories; radiological monitoring data; information on the radiological controls program; monthly reports; and incident documentation. Thorium inventory data were captured from microfiche at SRS and transcribed to a NIOSH document (Inventory Data, 1976-1998).

5.0 Radiological Operations Relevant to the Class Evaluated by NIOSH

ATTRIBUTION: Section 5.0 was 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.

The following subsections summarize SRS radiological operations involving thorium from October 1, 1972 through December 31, 2007, 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 quantities of thorium, and information describing both the processes through which radiation exposures to workers may have occurred and the physical environment in which they may have occurred. The information NIOSH has included within the initial SEC-00103 Evaluation Report and the report's addenda is intended only to be a summary of the available information.

While the time frame covered by this Addendum 3 begins in October 1972, NIOSH has updated inventory data for the THOREX processes conducted in the preceding years to show that THOREX operations ended in 1969. There were five major thorium-processing campaigns conducted at SRS, of which the last campaign ended in 1970. Table 5-1 summarizes the particulars of the thorium campaigns.

Table 5-1: SRS Thorium Processing Campaigns						
Started	**THOREX Process**	**Thorium Feed (T)**	**Nominal U (g/T)**	**U (kg)**	**U-232 (ppm)**	**U-233 Content (%)**
3/1964	Interim 23	7.8 metal	2,700	21	50	97
		5.7 metal	8,300	48	220	91
12/1964	Interim 23	8.6 metal	2,200	19	38	97
		7.8 metal	7,500	64	228	91
9/1965	THOREX	17 metal	1,300	22	2.6-3.9	93-96
		77 ThO_2	2,000	152	4.3-6.4	98^+
5/1968	THOREX	35 ThO_2	2,300	80[a]	---	---
7/1969	THOREX	80 ThO_2	2,300	181[a]	---	---
6/1970	2nd cycle[a]	N/A	N/A	261	6.7	97.9

Source: Thorium Processing, 1970

[a] Uranium from the last two campaigns was composited and processed through a second uranium cycle and finishing operations in June and July 1970.

--- means data not available.

Upon the conclusion of the last campaign in 1970, the separations tanks were flushed many times and the targets were stored in the Receiving Basin for Offsite Fuel (RBOF), also known as Building 244H, and in reactor basins, mainly the 100 K Basin. The process and flush liquid waste were sent to the waste tank farm and eventually transferred to rail cars for shipment to Fernald. Small amounts of solid waste from target manufacturing and the Savannah River Laboratory (SRL) were sent to 643-E (Old Burial Ground) and 643-7E (New Burial Ground). SRL support to the THOREX IIB campaign also diminished upon the conclusion of the campaign in 1970 (Thorium Processing, 1970). Thorium inventories available for 1968 through 1971 shows thorium byproduct materials from THOREX campaigns had been shipped offsite by 1971. From 1968 through 1971, 138,516 kg thorium was shipped to Fernald (Inventories, 1994).

Thorium accountability ledgers for fiscal years 1972 and 1973 provide information on thorium inventory and how it was distributed among the SRS Buildings after the last THOREX campaign. Thorium ledger data and data from the DOE NMS database were examined to reconstruct thorium inventories from 1972 through 2007, as shown in Table 5-2. By 1973, the thorium building inventory shows that more than 95% of the site's thorium inventory, 6679 kg (668 mCi), was stored in the RBOF as metal and oxide targets, the majority of it being thorium oxide targets. Approximately 154 kg (15.4 mCi) of thorium were in Building 773A. About 52 kg (5.2 mCi) of irradiated thorium targets were stored in the disassembly area of the K Basin. Other buildings identified with thorium inventory include Buildings 305M, Test Pile; 221F/FB Line, Metal Conversion Line; 235F, Plutonium Experiment Facility (PEF); 777M, Process Development Pile (PDP); 321M, Fuel Fabrication Facility; and 313M/305M, Slug Fabrication and Testing Facilities. Thorium was used in small gram quantities in glove boxes as a surrogate for Am-241 in 313M in 1972 (Thorium Impurity, 1972).

Table 5-2: SRS Thorium Inventory, 1972-2007 (kg)										
Year	**773A**	**723A**	**235-F**	**772-F Lab**	**M Area**	**777M**	**217-A Storage**	**100-K Basin**	**100-L Basin**	**RBOF**
1972/3	154.0[1]	---[2]	0.0[3]	---	57.2	6.4	0.0[3]	52.0	---	6679[1]
1974	104.0	---	---	---	---	---	---	52.0	---	
1975	104.0	0.5	1.1	1.1	43.2	5.4	---	52.0	---	6757
1976	89.4	1.1	0.9	0.9	40.7	2.0	0.0	52.0	---	6757
1977	85.4	1.1	0.9	0.9	25.4	2.0	0.0	52.0	---	8329
1978	56.6	---	4.0	4.0	25.2	2.1	0.0	52.0	---	8729
1979	83.4	---	4.0	4.0	31.1	2.1	0.0	52.0	---	8729
1980	108.6	---	4.5	4.5	31.1	---	8.0	52.0	3.1	8726
1981	110.9	---	4.0	4.0	23.1	---	0.0	55.1	3.1	8726
1982	85.5	---	4.0	4.0	23.1	---	0.0	55.1	3.1	8726
1983	32.5	---	4.0		2.0	---	0.0	55.1	3.1	8726
1984	21.6	---	4.0	1.0	2.0	---	---	55.1	3.1	8726
1985	17.9	---	4.0	1.0	2.0	---	---	55.1	3.1	8726
1986	5.4	---	4.0	1.0	2.0	---	---	51.9	3.1	8726
1987	4.9	---	4.0	1.0	2.0	---	---	51.9	3.2	8726
1988	17.0	---	4.0	1.0	2.0	---	---	51.9	3.2	8726
1989	41.6	---	4.0	1.0	2.0	---	---	51.9	3.2	8726
1990	207.1	---	4.0	1.0	2.0	---	---	51.9	3.2	8726
1991	208.0	---	4.0	1.0	2.0	---	---	51.9	3.2	8726
1992	205.9	---	4.0	1.0	2.0	---	---	51.9	3.2	8726
1993	167	---	5	1	---	---	---	52	3	8727
1994	170	---	5	1	---	---	---	52	3	8727
1995	170	---	5	---	---	---	---	52	3	8730
1996	170	---	5	---	---	---	---	52	3	8730
1997	171	---	4	---	---	---	---	52	3	8730
1998	175	---	4	---	---	---	---	52	3	8730
1999	175	---	---	---	---	---	---	52	3	8730
2000	286	---	---	---	---	---	---	52	3	8730
2001	286	---	---	---	---	---	---	52	3	8730
2002	399	---	---	---	---	---	---	52	3	8730
2003	299	---	---	---	---	---	---	52	3	8730
2004	8	---	---	---	---	---	---	52	3	8730
2005	7	---	---	---	---	---	---	52	8785	---
2006	4	---	---	---	---	---	---	---	8968	---
2007	4	---	---	---	---	---	---	---	8968	---

Source: DOE NMS database, Inventory Data, 1976-1998, Inventory Reports, 1974-1975, SS Material, 1975, Inventory Spreadsheet, 1975a, Inventory Spreadsheet, 1975b

Notes:

1 Data are listed in table as reported. In later years (1993 forward), data were recorded on SRS ledgers as whole numbers. Ledger data for 244-H were rounded off in the table.

2 Three hyphens (---) mean no data available.

3 0.0 kg means "< 0.099" quantities.

Reviews of the SRS documents available to NIOSH have not revealed any meaningful thorium activities either in production or research during late 1972. Thorium materials were being stored rather than processed in 773A and other buildings, other than the very small quantity used as a surrogate in a glove box environment in 1972 (Personal Communication, 2012c; Thorium Impurity, 1972). The Alpha Materials Laboratory (in 773A) was placed in operation in 1973 and used thorium oxide as a surrogate for testing in glove boxes with the Pu-238 fuel form program (Pu-238 Fuel Form, Oct1972). In 1973, gram-quantity ThO_2 (thorium surrogate) shards were used in 773A hot cells to test chemical vapor deposition of molybdenum (Pu-238 Fuel Form, Jul1973); conducting the work in hot cells reduced the potential thorium exposures to effectively none. The use of gram quantities of thorium as a surrogate continued in 1974. NIOSH has found no significant production and research activities involving thorium documented for 1974 and 1975. The thorium inventory in Building 235F (that housed the Hot Press Facility for making fuel-forms) was increased to about a kilogram (0.1 mCi) for use as a surrogate (Pu-238 Fuel Form, Nov1972).

During 1976, nominal use of thorium as a surrogate likely continued with remaining thorium inventories being stored or shipped off site. In 1977, thorium contamination (gram quantities) of the neptunium product in Mark 16 fuel was successfully removed in H canyon. Thorium was also removed from dissolved plutonium scrap (Works Technical, Aug1977, pdf pp. 42, 55, 57-58). Thorium (oxalate powder prepared in 773A) was used as a surrogate for plutonium in testing of HB-line exchange columns (Works Technical, Aug1977, pdf p. 60).

In 1977, SRS began work in 773-A as part of the Thorium Fuel Cycle Technology Program (TFCT Program) to develop processing technology for spent thorium fuel. The scope of the program included broad evaluations to "identify viable thorium/uranium recycle strategies; research and development programs to confirm the feasibility of the selected fuel cycle or cycles; a design integration study to identify development areas and safeguards and proliferation aspects; and the development and testing of key systems, equipment, and components" (SRL History Vol. I, 1984, pdf, p. 292). Numerous thorium research and testing works were performed from 1977 until the TFCT program was terminated in 1980. In November 1980, SRL began stocking thorium nitrate crystals in the 773A "Chem Stores" for use in research and as surrogate material with an inventory of 3.4 kg (0.34 mCi) (Accountability, 1976-1998; Inventory Write-off, 1979). The quantity shown in the material accountability ledgers had decreased to 2.9 kg (0.29 mCi) in March 1982, to 2.7 kg (0.27 mCi) in May 1982, and to 1.2 kg (0.12 mCi) in August 1984. A notation denoted the latter entry as "inventory write-off." A 1979 du Pont memo authorized thorium to be written off inventory as purchased from stores (Inventory Write-off, 1979). The inventory was further decreased to 1.0 kg (0.1 mCi) in February 1986 and remained at that amount until February 1991 when no further entries for thorium were listed for 773A "Chem Stores" (Accountability, 1976-1998).

SRL procured un-irradiated ThO_2 and ThO_2-UO_2 fuel pellets for TFCT analysis (Monthly Status, Nov1977). SRS received shipments of spent fuel from SRE, Dresden and Elk River (Monthly Status, Nov1977) to support TFCT and the possible future expansion of the program. The fuels were stored in the RBOF. NIOSH has found no indication that actual research was conducted with the spent thorium fuel. The spent fuel was still being stored in the RBOF through 1998 (Accountability, 1976-1998).

By 1978, nine cells in the high-level caves of 773A were prepared for the Alternate Fuel Cycle Technology Program of which TFCT was a part (SRL History Vol. IV, 1984). Four and one-half kg (0.45 mCi) of un-irradiated thorium oxide reflector pellets were received and used to test the effects of heat treatment on physical characteristics and dissolution (Monthly Status, Feb1978). This work, performed in the high-level caves, involved mechanical grinding of ThO_2. Testing of a conceptual THOREX process was also evaluated using some of that same thorium oxide inventory (Monthly

Status, Feb1978). Testing of the conceptual THOREX flowsheets continued at SRL using irradiated thorium and uranium from spent fuels. SRL staff cut sections of irradiation Elk River fuel rods (ThO_2/UO_2 pellets clad in stainless steel) to test off-gas removal characteristics (Monthly Status, Apr1978). Laboratory analyses were performed to evaluate alternative chemical reagents in the dissolution of thorium oxide (Monthly Status, May1978). SRL continued the investigation of tritium removal and retention processes for thorium oxide fuels and the associated evaluation of other volatile radioisotopes. Four types of mechanically-blended ThO_2-UO_2 non-irradiated fuel pellets were received from General Electric of Canada for use in thorium oxide experiments (Monthly Status, Jul1978). SRL analysis of off-gas removal work continued with simulated voloxidation (heating fuel in a furnace under oxidizing conditions) of UO_2 fuels in August 1978. Two additional types of ThO_2-UO_2 non-irradiated fuel pellets were received from General Electric of Canada (Monthly Status, Sep1978). Work at SRL on these types of analyses continued through December 1978 (Monthly Report, Dec1978).

In order to test the Plutonium Experimental Facility (PEF), Building 235-F, where Pu-238 heat source development was to be done, SRL staff put about 300 grams thorium oxide into the process line in March 1978 to functionally test the facility. The cited reference stated that no health physics problems were encountered (Works Technical, Mar1978). By April 1978, all PEF equipment except for the hot press had been tested using ThO_2 as a surrogate in glove boxes (Monthly Status, Apr1978).

In 1979, SRS and Hanford were planning and preparing a small number of 80% ThO_2-20% UO_2 rod assemblies for irradiation in FY 1980, and subsequent post-irradiation characterization (SRL History Vol. I., 1984). While thirty fuel rods (of varying thorium and uranium mixtures) were prepared at Hanford in 1979 and shipped to SRL, the irradiation was canceled in May 1980 (Program Termination, 1980; SRL History Vol. I., 1984).

At CMX, SRL performed long-term flow testing for six months using one of the Hanford fuel rods (100% ThO_2) (Program Termination, 1980). Thirty rods were prepared by Hanford for SRL flow experiments; twelve of the rods were 100% ThO_2 and the remainder of the lot was a mixture of uranium and thorium. Nine of twelve 100% ThO_2 rods were used for the long-term flow test of the thoria assembly. During the program through May 1980, all thirty rods were stored in a cage in 773A, Room C 070 (Program Termination, 1980). At the end of the flow testing, the unneeded urania was transferred to Oak Ridge for reclamation of U-235. The unneeded thoria and thoria/urania materials were transferred to SRS waste (Thorium Irradiation, 1981).

SRL continued to use thorium in laboratory analyses in 1981 as a direct reagent and as a surrogate for other radionuclides (Bibliography, 1987, pdf pp. 179, 183; Thorium Oxylate, 1981). In 1982, SRL conducted bench-scale roasting and dissolution of reactor-grade ceramic fuel (mixtures of ThO_2 and ThO_2/ UO_2). This work was done as part of the TFCT to define the specific process conditions and equipment required to reprocess the thorium fuel materials (Roasting, 1982).

Beginning in 1980 and continuing into 1981, SRL developed a process for fabrication of general purpose heat-source pellets as part of the Pu-238 Fuel Form Program (PuFF). Thorium was used as a surrogate for some of the work performed in hot cells in the PuFF Facility, located in Building 235-F. Pellet fabrication was tested in the Plutonium Experimental Facility (PEF). Thorium was also used as a doping agent of the iridium welding agents. SRS found that some of the pellets made in PuFF were more extensively cracked than those made in PEF, and many were fractured after heat-treating. Pore surfaces around the cracks contained unusually high levels of thorium which was used as a doping agent. This work continued through 1995 (Cassini, 1995; Fabrication, 1982; Iridium, 1982; Pu-238 Fuel Form, Jan-Mar1982; SRL History Vol. III, 1984, pdf pp. 118, 162-172).

SRS manufactured Pu-238 heat sources for the Galileo program through 1987 (average about 20 days per year). As part of this work, SRS workers made numerous welds for about 500 GPHS capsules. Manufacturing work was performed in PuFF and PEF while some testing was performed by SRL in hot cells, which effectively eliminated the potential for radiological exposures. Most of this work did not involve the use of thorium other than its use as a surrogate for plutonium during process testing. The actual doping agent was made at ORNL (Cassini, 2000).

NOTE: The thorium inventory in 773A steadily declined from 1981 (when the TFCT program ended) through 1987 with most of the thorium being sent to the burial grounds. Less than 5 kg (0.5 mCi) thorium remained in 773A during 1987.

With the completion of the Galileo project, DOE moved the manufacture of Pu-238 capsules for the Cassini probe to Los Alamos Nation Laboratory (LANL) due to restructuring and changing missions; Pu-238 fuel was obtained from SRS, which along with ORNL and the Y-12 plant, were assigned by DOE to assist in further development and testing of welds and welding inspections (Cassini, 2000; Welds, 1998**)**. In July 1989 and April 1990, SRS received significant quantity shipments of thorium from ORNL (0.25 mCi) and LANL (0.017 mCi), most likely for use in the effort to assist LANL's production of the Cassini radioisotopic thermoelectric generators. All of the thorium was stored in Building 773A; the maximum quantity was 208 kg in February 1991. NIOSH lacks documentation on how much of this inventory was used for Cassini program development but, by December 1993, the thorium inventory had declined by 0.4 mCi and remained constant until February 1998 when the inventoried amount in Building 773A dropped to 0.4 mCi (4 kg). Using the inventory as the source, NIOSH concludes that SRS use of thorium in the Cassini program ended by December 1993, which is consistent with the SRS role of process development. A weld inspection report states that the development worked ended by April 15, 1993 (Welds, 1998).

Separately from the Cassini work, SRS used thoriated-welding electrodes. Health Physics was asked to evaluate the need for radiological controls for work with thoriated-welding electrodes (Thorium Welding, 1993). Health Physics reported that as long as the SRS welding safety procedure was followed no additional controls were required. However, Health Physics also stated that wastes from the tapering (grinding) of electrodes should be controlled to limit potential contamination, and that Health Physics should review each electrode-grinding location to ensure that adequate contamination-control methods were to be used. Health Physics had to approve new or temporary electrode-grinding locations before they could be used for that purpose (Thorium Welding, 1993).

SRL continued to perform laboratory analyses and research using thorium through 1995 (Bibliography, 1987, pdf pp. 25, 124, 180, 193; SROO, 1996; SRTC, 1995; Waste Glass, 1992; Immobilization, 1994). Some of this work involved testing methods for defense waste stabilization and immobilization (SROO, 1996; Waste Glass, 1992). Thorium was used as a surrogate for plutonium and for other radionuclides, and as an analyte of evaluation (Glass, 2003; Glass, 2006;

Neptunium, 1997; Thorium Analyte, 2000). Further work using thorium to test immobilization was done through 2010 (Glass, 2003; Waste Processing, 2005; Waste Processing, 2011).

Thorium Waste

NIOSH also assessed the source term for thorium waste. Thorium wastes (which include spent fuel) were stored in underground and above-ground tanks, disposed of in waste trenches in the low-level (low-activity) burial ground, and stored in spent-fuel repositories. SRS waste management operations have distinguished among low-activity, intermediate-activity, and alpha-contaminated waste products. From 1952 through 1964, thorium and other alpha wastes were buried in plastic bags and cardboard boxes in earthen trenches and kept separate from other types of waste. Between 1965 and 1974, alpha wastes were sorted into two categories. Waste containing less than 0. 1 curie per package was buried un-encapsulated in separate trenches. Waste containing greater than 0.1 curie per package was buried in concrete containers. When greater than 0.1 curie waste would not fit into prefabricated concrete containers, such waste was encapsulated in concrete prior to burial (Disposal Facilities, 1997).

Between 1952 and 1972, low-level solid and sludge wastes were buried in waste trenches in the Old Radioactive Waste Burial Ground (643-E) located in the burial ground complex (E Area). Liquid wastes and solvents were stored in some of the twenty-two underground thin-walled steel tanks located at E Area. A new burial grounds space, the Low-Level Radioactive Waste Disposal Facility (LLRWDF, Building 643-7E) was placed in operation in 1969 (Disposal Facilities, 1997). From 1974 through 1994, alpha-waste-products containing greater than 10 nCi/g were stored on concrete pads. In 1994, a new vault facility for defense waste processing was implemented; that facility is known as the E Area Vaults Disposal Facility, Building 643-26E (Disposal Facilities, 1997). The EAV Disposal Facility currently consists of one low-activity (LAW) vault, one intermediate-activity (IAW) vault, one long-lived waste storage building, one set of suspect soil trenches, and one Naval Reactor Component disposal area. Waste products disposed of in the suspect soil trenches include soil, debris, rubble, and wood.

Two additional waste treatment and storage facilities were implemented in the 1990s. The Defense Waste Processing Facility (DWPF), located in S Area, is a vitrification plant that encapsulates liquid high-activity radioactive waste streams from the H Area Extended Sludge Processing facility (sludge from H Area waste tanks) and the In-Tank Precipitation facility (liquids from H Area waste tanks) in glass. Waste glass continues to be blended and is stored in S Area awaiting shipment to a federal repository (Disposal Facilities, 1997).

The Saltstone Processing Facility (SPF) and the Saltstone Disposal Facility (SDF) are located in Z Area. Decontaminated salt solutions from the Effluent Treatment Facility and the In-Tank Precipitation facility are blended with cement, fly ash, and blast-furnace slag to produce saltstone grout. The resulting grout is pumped to concrete vaults in the SDF for disposal, where it solidifies into stable blocks (Disposal Facilities, 1997).

SRS performed decontamination and decommissioning (D&D) of some of the structures in which thorium had been used in 2004 and possibly other years through the end of the period under evaluation in this report. Concrete floors and pads were cleaned to remove contamination in 300-M buildings, TNX, and 400-D (Air Data, 2004).

The primary activities performed with thorium materials from October 1972 through 2007 are listed in Table 5-3. Locations where work was performed are assumed to be the same locations where the corresponding inventories were noted. The Total Inventory column shows the sum of the various location inventories that were available, not including wastes and spent-fuel sources.

Table 5-3: Thorium Operations (non-waste)
(This table spans two pages)

Year	Operation	Locations	Total Inventory (kg)	Activity (millicuries)
1972/3	storage, surrogate	773A, M Area (storage)	218	21.8
1974	storage, surrogate	773A, M Area (storage)	104	10.4
1975	storage, surrogate	773A, 235-F, M Area (storage)	155	15.5
1976	dissolution studies, storage, surrogate	773A, 235-F, M Area (storage)	135	13.5
1977	alternative fuels program, dissolution studies, storage, surrogate	773A, 235-F, M Area (storage)	116	11.6
1978	alternative fuels program, dissolution studies, storage, surrogate	773A, 235-F, M Area (storage)	92	9.2
1979	alternative fuels program, tritium studies, storage, surrogate	773A, 235-F, M Area (storage)	125	12.5
1980	alternative fuels program, tritium studies, storage, surrogate	773A, 235-F, M Area (storage)	157	15.7
1981	alternative fuels program, welding agent studies, storage, surrogate	773A, 235-F, M Area (storage)	142	14.2
1982	welding agent studies, storage, surrogate	773A, 235-F, M Area (storage)	117	11.7
1983	welding agent studies, storage, surrogate	773A, 235-F	39	3.9
1984	welding agent studies, storage, surrogate	773A, 235-F	29	2.9
1985	welding agent studies, storage, surrogate	773A, 235-F	25	2.5
1986	welding agent studies, storage, surrogate	773A, 235-F	12	1.2
1987	welding agent studies, storage, surrogate	773A, 235-F	12	1.2
1988	welding agent studies, storage, surrogate	773A, 235-F	24	2.4
1989	welding agent studies, storage, surrogate	773A, 235-F	49	4.9
1990	defense waste research, welding agent studies, storage, surrogate	773A, 235-F	214	21.4
1991	defense waste research, welding agent studies, storage, surrogate	773A, 235-F	215	21.5
1992	defense waste research, welding agent studies, storage, surrogate	773A, 235-F	213	21.3
1993	defense waste research, welding agent studies, storage, surrogate	773A, 235-F	173	17.3
1994	defense waste research, storage, surrogate	773A, 235-F	176	17.6
1995	defense waste research, storage, surrogate	773A, 235-F	175	17.5
1996	defense waste research, storage, surrogate	773A, 235-F	175	17.5
1997	defense waste research, storage, surrogate	773A, 235-F	175	17.5
1998	defense waste research, storage, surrogate	773A, 235-F	179	17.9

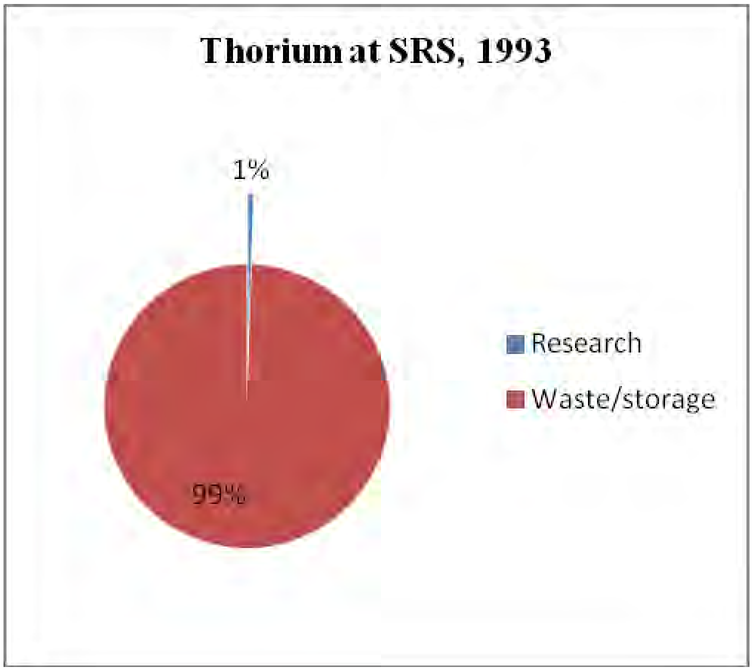
Table 5-3: Thorium Operations (non-waste) (This table spans two pages)				
Year	**Operation**	**Locations**	**Total Inventory (kg)**	**Activity (millicuries)**
1999	defense waste research, storage, surrogate	773A	175	17.5
2000	defense waste research, storage, surrogate	773A	286	28.6
2001	defense waste research, storage, surrogate	773A	286	28.6
2002	defense waste research, storage, surrogate	773A	399	39.9
2003	defense waste research, storage, surrogate, D&D	773A	299	29.9
2004	defense waste research, storage, surrogate, D&D	773A	8	0.8
2005	defense waste research, storage, surrogate	773A	7	0.7
2006	defense waste research, storage, surrogate	773A	4	0.4
2007	defense waste research, storage, surrogate	773A	4	0.4

Source: The above data were compiled from all inventory-related sources called out in this section of this Addendum 3 evaluation.

As of June 25, 1991, 194 kg (19.4 mCi) of thorium was buried in 643-E, 94.4 kg (9.4 mCi) of mixed wastes with thorium was buried in 643-28E, and 67.7 kg of thorium wastes was buried in the newer low-level facility, 963-G. Due to work performed by SRS to implement the E Area Vaults Disposal Facility, inventories of liquids and solids in the solvent tanks and other storage areas were performed as part of the SRS COBRA database. A version of this database was available by 1993 and reported that about 31,500 kg (3.15 curies) of thorium in liquids were stored in a combination of underground waste-storage tanks and ponds, pits, or cribs (Inventories, 1994). Originally stored in the underground tanks in 643-E, the liquid wastes were moved from 643-E to double-walled underground tanks (S-33 through S-36) in H-area by 1997 (Treatment Plan, 1996; Treatment Plan, 1998).

Over the course of the period under evaluation by NIOSH, SRS stored spent fuel containing thorium from its reactors, and also received spent fuel containing thorium from other entities for potential use with the TFCT Program circa 1978. SRS spent-thorium fuels were stored in K and L basins while the externally-supplied fuel was stored in 244-H. Spent fuels were moved from 244-H to L-basin in 2003 and 2004 (Spent Fuel, 2003; Spent Fuel, 2007). In 2006, a small quantity of spent fuel was prepared for shipment to the DOE WIPP facility and to Bettis Lab. In 2006, SRS also moved about 220 kg (22 mCi) of aluminum-process irradiated thorium wastes to the L-basin. The maximum spent fuel in SRS inventories in 2007 was 8968 kg (897 mCi); more than 97% of that was the spent fuel from SRE, Dresden and Elk River. Inventory data of spent fuel containing thorium available for SRS is given in Table 5-2.

Gibbs compiled the inventories of thorium and other radionuclides through 1993 (Inventories, 1994). Using 1993 as a year of reference, the distribution of thorium by research and by waste or storage is shown in Figure 5-1. Only 173 kg, or 17.3 mCi, (from Table 5-3) was available for defense waste and welding research (or about 1 percent of the total SRS inventory that included 31,500 kg, or 3.15 curies of waste) (Inventories, 1994).



Source: Inventories, 1994

Figure 5-1: Distribution of Thorium at SRS by Use

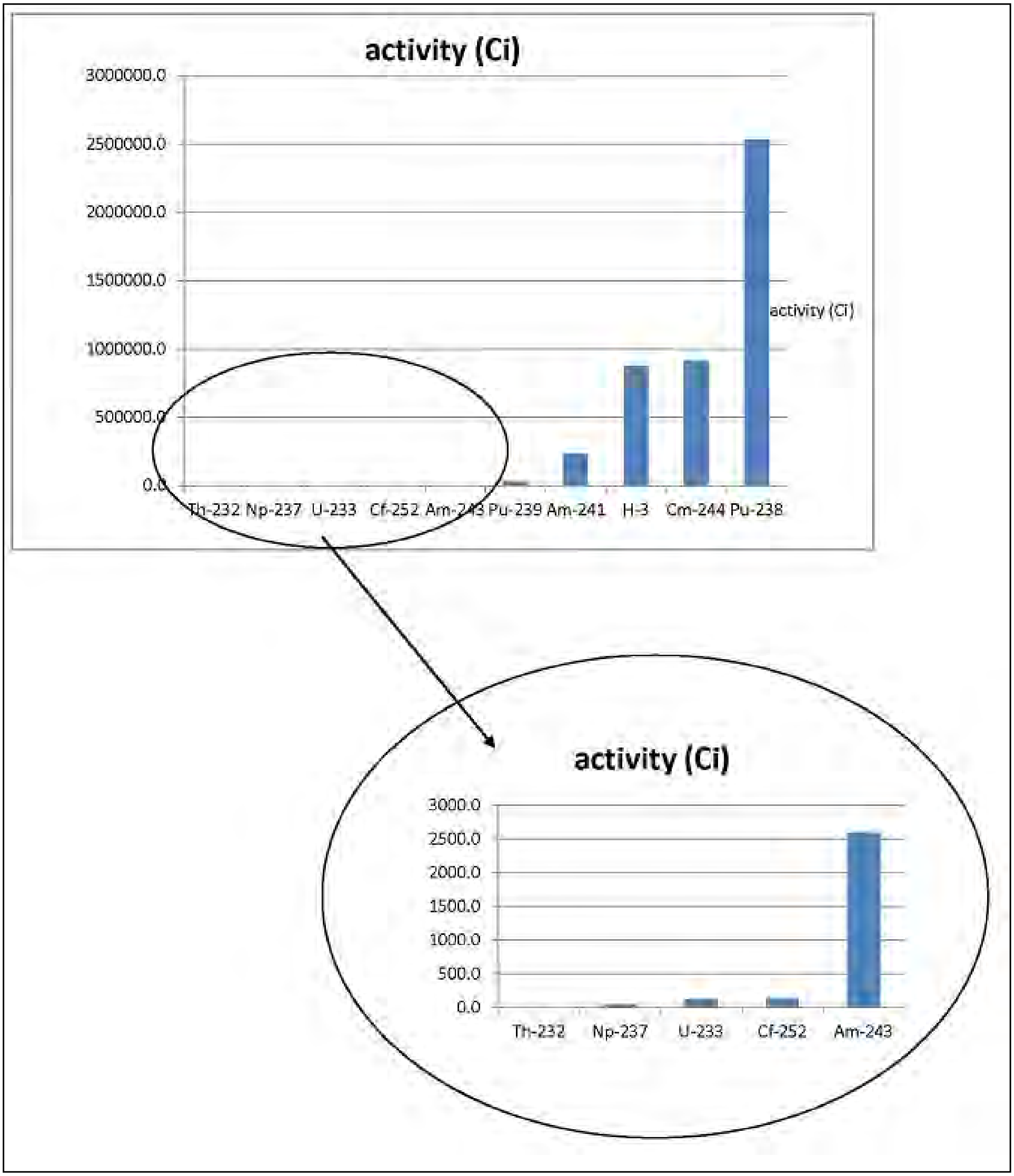
To demonstrate the amount of thorium in comparison to other radionuclides of concern at SRS, NIOSH calculated activities (curies) for ten radionuclides detailed in the Gibbs inventories (Inventories, 1994). The radionuclides and activities are given in Table 5-4. While the quantity of thorium by grams was one of highest amount by gram weight, thorium was the smallest by activity, or about 4 curies. By comparison, the activity amount of Pu-238 was calculated to be over 2,000,000 curies.

Table 5-4: Radionuclide Activities			
Isotope	**Inventory (g)**	**SA (Ci/g)**	**Activity (Ci)**
Th-232	4.12E+07	1.10E-07	4.5
Np-237	6.90E+04	6.90E-04	47.6
U-233	1.34E+04	9.50E-03	126.8
Cf-252	2.50E-01	5.40E+02	135.1
Am-243	1.37E+04	1.90E-01	2597.3
Pu-239	5.13E+05	6.20E-02	31806.0
Am-241	7.23E+04	3.20E+00	231360.0
H-3	9.07E+01	9.70E+03	879693.0
Cm-244	1.12E+04	8.20E+01	915940.0
Pu-238	1.49E+05	1.70E+01	2533000.0

Source: Data values derived from reference: Inventories, 1994

The activities listed above include waste materials. In 1994, there were only 17.6 millicuries of Th-232 non-waste (see Table 5-3).

The activities stated in Table 5-4 were plotted in a bar chart, as shown in Figure 5-2. The activity of thorium (4.5 curies) is so small compared to activities of Cm-244 and Pu-238 that the bar for Th-232 is not noticeable. The activities for Th-232, Np-237, U-233 and Am-243 are shown in the blow-up chart. Even in the blow-up, the activity of Th-232 compared to Np-232, U-233, Cf-252 and Am-243 is still barely noticeable. Table 5-4 and Figure 5-2 demonstrate that the activity of Th-232, and its associated radiological hazards, were insignificant compared to other radionuclides used and stored at SRS. Almost all of the thorium present was waste or spent fuel being held.



Source: Bar chart values taken from Table 5-4.

Figure 5-2: Comparison of Activities of Various ROCs at SRS

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

The following statements apply to the thorium exposure analysis in this SEC Evaluation Report Addendum 3:

- Thorium inventories used in this evaluation were extracted SRS thorium inventory ledgers, SRS material accountability documents and in exports from the U. S. Department of Energy (DOE) Energy Material Balance Reports, 1998-2011, provided by DOE.

- Thorium personal air sampling data used in this evaluation came from official SRS documentation.

- 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), *Addendum to Savannah River Site (SEC-00103) Special Exposure Cohort Evaluation Report* (NIOSH, 2010), and *Addendum 2 to Savannah River Site (SEC-00103) Special Exposure Cohort Evaluation Report* (NIOSH 2011).

7.1 Evaluation of Bounding Internal Radiation Doses at Savannah River Site

7.1.1.8 Thorium (Th-228, Th-232)

Using Trivalent Bioassay as a Substitute for Thorium Bioassay

In *Determination of Actinides in Biological Samples with Bidentate Organophosphorus Extractant* (Actinides, 1970), the authors reported a new method of analyzing bioassay samples for trivalent radioactivity placed into use at SRS in 1970. The authors describe the topic as follows:

> *A procedure for the determination of actinides was developed using the bidentate extractant dibutyl N, Ndiethylcarbamylphosphonate. Nine actinides were extracted from 12N HN03, back-extracted to 2N HN03, and counted in a low-background alpha counter. A procedure was developed for sequential extraction of plutonium, neptunium, and uranium with tri-isooctylamine (TIOA), followed by extraction of thorium, americium, curium, berkelium, californium, and einsteinium with bidentate. Compared with previous methods, the new procedure is simpler, requires less analysis time, and gives better recovery. The recovery of Am-Cm-Cf from 250 ml of urine or 20 grams of feces was 90%. Sensitivity of analysis is 0.02 ± 0.01 d 1 min /sample. An alternative method of exchange of trivalent actinides as oxalate anion complexes with TIOA is also described.*

The authors state that all alpha-emitting actinides from thorium through einsteinium were extracted giving an excellent gross alpha analytical method. Data from the research showed that, in the analysis of americium, curium, and californium, any contaminating plutonium, neptunium, or uranium had to be removed. However, SRS found that thorium, berkelium, and einsteinium were not present in sufficient quantities to require separation.

In light of the above information, NIOSH intends to use trivalent americium, curium, and californium data to bound potential internal doses received from exposure to thorium remaining at SRS after September 1972. NIOSH has already developed co-worker bioassay indices for trivalent radionuclides. NIOSH intends to model these data for thorium intakes which will provide bounding thorium doses for SRS workers potentially exposed to the low-activity levels of thorium.

Exotic trivalent radionuclides bioassay results were obtained directly from SRS in the form of an electronic database for 1991 through 2007. For the period before 1991, SRS does not have an electronic database of bioassay results; however, the bioassay data in NOCTS for SRS employees were used to develop a representative database of co-worker bioassay data for the years before 1991 (ORAUT-OTIB-0075). In addition, neptunium and americium urinalysis bioassay data were obtained from SRS laboratory notebooks (DuPont 1963–1970; DuPont 1969; DuPont 1969–1973; DuPont 1970–1973, DuPont 1973–1978, DuPont 1973–1979, DuPont 1978–1983, DuPont 1979–1980, DuPont 1980–1981a, DuPont 1980–1981b, DuPont 1981–1986, DuPont 1986–1989). The data were transferred to a spreadsheet and subjected to quality assurance (QA) verification presented in *A Comparison of Exotic Trivalent Radionuclide Coworker Models at the Savannah River Site* (ORAUT-RPRT-0055).

Records showing per-unit-volume were adjusted to "per-1.5L" based on an assumed 1.5 L/d of urinary excretion. Volumes greater than 1 L were assumed to represent a full day's voiding and were not adjusted. Volumes less than or equal to 1 L were normalized to 1.5 L. The data in the logbooks consisted of one or more corrected activity rate results for each urine sample in units of dpm per disc, depending on how many times a sample was counted, and on count-specific results in units of net dpm/1.5 L. The result in dpm/1.5 L for each count of a sample was generally recorded as an uncensored value (i.e., the calculated result was recorded regardless of its value). In contrast, the "reported" values were generally censored (i.e., results less than some level, typically the detection or reporting limit were reported as a "less than" result). Some dpm/1.5 L data that were less than zero were reported as zero.

One year of results for each of three individuals in the pool of workers with pre-1991 monitoring data were excluded because they were not representative of co-worker inhalation intakes. These included an ingestion intake, a plutonium wound intake, and an incident that resulted in the highest-assigned intake of Cm-244 in SRS history, respectively. These incidents and intakes were characterized by an extremely high number of bioassay results, many of which were orders of magnitude higher than the bioassay data for other individuals and were considered unrepresentative of the routine potential exposure to thorium for an unmonitored worker.

Chest Counting Information and Available Data

SRS identified chest counting as the monitoring method of choice for thorium in the 1990 and 2000 versions of the internal dosimetry technical basis documents (Internal Dosimetry, 1990; Internal Dosimetry, 2001). Th-232 is assumed to be the principal source of thorium intakes. NIOSH has not identified claimant results of *in vivo* analyses performed for thorium. However, the chest counter was calibrated to detect photons from the Th-232 progeny, including Th-228 and Pb-212. The chest counter, placed in operation in 1989, was configured with an array of four low-energy germanium detectors with thin carbide windows capable of measuring 15 to 400 keV photons (Internal Dosimetry, 2001). That energy range spans the energies of interest for the Th-232 and its progeny. The 84.4 keV gamma energy line of Th-228 and the 238.6 keV energy line of Pb-212 were not normally listed in the SRS chest-counter software analysis library. However, if statistically significant activity was present in the individual worker examinations, then photo peaks of those energies would have been listed on the chest count report as *unidentified*. These *unidentified* peaks would have been resolved and identified as thorium during the report review process. Depending on the skill of the SRS HP analyst, the possibility exists that the association of the unidentified peaks with Th-232 may have been missed. However, unresolved *unidentified* peaks would be listed on the *in vivo* count reports available to the NIOSH dose reconstructor for resolution when reviewing the individual's dose records.

<u>The SRS Health Physics Program</u>

Although Section 7.2 is focused on bounding internal doses, NIOSH also evaluated the entire Health Physics program to assess the thoroughness of SRS efforts to minimize all radiation exposure at the site, as discussed below.

From 1972 through 1990, work involving radioactive materials was controlled under *Savannah River Plant Radiation and Contamination Control*, DPSOP-40 (Radiation Control, 1959-1971; Radiation Control, 1978), and *Radiation Hazards Technical Standards*, DPST-RH (Technical Standards, 1974). Eight basic policy matters were addressed in DPSOP-40:

1. Work in regulated areas
2. Investigating radiation and contamination incidents
3. Protective clothing
4. Injury in regulated areas
5. Disposal of contaminated waste
6. Fires in regulated areas
7. Radiation exposure control
8. Internal radiation exposure control

The procedure set cited above specified requirements for external and internal worker monitoring, surface and air contamination monitoring, protective clothing, transportation of radioactive materials, and waste disposal of radioactive wastes. The listed bases for SRS personnel monitoring specified in DPST-RH in 1974 were: published guides in Atomic Energy Commission Manual Chapters 0524 and 0230; recommendations of the Federal Radiation Council (FRC), the National Committee on Radiation Protection (NCRP), and the International Commission on Radiological Protection (ICRP); and National Bureau of Standards Handbooks Numbers 42, 48, and 69. SRS implemented a set of procedures for its comprehensive radiation protection program in *Health Protection Department Radiation Survey Procedures*, DPSOP-193 (Survey Procedures, 1992).

SRS, in part, limited radiation exposures through the use of zones. SRS defined a Clean Zone as free of contamination as determined by smear contamination surveys. Radiological limits for Clean Zones are given in the SRS manual, *Radiation and Contamination Control* (Radiation Control, 1978). A Regulated Zone was a delineated area where radioactive materials were handled or where radiation or contamination exceeded natural background, but where the radiation level did not exceed 300 mrads or 50 mrems/hr and contamination was maintained below levels established by Health Physics. A Radiation Danger Zone was a delineated area where radiation or contamination levels exceeded limits for a Regulated Zone. (Radiation Control, 1978).

In 1990, area designations were changed to Clean Areas, Radiologically Controlled Areas, Radiation Areas, High Radiation Areas, Very High Radiation Areas, and Contamination Areas (Survey Procedures, 1992). Survey procedures provided the following definitions.

- Radiologically Controlled Areas (RCAs) were established where radioactive materials or elevated radiation rates might be encountered. RCAs were generally maintained clean (no detectable contamination). In areas that were not continuously occupied by personnel, "elevated radiation rates" were typically defined as 2 mrem/hr or greater. In areas continuously occupied by personnel, any radiation rate above background was considered an "elevated radiation rate."

- Radiation Areas were established where personnel could receive a dose equivalent of 5 mrem (but less than 100 mrem) in one hour at 30 centimeters from the radiation source, or any surface through which the radiation emanates. Typically, Radiation Areas were established based on a dose equivalent rate, i.e., 5 mrem/hr (but less than 100 mrem/hr) at 30 centimeters.

- High Radiation Areas were established where personnel could receive a dose equivalent of 100 mrem (but less than 5 rem) in one hour at 30 centimeters from the radiation source, or any surface through which the radiation emanates. Typically, High Radiation Areas were established based on a dose equivalent rate, i.e., 100 mrem/hr (but less than 5 rem/hr) at 30 centimeters.

- Very High Radiation Areas were established where personnel might receive a dose equivalent of 5 rem or greater in one hour at 30 centimeters from the radiation source or the surface from which the radiation emanates. Typically, Very High Radiation Areas were established for dose equivalent rates of 5 rem/hr or greater at 30 centimeters.

- Contamination Areas were established where surface contamination levels exceeded the limits of DOE Order 5480.11.

- Airborne Radioactivity Areas were established where airborne concentrations of radioactive material exceeded ten percent of the Derived Air Concentration (DAC), which was 7×10^{-13} μCi/cc for Th-232 in 1990.

SRS implemented a new radiation control manual in 1991, *Radiological Control Manual* (WSRC-5Q) to comply with DOE Order 5480.11, *Radiation Protection for Occupational Workers* (December 21, 1988 and Change 1, July 20, 1989), and updated it for the *DOE Radiological Control Manual (1992)*, DOE N 5480.6 (Radiological Control, 1992), *DOE Radiological Control Manual (1994)*, DOE/EH-0256T (Radiological Control, 1994), and *Occupational Radiation Protection, Final Rule* (10 C.F.R. pt. 835). Health physics procedures provided in DPSOP-193 were updated to reflect this revised DOE guidance.

SRS maintained the practice of maintaining radiation exposures as low as reasonably achievable (ALARA) (ALAP, 1975; ALARA, 1992; ALARA Assessment, 1993; ALARA Goals, 1992). DPSOP-40 stated the policy as follows:

> *It is plant policy to limit radiation exposure to employees to the lowest reasonably achievable level. Guides furnished in references listed above shall not be considered as desirable dose commitments. We should operate as far below these guides as reasonably achievable.*

With implementation of 10 C.F.R. pt. 835 in 1995, SRS implemented the *Radiological Guide for Planners* (Radiological Guide, 2000). The document was developed to provide consistent guidance to SRS personnel responsible for planning tasks involving radiological work. It documented responsibilities for work planners, supervisors, and health physics staff with the goal of maintaining all radiation exposures as low as reasonably achievable by identifying hazards and radionuclides, and required work steps, protective clothing, and monitoring. A flow chart of the planning process is provided in the guide.

Although SRS administered a thorough radiation and contamination control program, which included worker training, material spills and other incidents involving radiation did occur (Incidents, 1973-1977). While no Special Hazards incidents involving the use of thorium have been identified by NIOSH, they have identified incidents that occurred in buildings known to have had thorium inventories during the period under evaluation for this Addendum 3 (Special Hazards, 1962-1974; Special Hazards, 1974-1983; Special Hazards, 1983-1989).

Facility design was an important aspect of exposure control used at SRS (Operational Health Physics, 1980). The adequacy of shielding was frequently reviewed. Ventilation was designed to provide air flow from clean areas into regulated areas. New facility designs or plans for modifications to existing facilities were reviewed by HP to assure that adequate consideration had been given to shielding, ventilation, containment, personnel traffic patterns, stationary radiation monitors, and effluent controls.

Routine radiation and contamination surveys played important parts in SRS's assessment of the radiation and contamination program effectiveness. Survey frequency depended on the potential associated with the specified work area. Work in some areas required constant surveillance while work in some other areas only required occasional monitoring. The SRS radiation control manuals and procedures gave limits and action levels for fixed and surface contamination, air monitoring (including limits for Th-232), and external and internal monitoring of workers; they also described measures and controls to limit radiation exposure. Health Physics maintained a rigorous contamination survey program. In addition to monitoring areas for contamination, Health Physics surveyed workers, laundry, and tools as these were moved throughout the site. Health Physics monitored waste as it moved between plant locations and off site. Health Physics radiation limits for tools, laundry, and off-plant shipments are listed in Table 7-1.

Table 7-1: Health Physics Radiation Limits for Tools, Laundry, and Off-plant Shipments

Material Type	Radiation Limit	
Tools:	**Transferable:**	**Fixed:**
- alpha	< 500 dpm/ft^2	As low as practical
- beta-gamma	< 1000 cpm/ft^2	10 mrad/hr at 3 inches
Laundry:	**Pre-laundry:**	**Post-laundry:**
- alpha	< 20000 dpm/100 cm^2	< 1000 dpm/100 cm^2
- beta-gamma exposure rate	<12 mrad/hr at 3 inches	<12 mrad/hr/100 cm^2
Off-plant Shipments:	**Transferable:**	**Fixed:**
- alpha	< 220 dpm/100 cm^2	< 220 dpm/100 cm^2
- beta-gamma	< 2200 dpm/100 cm^2 (except exclusive use)	< 2200 dpm/100 cm^2
- beta-gamma exposure rate	< 0.5 0 mrem/hr at surface	

Source: Radiation Control, 1978

There was some potential for exposure to small amounts of unencapsulated thorium in SRL (773A and TNX), M area, and at 235-F where thorium was used as a stand-in, for sample analysis, and for testing of a doping agent for welding of heat sources. As discussed in Addendum 2 (NIOSH, 2011), and as guided by the SRS radiation and contamination control manuals (Radiation Control, 1959-1971; Radiation Control, 1978), Health Physics actively monitored locations where thorium operations were conducted during the period under review for that evaluation (January 1, 1953 through December 31, 1972). Health Physics continued to monitor workers and locations for radioactive contamination and exposures through 2007. NIOSH captured a sample of the contamination survey sheets from survey logs on file at SRS that were completed in areas with thorium inventory. A listing of surveys by location and year are provided in Table 7-2. SRS also surveyed spent fuel casks and operations routinely at 244-H; sample surveys have been obtained by NIOSH (Survey Logs, 1976; Cask Surveys, 1977; Radiation Surveys, 1977).

Table 7-2: Samples of Contamination Surveys Available by Location and Year		
Location	**Year**	**SRDB Ref ID**
M Area	1972	113925
M Area	1973	113836
M Area	1973	113934
M Area	1973	113956
235-F	1974	114646
M Area	1974	113920
235-F	1975	114644
773-A	1975	113930
M Area	1975	113920
M Area	1975	113922
773-A	1980	113886
773-A	1980	113985
773-A	1980	113986
TNX	1980	116641
773-A	1981	113960
773-A	1981	113863
773-A	1981	113987
773-A	1986	116776
773-A	1986	116778
773-A	1987	116774
773-A	1987	116778
TNX	1987	116681
TNX	1987	116681
773-A	1988	113978

SRS Health Physics maintained an air sampling program that used routine fixed-area samplers, portable samplers, and personal air samplers. Stationary continuous air monitoring systems (CAMs) were installed in many facilities to give warning of airborne radioactivity. The Kanne ionization chamber served to detect gaseous radioactivity while low-volume or high-volume CAMS provided early warning of increasing airborne particulate radioactivity. NIOSH captured some SRS air monitoring data for the period under evaluation to support the statement that routine, portable (special) and personal air sampling were performed. NIOSH captured a sample of the air monitoring data on file at SRS that were taken in areas with thorium inventory. While no specific thorium air monitoring data has been identified, a listing of air monitoring surveys by location and year are provided in Table 7-3. To prevent significant intake of radionuclides, and thus prevent internal radiation exposure, respiratory protection was frequently prescribed as a precautionary measure. Filter-type respirators used at SRS were NIOSH-approved. SRS required respiratory protection whenever the air concentration exceeded ten percent of the radioactivity concentration guide (RCG) based on air sampling data.

Table 7-3: Samples of Air Monitoring Surveys Available by Location and Year

Location	Year	Type	SRDB Ref ID
235-F	1972	Routine	114645
235-F	1972	Special	114645
244-F	1972	Routine	114712
235-F	1973	Routine	114647
235-F	1973	Special	114647
244-F	1973	Routine	114712
235-F	1974	Routine	114648
235-F	1974	Special	114648
244-F	1974	Routine	114712
235-F	1975	Routine	114643
235-F	1975	Special	114643
244-F	1975	Routine	114712
321-M	1975	Special	113971
244-F	1976	Routine	114712
244-F	1977	Routine	114712
773-A	1984	Routine	108690
773-A	1985	Routine	108643
773-A	1986	Routine	108626
773-A	1987	Routine	116652
773-A	1987	Routine	108585
773-A	1988	Routine	116652

In 1992, with the implementation of the *DOE Radiological Control Manual (1992)*, DOE N 5480.6, the SRS dosimetry requirement changed to "personnel dosimetry shall be required for personnel who are expected to receive an annual external whole body dose greater than 100 mrem" (Radiological Control, 1992). In addition, self-reading dosimeters were required anytime an individual worked in a field of 25 mR/hr or greater. NIOSH analyzed EEOICPA claimant data reported by DOE for SRS to determine the extent of both external and internal monitoring of claimants during the period from October 1972 through December 1998. Data for claimants who worked from October 1992 through December 1998 were included in the evaluation (22 claims). Twenty-one of the claimants were monitored by bioassay and for external dose by TLD, although some of the claimants were not monitored each year for external dose. Ten of the 22 claimants were monitored by TLD each year, 1972 through 1998. All claimants who self-reported having been construction workers were monitored for external and internal exposures during the years employed in a construction craft.

Examination of data for claimants with some missing periods of monitoring showed that they were likely not exposed to sustained radiation exposure at a rate greater than one mrem/hr, or intermittent exposures that would accumulate to greater than 25 mrem in one week. Nonetheless, NIOSH has collected all external dosimeter data on SRS co-workers in the HPAREH database. For the period 1973 through 1998, the number of workers monitored by TLD for at least one cycle (quarter) for the specified year is shown in Table 7-4. NIOSH has derived co-worker penetrating and shallow doses for unmonitored workers (ORAUT-OTIB-0023). With respect to internal radionuclide monitoring, NIOSH has obtained thousands of bioassay results from claimant records in NOCTS and from data obtained directly from SRS.

Table 7-4: Workers Monitored by TLD for at Least One Cycle (Quarter)

Year	No. Monitored	Year	No. Monitored
1973	3534	1986	10949
1974	3809	1987	11700
1975	4329	1988	12438
1976	4784	1989	13674
1977	5057	1990	11350
1978	5760	1991	19908
1979	6286	1992	18734
1980	6571	1993	16077
1981	6764	1994	12587
1982	6515	1995	12450
1983	7393	1996	11400
1984	7074	1997	11069
1985	8323	1998	10484

All personnel entering areas in which they would have received a sustained radiation exposure at a rate greater than one mrem/hr, or intermittent exposures that would accumulate to greater than 25 mrem in one week, were required to wear a thermoluminescent dosimeter (TLD) badge somewhere between the waist and neck line (Technical Standards, 1974). All regulated areas and radiation zones were included in that requirement. Furthermore, dosimeters were assigned through 1988 based on work area. NIOSH discussed this SRS monitoring tenet in Addendum 2 of the SRS ER (NIOSH, 2011).

NIOSH has assembled a depth of documents and data that demonstrate the effectiveness of the SRS Health Physics monitoring programs and the data that may be used for reconstructing doses received from external and internal exposures to most radionuclides used or stored at the site. A matrix of these data is presented in Table 7-5.

Table 7-5: Available SRS Health Physics Program Documentation and Data
(This table spans two pages)

Year	Health Physics Report SRS	Health Physics Report SRL	Personnel External Monitoring	Co-worker External Doses	Bioassay Monitoring Data	*In vivo* Data	Co-worker Internal Doses
1973	Yes	No	HPAREH	Yes	Claim files	Claim files	Yes
1974	Yes	No	HPAREH	Yes	Claim files	Claim files	Yes
1975	Yes	No	HPAREH	Yes	Claim files	Claim files	Yes
1976	Yes	No	HPAREH	Yes	Claim files	Claim files	Yes
1977	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1978	Yes	No	HPAREH	Yes	Claim files	Claim files	Yes
1979	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1980	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1981	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1982	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1983	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1984	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1985	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1986	No	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1987	No	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1988	Yes	Yes	HPAREH	Yes	Claim files	Claim files	Yes
1989	No	No	HPAREH	Yes	Claim files	Claim files	Yes
1990	No	No	HPAREH	Yes	Claim files	Claim files	Yes
1991	No	No	HPAREH	Yes	SRS data file	SRS data file	Yes
1992	No	No	HPAREH	Yes	SRS data file	SRS data file	Yes
1993	Yes	Yes	HPAREH	Yes	SRS data file	SRS data file	Yes
1994	No	No	HPAREH	Yes	SRS data file	SRS data file	Yes
1995	No	No	HPAREH	Yes	SRS data file	SRS data file	Yes
1996	No	No	HPAREH	Yes	SRS data file	SRS data file	Yes

Table 7-5: Available SRS Health Physics Program Documentation and Data
(This table spans two pages)

Year	Health Physics Report SRS	Health Physics Report SRL	Personnel External Monitoring	Co-worker External Doses	Bioassay Monitoring Data	*In vivo* Data	Co-worker Internal Doses
1997	No	No	HPAREH	Yes	SRS data file	SRS data file	Yes
1998	No	No	HPAREH	Yes	SRS data file	SRS data file	Yes

Bounding Thorium Doses Using Trivalent Bioassay Data (1973 – 1994)

For the purpose of NIOSH's evaluation of the SRS class in this report, bioassay data were analyzed by year or multi-year span, depending on the amount of data available for each radionuclide during a given period as well as the expected biokinetics of each radionuclide. A lognormal distribution was assumed. After the data were log-transformed, the 50th and 84th percentiles were determined for each period using the method described in ORAUT-OTIB-0019. "Zero" bioassay results, which represent a large fraction of the data for every radionuclide, were also retained in the analysis to rank the results from lowest to highest.

ORAUT-OTIB-0075 presents the method of treating a claimant dataset as a simple random sample from the population of all monitored workers. One potential conundrum posed by using a claimant dataset is that workers involved in incidents usually submit more samples than workers who submit only routine (non-incident-related) samples. This is problematic because a small number of workers involved in incidents can dominate the claimant sample in a given year through the sheer number of samples submitted and because the samples in the dataset are no longer independent of each other. At SRS, the small population of workers subject to bioassay testing results in a similar problem. To compensate for the unequal number of samples submitted by workers, the "one person, one sample" (OPOS) technique is used, in which only one result is used for each person for each radionuclide for a given year. The OPOS statistic is calculated using the maximum possible mean methodology (ORAUT-RPRT-0053).

Bioassay techniques for americium, curium, and californium varied as a function of time at SRS. Of the techniques used, the most significant feature is that differentiation among americium, curium, and californium was not possible until the use of alpha spectroscopy began in 1995. Before 1995, regardless of the notation placed in an individual's bioassay record, the analytical technique was the same. As discussed in Section 7.1.1.8, the analytical procedure in use for americium, curium, and californium would also extract thorium, and any thorium in the urine sample would be included in the reported result. Therefore, the actinide results are assessed four separate times, once each for americium, curium, californium, and thorium. The nuclide resulting in the largest dose can be used to bound a given case. Beginning in 1995, isotopic analysis in the form of alpha spectrometry was performed on the urine samples and thorium was not specifically monitored; therefore, this dose reconstruction approach based on bioassay data cannot be used to bound thorium intakes beyond 1994.

Statistical analysis of the trivalent dataset was performed in accordance with ORAUT-RPRT-0053 to obtain geometric means of the bioassay excretion results for each year. The All Monitored Workers (AMW) dataset discussed in Section 3 of ORAUT-RPRT-0053 was used for thorium determination through 1989 but the same analysis was applied to all data through 1994. Results for thorium were considered equal to the trivalent bioassay results. These geometric means were then used to model a chronic intake of Th-232 from 1973 through 1994 using IMBA Expert-ORAU. The source data are given in Table 7-6. Each bioassay geometric mean was considered to have been collected on July 1 of the respective year.

Table 7-6: Annual Thorium Bioassay Results

Year	GM (dpm/day)	GSD	Date
1973	8.19E-03	7.78E+00	7/1/1973
1974	9.32E-03	1.03E+01	7/1/1974
1975	1.02E-02	7.38E+00	7/1/1975
1976	1.30E-02	6.27E+00	7/1/1976
1977	3.73E-03	1.12E+01	7/1/1977
1978	2.58E-02	9.96E+00	7/1/1978
1979	2.49E-02	1.09E+01	7/1/1979
1980	9.55E-03	7.36E+00	7/1/1980
1981	2.84E-03	5.48E+00	7/1/1981
1982	2.08E-03	3.91E+00	7/1/1982
1983	5.39E-03	8.39E+00	7/1/1983
1984	6.25E-03	1.10E+01	7/1/1984
1985	1.19E-02	1.01E+01	7/1/1985
1986	3.52E-03	1.14E+01	7/1/1986
1987	1.75E-02	5.05E+00	7/1/1987
1988	1.85E-02	7.65E+00	7/1/1988
1991	1.80E-02	3.16E+00	7/1/1991
1992	2.32E-02	2.62E+00	7/1/1992
1993	1.56E-02	4.15E+00	7/1/1993
1994	3.15E-02	3.02E+00	7/1/1994

Chronic intakes of 0.599 pCi/day (1.33 dpm/day) for Type M material and 8.06 pCi/day (17.89 dpm/day) for Type S material were derived from the fits of yearly bioassay. The NIOSH CADW tool was then used to estimate doses to lungs and to bone for a chronic intake from 1973 through 1994, with cancer diagnosis on December 31, 2007, as shown in Table 7-7. Equal activities of Th-228 and Ra-228 were used in the dose modeling, with each assigned to the same material type as that of Th-232. With Type M material, the larger dose over this 34-year period would be delivered to the bone (19.09 rem). For Type S material, the largest dose would be delivered to the lung (72.18 rem).

Table 7-7: Estimated Organ Dose from Thorium (Intake: 1973-1994)		
Material Type	**Lung Dose (rem)**	**Bone Dose (rem)**
Type M	2.60	18.66
Type S	79.92	23.34

Bounding Thorium Doses Using Chest Count Data (1995 – 2007)

The NIOSH approach for bounding post-1994 thorium dose at SRS employs the use of chest count data. In 2000, a chest-count MDA of 0.15 nCi was given for Th-232 (Pb-212 in equilibrium with Th-232) and an MDA of 3.2 nCi was given for the 84.4 keV peak of Th-228 (Internal Dosimetry, 2001). Although this information was given for the year 2000, the same chest-counting system had been used since 1990. Therefore, the MDA information applies to the post-1994 years for this bounding analysis. Using the Th-232 peak region to derive an intake of Th-232 assumes secular equilibrium of Th-232 with all progeny. Information given in Table 5-1 shows that the last thorium separation was performed in1969. Any remaining thorium would have been in equilibrium by 1995 (Th-228 reaches equilibrium with its progeny in less than one year).

NIOSH applied this approach of assumed equilibrium by using the Pb-212 MDA to derive an intake rate for Th-232 for the period from January 1, 1995 through December 31, 2007. Corrections for chest wall thickness would not be significant for the gamma energies associated with Pb-212 and Th-228. NIOSH used IMBA to calculate a chronic intake rate for Th-232 assuming a chest count measurement obtained on December 31, 2007 with a result of 0.15 nCi. The data were modeled for both Type M and Type S materials. The derived chronic intake rate for 1995 through 2007 was 22.67 pCi/day for Type M and 3.18 pCi/day for Type S. The NIOSH CADW tool was then used to estimate doses to lungs and to bone for a chronic intake from 1995 through 2007 with a cancer diagnosis on December 31, 2007, as shown in Table 7-8. Equal activities of Th-228 and Ra-228 were used in the dose modeling.

Table 7-8: Estimated Organ Dose from Thorium (1995-2007)		
Material Type	**Lung Dose (rem)**	**Bone Dose (rem)**
Type M	56.94	174.3
Type S	15.40	1.75

Feasibility of Bounding Thorium Doses

As demonstrated in this Addendum 3, SRS implemented a thorough radiological safety program that managed hazards from an array of radionuclides. NIOSH has shown that SRS thorium inventories were much smaller than inventories of other radionuclides. Nonetheless, SRS Health Physics did incorporate monitoring capabilities that would detect thorium for use as needed (e.g., when decontamination activities warranted). NIOSH concludes that doses received from potential thorium exposures can be bounded using *in vitro* and *in vivo* bioassay data and the reconstruction methods presented in this section. Based on its analysis, NIOSH believes these methods and approaches support its ability to provide sufficiently accurate internal thorium dose reconstructions for SRS workers during the evaluated period.

NIOSH would assign monitored and unmonitored dose to SRS workers using a combination of available monitoring data and analysis of the trivalent actinide bioassay data for 1973 through 1994. Because the analytical method would have included americium, curium, californium, and thorium, the nuclide resulting in the largest dose can be assigned to bound the internal dose. The application of this method for unmonitored workers for this period would be applied to SRS workers who had the potential for exposures to thorium.

For 1995 through 2007, chest-count data would be used to support bounding thorium dose. Based on its analysis of the available radiological program documentation, NIOSH has concluded that by that point in the SRS bioassay monitoring program, those who should have been monitored were monitored. Therefore, the dose for personnel who have confirmed work in thorium areas or exposure to thorium can be bounded by assigning thorium internal doses based on any positive chest-count data and assigning missed internal thorium dose as discussed in this ER (i.e., using existing dose reconstruction methods). The dose for those personnel who may have worked in a thorium area or may have been exposed to thorium can be bounded by assigning missed internal thorium dose, as discussed in this ER as unmonitored dose.

7.6 Summary of Feasibility Findings for Petition SEC-00103

This report addendum evaluates the feasibility for completing dose reconstructions for employees at the Savannah River Site from October 1, 1972 through December 31, 2007. NIOSH found that the available monitoring records, process descriptions and source term data available are sufficient to complete dose reconstructions for the evaluated class of employees.

Table 7-9 summarizes the results of the feasibility findings at the Savannah River Site for each exposure source during the time period October 1, 1972 through December 31, 2007.

Table 7-9: Summary of Feasibility Findings for SEC-00103
October 1, 1972 through December 31, 2007

Source of Exposure	Reconstruction Feasible	Reconstruction Not Feasible
Internal	**X**	
- Th	X	
External	**X**	
- Gamma	X	
- Beta	X	
- Neutron	X	
- Occupational Medical X-ray	X	

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.

NIOSH's evaluation determined that it is feasible to estimate radiation dose for members of the NIOSH-evaluated class with sufficient accuracy based on the sum of information available from available resources. Therefore, a health endangerment determination is not required.

9.0 Class Conclusion for Petition SEC-00103

Based on its full research of the class under evaluation, NIOSH found no part of said class for which it cannot estimate radiation doses with sufficient accuracy. This class includes all workers who worked in any thorium area at the Savannah River Site from October 1, 1972 through December 31, 2007.

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.

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