Table 5-5 summarizes the respective neutron energy categories used by EEOICPA in accordance with the *External Dose Reconstruction Implementation Guideline* (OCAS-IG-001) applied to Mound site workplaces by facility and operation. (ORAUT-TKBS-0016-6)

Table 5-5: Neutron Energy by Facility and Operation

Facility	Operation	Period	IREP Energy Category (MeV)	Percentage
PP Building: Waste Handling area	Th-232 storage and re-drumming	1955-1975	0.1 – 2.0 2.0 - 20	75 25
R Building: R 117	Storage Vault	1949-1990	0.1 – 2.0 2.0 - 20	50 50
SW Building: SW 8	Xe isotope separation	1957-1960	0.1 – 2.0 2.0 - 20	50 50
SW 11-14 & 16 (area 1B)	Decon of $BiSO_4$ Pa-231 purification	1951-1953 1956		
SW 19 (Old Cave)	Radium-actinium separation	1951-1953		
SW 140 (New Cave), 132, 136, 137	Processing residue from pitchblende production	1970-1979		
SW 146-147	Metallurgy laboratory	1967-1985		
SW 219	Neutron source production	1962-1965		
T Building: All but T 43, 44, 48, 50-51, 57-59, 348-359	Po neutron source program	1949-1973	0.1 – 2.0 2.0 - 20	25 75

5.4.4 Photons

Photon sources were present in almost all Mound facilities. Most Mound facilities had mixed fields of neutrons, beta, and photons. The beta field is a lesser concern for many Mound workplaces with respect to external radiation protection because the shielding around the glovebox or process shielding is thicker than the maximum beta range. The energy spectrum was dependent on the particular on-going operation. Table 5-6 summarizes the respective IREP input photon energy category by facility and operation (ORAUT-TKBS-0016-6).

Table 5-6: Photon Energy by Facility and Operation

Facility	Operation	Period	Energy (keV)	Percentage
HH Building:				
HH 3, 4, 5, 8	Separation of He-3; Kr-85	1960-1995	30-250 >250	50 50
HH 5, 6	Pa-231/sludge separation	1955-1956		
HH 8, 10-12	Hydrolysis of Al and Bi chlorides	1949-1958		
PP Building: Waste Handling area	Th-232 storage and re-drumming	1955-1975	30-250 >250	75 25
R Building: R-117	Storage Vault	1949-1990	30-250 >250	50 50
SW Building:				
SW 8	Xe isotope separation	1957-1960	30-250 >250	50 50
SW 11-14 & 16 (area 1B)	Decontamination of $BiSO_4$ Pa-231 purification	1951-1953 1956		
SW 19 (Old Cave)	Radium-actinium separation	1951-1953		
SW 140 (New Cave), 132, 136, 137	Processing residue from pitchblende production	1970-1979		
SW 146-147	Metallurgy laboratory	1967-1985		
SW 219	Neutron source production	1962-1965		
T Building: All but T43, 44, 48, 50-51, 57-59, 348-359	Po neutron source program	1949-1973	30-250 >250	50 50
H Building	Hot laundry	unknown	30-250 >250	25 75
WD Building:				
WD 1, 8, 101, 104	Wastewater treatment	1949-1990	30-250 >250	50 50
WD 107	Ultra-filtration	1976-1981		
WD 112, 113	Analytical work	1966-1979		
WD 113, 118 A&B	Storage, waste incineration	1979-1994		
WD Penthouse	Filter banks	1949-1993		
B Building	Internal dose research	1950-1955	30-250 >250	25 75

5.4.5 Incidents

Documentation of incidents is typically limited to reports of elevated urine activity or specific information describing the exposure scenarios. Based on information NIOSH reviewed, area access controls (e.g., designated/isolated work areas, gloves, vented fume hoods, and glove boxes), personnel protective equipment, and engineering controls were used to limit worker exposure.

Incident reports are available through the Corrective Action Reporting System (CARS). The DOE also had an accident reporting system, known as the DOE Occurrence Reporting System (ORPS). An Energy Employee's (EE's) dose from an incident is expected to be included in the individual dose record provided by the site. If the EE (monitored or unmonitored) states that he/she was involved in an incident(s) in a telephone interview and there are no records in the claim file, an additional data request is made to Mound to attempt to verify the verbal information.

6.0 Summary of Available Monitoring Data for the Proposed Class

Radiation protection was a major concern at Mound from the beginning of operations. Initial Mound external and internal radiation monitoring and protection programs were implemented when work with radioactive materials was undertaken (Meyer, 1992). As at other DOE sites, advances in monitoring knowledge and assay skills led to monitoring improvements and expansion of the scope of Mound worker monitoring.

The primary sources of monitoring data for this evaluation include the NIOSH Site Research Database (SRDB), the NIOSH OCAS Claims Tracking System (NOCTS), logbooks and forms located during data capture events at Mound, and three Mound databases. The Mound databases are designated as the Polonium Reconstruction (PORECON) database, the Plutonium Reconstruction (PURECON) database, and the Mound Environmental, Safety, and Health system (MESH). Two additional databases, the "Data Base of Excretion Data of Other Radionuclides" (ORAU 2003e) and the "Database of Ra-Ac-Th Excretion Data" (ORAU 2003d) have been compiled in part from non-plutonium data found in the PURECON database and from logbooks, cards, and forms reviewed during the Pre-1989 Dose Assessment Project. These latter two databases and the PURECON and PORECON databases contain only internal monitoring data.

Additional data that are available include specific process information regarding Mound operations, including radionuclides and proportions in process systems for some years. These are currently available in the form of progress reports on research activities through 1951, in 1952 and 1953, and from late 1960 onward. Individual reports document specific processes, such as *Bismuth Recovery Process, Engineering Research Final Report* (Bismuth, 1952).

Personnel dose monitoring data are also available in periodic health physics reports, which include summaries of external dose monitoring that state the number of dosimeters processed and the relative doses received. These data are not sufficient to assign individual doses, but do allow assignment of maximum doses when individual doses cannot be reconstructed more precisely based on other records. These data are available for the years 1948 to 1954; additional partial data are available for 1955 through 1959. In this same category are complete records of air monitoring data for some buildings in some years (e.g., R and T Buildings in 1949). This information allows calculation of air concentrations in specific rooms, and overestimated internal doses may be calculated from these values when individual bioassay data are unavailable or unusable. Air concentration data are also summarized in periodic health physics reports. Though these are not useful for assigning individual doses, they do allow estimation of maximum doses.

Some qualitative information in the reports is useful to ensure that health physics practices are modified to take changing source terms into account. Incidents and activities are also described. Quantitative data on the number of wipe surveys performed, the number of air samples taken, by area and room, support the correlation of air sample results with specific potential source terms.

6.1 Mound Internal Monitoring Data

Summaries of the available *in vitro* and *in vivo* data, as well as general overviews of sampling and analytical protocols, are provided in the following subsections. Additional details, including analytical methods, detectable activities, and reporting protocols can be found in the Mound Occupational Internal Dosimetry TBD (ORAUT-TKBS-0016-5) and in the *History of Mound Bioassay Programs* (Meyer, 1992).

As noted in ORAUT-TKBS-0016-5, radionuclides were categorized by Mound staff as either primary or secondary based on the potential extent of use and the amount of bioassay data available. Primary radionuclides of concern are discussed in Mound internal dosimetry documentation, the *History of Mound Bioassay Programs* (Meyer, 1992), and *Mound Site Radionuclides by Location* (King, 1995).

Primary radionuclides assessed for occupational internal exposure included:

- Po-210
- Plutonium Isotopes: Pu-238, Pu-239*
- Tritium

* Because Pu-240, Pu-241, and Pu-242 do not comprise a dosimetrically-significant proportion of the major plutonium source terms, NIOSH has chosen not to include these in its discussion.

The above radionuclides were identified as primary because they were present in larger quantities and were more widespread at the site, often in multiple buildings and facility processes. Correspondingly, more monitoring data and site documentation are available (than for secondary radionuclides) to evaluate internal doses associated with these radionuclides. Primary on-site operations used all of these radionuclides in conducting key mission activities.

Secondary radionuclides include those that were of limited use at the site or involved limited worker exposures. Often referred to as “other” radionuclides in Mound documents, they were part of smaller programs involving relatively few people. Many of the programs were relatively short-term research projects and brief production runs, and source material was received intermittently (MJW, 2002, Phase II, Appendix C). Fewer internal dosimetry data are available for these radionuclides than for the primary radionuclides. Available data for secondary radionuclides were collected from several sources during the Pre-1989 Dose Assessment Project and combined into two Excel spreadsheets: *Database of Ra-Ac-Th Excretion Data* (ORAU 2003d) and the *Database for Other Radionuclides*

(ORAU 2003e). Data sources included logbooks, cards, and non-plutonium data extracted from the PURECON database.

In addition to daughter products from the uranium and thorium decay chains, secondary radionuclides included:

- Americium-241
- Curium-244
- Uranium Isotopes: U-238, U-235, U-234, U-233
- Thorium Isotopes: Th-232, Th-230, Th-228
- Actinium-227
- Radium Isotopes: Ra-228, Ra-226, Ra-224, Ra-223
- Radon Isotopes: Rn-222, Rn-220, Rn-219
- Protactinium-231

Mound also engaged in biomedical research using Calcium-45, Iron-59, Cobalt-60, Zinc-65 and other radionuclides. The quantities were minor compared to the primary and secondary radionuclides, and they were used in very few buildings for limited periods. Most of these radionuclides were present as sealed sources. Worker exposure was less likely, and bioassay data were not collected.

Mound bioassay included primarily *in vitro* urine data and limited fecal sample results. *In vitro* urine data are the primary source of information to support dose reconstruction. Fecal analyses, *in vivo* chest counting, and air sampling information are considered of limited use due to limited availability (ORAUT-TKBS-0016-5). Additionally, these latter data are not kept in a central electronic database, but rather are maintained as hard-copy records, usually associated with an individual worker's file. Fecal monitoring results from 1990 onward are available from MESH; 29 fecal results associated with eleven people sampled between 1966 and 1982 are in the PURECON database. Derived air concentration (DAC) data are available electronically from 2000 onward, but all other air monitoring data are on hardcopy. *In vivo* data are only available on hardcopy.

Various bioassay programs were conducted at Mound from 1945 to the present using routine urine samples collected from workers (Meyer, 1992). Table 6-1 lists primary bioassay programs with reported radionuclide action levels for a urine sample in counts per minute, workers who were monitored, and frequency of monitoring.

Table 6-1: Bioassay Programs and Action Levels				
Bioassay program	**Period**	**Action levels[a]**	**Monitored workers**	**Frequency**
In vitro monitoring				
Po-210 (Postum) recovery	1945-1974	10 cpm 50 ml^{-1}	Operations personnel	Weekly 24 hr to Monthly
Ac-227, Ra-226, Th-228	1951-1960	8.3 cpm 24 hr^{-1}	Research personnel	Weekly 24 hr
Th-232 sludge, re-drumming	1955-1975	2.8 cpm 24 hr^{-1}	Th Refinery personnel	Monthly 24 hr
Th-230 (Ionium) research	1956-1959	3.5 cpm 24 hr^{-1}	Research personnel	Bi-Weekly 24 hr
Pa-231 extraction	1956-1960	2.2 cpm 24 hr^{-1}	Research personnel	Monthly 24 hr
U-233 research	1958-1960	20 cpm 1,500 ml^{-1}	10 Research personnel	Weekly 24 hr
Tritium (hot gas) production	1957 to plant closure	10 µCi L^{-1}	Recovery personnel	Weekly Spots Weekly 24 hr
Pu-239 neutron source	1957 to plant closure	3.5 cpm 24 hr^{-1}	Processing personnel	Weekly 24 hr to annually
Pu-238 heat source	1960 to plant closure	3.5 cpm 24 hr^{-1}	Processing personnel	Weekly 24 hr to annually
Am-241 & Am-243	1983 to plant closure	0.0 pCi/d [b]	Potentially exposed personnel	As needed
Cm-244	1983 to plant closure	0.0 pCi/d [b]	Potentially exposed personnel	As needed
In vivo monitoring				
Whole body counting	1960-1970	Not Available	Operations personnel	Annual
Chest counting	1983 to plant closure	Variable[c]	Operations personnel	Annual

a. AL = action levels; observed counts per minute for 50 ml or 24-hour samples that result in a worker dose of 300 mrem/wk to the target organ.
b. Smallest reported activity in database.
c. Chest counting MDAs reported in the Mound TBD, Table 5-19 for Am, Pu, Th, and U isotopes. MDAs range from 0,1 nCi for Am-241 to 130 nCi for Pu-239.

Routine bioassay monitoring included collection of spot and 24-hr urine samples, as identified in Table 6-1. For example, only those workers conducting research to separate and purify protactinium were monitored monthly for Pa-231. Twenty-four hour samples were also requested for Po-210 and the plutonium isotopes, typically as a follow-up to a potential intake. Monitoring frequencies were inferred from personnel sampling records.

Individuals identified as being involved in an internal exposure incident, or who had urinalysis results in excess of the reporting limits, were required to submit additional 24-hr urine samples for analysis. Administrative personnel were not monitored and monitoring was discontinued for operational personnel if their work on a specific project was no longer needed. Operational personnel were monitored annually by whole-body or chest counting, or if there was a suspected exposure incident.

Mound used the action levels in Table 6-1 to evaluate and control worker doses to a 300 mrem/week target organ dose limit. Results in excess of action levels triggered re-sampling and placement of the worker on the “hot roster” to control further exposures, if necessary. Typical dosimetry controls were in place by 1949 when Mound operations were moved from the Dayton facility. These controls followed the limits stated in the *National Bureau of Standards Handbook 52* (NBS, 1953).

Gross alpha analyses were conducted at Mound, and until 1980, activity was assigned to specific isotopes of plutonium and other alpha emitters based on sequential gross alpha counting or chemical separation followed by gross alpha counting. Alpha spectrometry capable of identifying specific alpha-emitting isotopes was not introduced until 1980.

Individual radium bioassay samples were counted three times in a low-background proportional counter over a period of weeks. The individual radium isotope activities were then estimated by solving a system of simultaneous equations. This procedure requires equilibrium assumptions to properly infer activity associated with individual decay chain radionuclides. For example, sequential gross alpha counting was conducted on bioassay urine samples following radium extraction by co-precipitation to quantify Ra-223, Ra-224, and Ra-226 activity. Evaluation of alpha activity with decay time allowed the activities of individual radium isotopes to be estimated.

6.1.1 Tritium Bioassay

Tritium urinalysis for workers started in 1957. In 1958, an analytical method using a vibrating Reed Electrometer was officially adopted from a Savannah River Plant procedure and continued to be used into the early 1960s. Liquid scintillation counting began in 1961. Tritium results were always reported in units of activity per liter of urine.

Available tritium data are contained within the MESH database. Data from 1957 through 1981 (over 30,000 records) are in the form of annual dose summaries for workers. The remaining employee records (~ 250,000) span from 1981 through January 2006 and include bioassay results.

6.1.2 Polonium-210 Bioassay

All Mound employees working in polonium operations in T, HH, WD, H, B, and R Buildings were required to submit weekly spot urine samples (Meyer 1992). Samples were usually collected on Monday and Wednesday, or on Monday, Wednesday, and Friday. Po-210 bioassay data were documented on several different types of records at Mound (Meyer, 1992; Spitz, 1989). Weekly reports of urinalysis data were kept for workers; they were grouped by location with entries in cpm per specified volume and with 24-hr samples identified. Weekly results were transcribed onto Polonium Cards for individual workers with entries in cpm/50-ml unless otherwise stated. Twenty-four Hour Reports were also kept and used to convert individual 50-ml spot samples collected on a single day to a volume-weighted average 24-hr excretion in cpm. Finally, Special and Unscheduled Sample Forms were kept when any additional urine samples were required to document possible worker exposures, or to confirm previous results, with all entries in cpm and duplicate sampling indicated.

Bioassay data for Po-210 have been placed in the PORECON database by MJW by evaluating individual dosimetry files from original logbooks and data cards during their work on the Pre-1989 Dose Assessment Project (MJW, 2002, Phase I; MJW, 2002, Phase II). This database contains 207,750 individual sample results spanning from 1944 to 1973. Bioassay results are reported as Bq/d, cpm, and dpm in this database.

A summary of the number of records/year applicable to the proposed class time frame is presented in Table 6-2.

Table 6-2: PORECON Polonium Record Summary

Year	**1949**	**1950**	**1951**	**1952**	**1953**	**1954**	**1955**	**1956**	**1957**	**1958**	**1959**	**1960**	**1961**
Records	16,550	18,064	17,332	18,360	10,957	2,638	1,787	1,752	2,309	2,754	3,219	5,124	6,472
Year	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	
Records	7,743	7,890	8,343	7,090	6,659	7,526	6,444	3,194	1,043	353	74	31	

6.1.3 Plutonium-238 and Plutonium-239

Bioassay of the plutonium isotopes at Mound underwent considerable change and improvement with the development of specific methodologies to isolate and count Pu-238 and Pu-239. The various methodologies are discussed in the Mound Occupational Internal Dosimetry TBD (ORAUT-TKBS-0016-5); however the major features of the internal dose monitoring program for plutonium are summarized in Table 6-3 below.

Table 6-3: Summary of Historical Plutonium Analytical Procedures

Period	**Reporting level**[a]	**Analytical method**
1954–1960	(Kirby, 1954) 0.05 dpm 1.5 L^{-1} 0.5 dpm 1.5 L^{-1}(Corrected DL)[b]	Alkaline earth phosphate co-precipitation; plutonium separation with cerium carrier; gross alpha for plutonium; proportional counting; recoveries 6-85% due to colloidal plating of metabolized Pu.
1961–1967	(Kirby, 1954) 0.1 dpm 1.5 L^{-1}	Sample acidification; alkaline earth phosphate co-precipitation; plutonium separation with cerium carrier; gross alpha for plutonium; proportional counting; recoveries 90 ± 3%. Uranium and plutonium results reported separately only in 1966 using anion exchange methods.
1968–1977	MD-20736 (Mound 1963) 0.1 dpm 1.5 L^{-1}	Alkaline earth phosphate co-precipitation; plutonium separation with cerium carrier; anion exchange; electro-deposition; gross alpha reported for plutonium; proportional counting.
1978–1979	MD-80030 (Mound 1981) 0.1 dpm 1.5 L^{-1}	Alkaline earth phosphate co-precipitation; plutonium separation with cerium carrier; anion exchange; electro-deposition; alpha spectroscopy for Pu-238 and Pu-239/240; Pu-242 tracer.
1980–present	MD-80030 (Mound 1981) 0.07 dpm 1.5 L^{-1} for routine samples	Alpha spectroscopy for Pu-238 and Pu-239/240; anion exchange; Pu-242 tracer; blanks counted for decision level determination.

a. The 24-hr reporting levels are based on a standard sample volume of 1.5 L. Standard man in ICRP Publication 2 (ICRP, 1959) and Reference Man in ICRP Publication 23 (ICRP, 1975) both have a urine volume of 1.4 L. Actual collected urine volumes will vary.
b. Detection limit was corrected for a low chemical recovery of 10% due to colloidal plating of plutonium.

Plutonium data are now readily available from the PURECON database. The PURECON database was established in 1991 by work performed by the University of Lowell Research Foundation. This work was undertaken to meet the requirements of DOE Order 5480.11, *Radiation Protection for Occupational Workers* (DOE, 1988), which became effective on January 1, 1989. In brief, Mound staff recognized that it needed to develop more reliable internal dosimetry record-keeping for plutonium; this resulted in the construction of a computer database from the original raw data. Subsequent QA/QC and repair work on the PURECON database has been performed (and documented) by MJW during its work on the Pre-1989 Dose Assessment Project (MJW 2002, Phase I; MJW, 2002, Phase II).

A summary of the number of records/year applicable to the proposed class time frame is presented in Table 6-4.

Table 6-4: PURECON Plutonium Record Summary

Year	**1956**	**1957**	**1958**	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**
Records	78	95	81	98	343	808	1,454	2,267	2,797	3,632	11	3,718
Year	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**
Records	3,299	2,699	2,642	2,384	2,804	2,312	2,093	1,573	1,160	1,322	1,365	1,238
Year	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
Records	1,227	1,250	1,276	1,380	1,388	1,422	1,318	939	926	1,112	1,562	1

6.1.4 Radon Isotopes

Sources of radon (Rn-222), thoron (Rn-220), and actinon (Rn-219) were present at Mound due to radium and thorium processing and separation of Pa-231 and Ac-227. Thorium sludge from Th-232 extraction and purification operations was stored outside in drums from 1954 to 1966. In 1966, thorium sludge stored in individual drums was transferred to storage basins in Building 21. The thorium was re-drummed and removed from Mound in 1974 and 1975. In 1975, 1,258 drums of Cotter Concentrate were stored to support purification of Pa-231 and Th-230. Table 6-5 shows the results of various radon surveys at Mound.

Table 6-5: Radon Isotope Survey Data by Building and Period						
Building	Survey dates	Gas concentration (pCi/l)			WL	WLM yr^{-1} (a)
		Radon	Thoron	Actinon		
SW Tunnel	10/12/79	88,000	28,000	640,000		
SW19 before vent	6/79-10/79	67-160				
SW19 after vent	3/80-4/80	7.7-13.4			0.03	0.4
	12/89	2.6	Not Detected			
	12/99	**1.0-5.8**[b]				
	4/00	**0.7-7.2**				
	1998-2000	5.8-12				
SW21	5/83	17.5-52.8				
	12/89	**34-118**		0.3-0.7	0.4-1.3 0.85 median	4.7-15.3 10.0 median
	4/90-6/90	117-161				
		125				
SW22	6/90	**125**				
SW48	12/89	3.2				
Old SD	12/89	1.5-2.4				
Fire station	12/89	1.2-1.4				
Paint shop	12/89	0.9-1.2				
A	10/88-2/89	**0.1-1.1**				
All other buildings	12/89	4 0.4-0.9				
Outside facilities	5/83	0.24-0.59				
Reported background		0.1 to 2.1 Average = 0.5				

a. Working level months per year (WLM yr^{-1}) were determined as WL (2000 hr yr^{-1}) (1/ 170 hr WLM^{-1}).
b. Bolded concentrations were derived from charcoal canister measurements.

The following radionuclide-specific program and internal data availability information was initially collected during work performed for the Pre-1989 Dose Reconstruction Project. Unless noted otherwise, the source first summarizing the information presented below is the *"Other" Radionuclides Position Paper* contained within the Phase II final Report (MJW, 2002, Phase II). Available bioassay data for the following radionuclides have been compiled into Excel spreadsheets titled *Database of Excretion Data of Other Radionuclides* (ORAU 2003d) and the *Database of Ra-Ac-Th Excretion Data* (ORAU 2003e).

6.1.5 Protactinium-231

Programs involving the recovery and purification of Pa-231 began in the early 1950s and continued intermittently to September 1979. The initial campaign ran from August 1954 through October 1958 and used a Mallinckrodt raffinate known as "Sperry Cake" as a feed material. Later efforts to recover Pa-231 used another type of residue from the uranium refining process called Cotter Cake. This material had been identified as a useful source of radionuclides during research associated with the Ionium (Th-230) program. One thousand, two-hundred-fifty-one drums of this material were received during 1975 for processing in the pilot plant built in the SW building. This plant ran from 1974 to 1979, during which 22 drums were processed to recover 339 g of Th-230 and 890 mg of protactinium.

The bioassay program to support the recovery/purification process of protactinium began in August 1955 (Meyer, 1992). The samples were subjected to various precipitation and dissolution procedures to extract radium, thorium and protactinium fractions (Kirby, 1952; Kirby, 1954; Kirby, 1959). The available protactinium data were found in a historical file within a notebook during the Pre-1989 Dose Reconstruction Project and are now compiled in the *Data Base of Excretion Data of Other Radionuclides* (ORAU 2003e).

6.1.6 Thorium-230

The bioassay program for Th-230 ran from March 1956 through September 1958. Initially, 24-hour urine samples were collected, thorium separation was performed, and the thorium fraction was analyzed. It appears that this process did not provide the desired results and, after about 10 samples (about mid-May 1956), the procedure was changed to a “radium separation.” It was most likely assumed that Ra-226 was in equilibrium with its parent Th-230; thus, all counts would be considered ionium counts.

Primary Th-230 bioassay records consisted of a log book and duplicate records in a brown notebook (ORAUT-TKBS-0016-5). Secondary Th-230 results included a form (Form 0-634) and then began as weekly reports on March 17, 1958. Weekly reports included Name, Isotope, and Result. Results reported on Form O-634 included: Name, Badge Number, Date, Type of Analysis, Isotope, and Result (MJW, 2002, Phase I). The *Database of Ra-Ac-Th Excretion Data* now serves as the repository for these data (ORAU, 2003d).

6.1.7 Thorium-232

The Thorium-232 Refining Program was a process intended to produce thorium salts. These salts were to be produced in a newly-constructed refinery and used to produce metallic thorium for the thorium fuel cycle of the breeder reactor. The research and development for the refining process, known as the Monex Process, was done in the R Building. The directive to construct the required refinery was issued in March 1955, but construction was canceled in May of the same year. Research work on the pilot plant continued and was completed in July 1955.

Although a small number of samples were processed between 1951 and 1954, the primary urinalysis sampling to support Th-232 refining and subsequent re-drumming of source materials began in August 1955 and continued until November 1959.

Approximately 170 samples are available for Th-232 in the years between 1960 and 1967. A total of 25 samples are available from the years 1972, 1978, and 1979 (combined). Bioassay records indicate that urine samples from persons involved in the Thorium-232 Program were analyzed for both radium and thorium. The thorium is assumed to be Th-232, Th-228, and Th-230.

6.1.8 Substitute Materials, Radium-226, Actinium-227, and Thorium-228 Records

As part of the Substitute Materials Program, a search was undertaken for other alpha-emitting isotopes with neutron-generating efficiency comparable to Po-210. Ac-227 was selected as a possible replacement for Po-210 for initiator production. This program involved the separation of Ac-227 from neutron-irradiated Ra-226.

Between June and October 1954, almost 48 g of radium had been processed and canned. This work resulted in 47.5 Ci of Ra-226, 14.9 Ci of Ac-227, and 24.6 Ci of Th-228 being purified by the end of the year.

Urine analysis techniques were developed to support the processing of neutron-irradiated Ra-226 in the SW Building. According to the *History of Mound Bioassay Programs* (Meyer, 1992), preliminary work for analyzing urine samples containing Ra-226, Ac-227, and Th-228 was completed in 1952. A few urine samples were analyzed in 1951 and 1952 as part of the research work for the program. Several cases of personnel exposure were detected by routine urinalysis in December 1952. Results of these 1952 samples do not appear to be in any logbooks, nor could data sheets be found. At the time, urine samples were being analyzed by a simple procedure for radium only.

Differential decay analyses indicated that in addition to the radium, varying amounts of actinium and thorium were present in the samples; therefore, a new procedure was developed to determine their respective activities. To accomplish this, thorium and radium were chemically separated from the urine samples and the radium fraction was counted for total activity. Ra-223 is a decay product of Ac-227 via Fr-223 (1%) and Th-227 (99%). Ra-224 is a decay product of Th-228. Ra-223 and Ra-224 have short half-lives so they grow in relatively rapidly. Decay and in-growth curves were plotted and activities calculated using these curves. Samples were counted periodically for several weeks and simultaneous equations were then used to determine the activity of Ra-226, Ra-223, and Ra-224. The quantity of Ac-227 and Th-228 could then be inferred from the results.

According to the *History of Mound Bioassay Programs* (Meyer, 1992), sixteen people are listed as having participated in the program. However, a compilation of data during the Pre-1989 Dose Assessment Project shows approximately 120 people as having submitted urine samples for radium analysis. The last routine sample was processed in February 1959 when decontamination of the Cave Area was completed. A few more samples were analyzed between 1963 and 1967.

6.1.9 Uranium Records

Several isotopes of uranium have been used at various times throughout the history of Mound. The largest uranium program appears to have involved about ten people in limited research on U-233 during 1958 and 1959. This was most likely a part of the reactor fuels program. Urine sampling for this program began in July 1958 and ended July 1959. Over 130 bioassay results are available for this time period.

From 1962 to 1972, another program produced U-234 by chemically separating it from aged Pu-238 (Meyer, 1992). About 10 grams (6.2E-02 Ci) were produced annually; the U-234 that was produced was shipped as the oxide. There was no indication of a specific bioassay program associated with this work.

There was also a program involving U-233 beginning in 1966 and continuing into the mid-1970s (Meyer, 1992). In this program, 1.5 kg of aged U-233 were processed to obtain 30 mg of Th-229. However, the Annual Overview section of the Meyer document only indicates a bioassay program for uranium through 1966. Available uranium bioassay records are limited to 44 bioassay results from 1965-1966. Of these, five were specifically labeled as U-233 results.

A gross alpha procedure was used for analyzing the uranium content of spot urine samples. The majority of available uranium urine sample results do not indicate which isotope of uranium was suspected to be present. Spot samples were used for screening; 24-hour samples were collected when a more precise or definitive result was needed. An anion exchange procedure was used on the later samples.

6.1.10 Americium-241 and Curium-244

Documentation for Am-241 and Cm-244 is very limited. Primary records for Am-241 and Cm-244 are unknown. The available data were first discovered in (and extracted from) the PURECON database during the Pre-1989 Dose Assessment Project (MJW, 2002, Phase II). Seven bioassay results are available for Am-241 for one person in 1987. Thirty-eight Cm-244 results are available for six workers in 1983, and two results for an individual in 1986. All Am-241 and Cm-244 urinalysis data are in units of activity (pCi). The MJW Report (MJW, 2002, Phase II) assumed that Am-241 and Cm-244 data in Mound dosimetry records are in units of activity excreted per 24-hour period. From currently available records, it is unclear in which programs the monitored people were involved.

6.2 Mound External Monitoring Data

The following discussion provides a summary of the Mound site external dosimetry program as well as the types, quantity, and quality of data that can be used for external dose reconstruction. Details regarding the dosimeters used are presented in ORAUT-TKBS-0016-6. Additional information regarding the external dosimetry equipment, methodologies, and techniques in use during most of the proposed class time period is provided in the *History of Personnel External Dosimetry Program at the Dayton Project and Mound Laboratory 1946-1993* (Meyer, 1994).

In 1948, as initial operations were being planned for the newly-established Mound Laboratory, Mound's health physicists, employed by the Monsanto Chemical Company, consulted with their counterparts at the Oak Ridge National Laboratory concerning external dosimetry techniques that would be appropriate for continuing the Po-210 production operations previously conducted at locations in the Dayton area. A continuous external dose monitoring program began. This program developed policies and made programmatic corrections as necessary. Mound used a film badge external dosimetry monitoring system from 1946 to 1977. From 1977 to the present, Mound has used a TLD system. Records of radiation exposures from personnel dosimeters worn by workers and co-workers are available for all years of the proposed class time period. The MESH database serves as the primary electronic repository of these records. It contains all radiation doses measured for Mound employees from 1947 to 2005. Periodic health physics reports contain summaries of the number of dosimeters read for each period, and the number of results in each of several dose ranges. When individual doses cannot be reconstructed more precisely, maximum doses can be based on these reported results.

Individual dosimeter cycle results are not complete in that, at the end of 1977, the Mound dosimetry group was unable to recover any individual monitoring data for the previous years from the mainframe computer. A summary report was generated of the annual recorded doses of all monitored employees from 1947 through 1977 (Guido, 2003; Meyer, 1994, Volume III, 1973 Appendix 3, pp. 207-211). Individual dosimeter results survive in some employee claimant files for employees with early termination dates (before about 1960). Discovery efforts are on-going to retrieve the balance of individual employee cycle data.

Positive photon doses are present in the records for many workers from the beginning of Mound site operations, and neutron doses were first recorded in 1949.

Recorded beta doses are uncommon in Mound site records until approximately 1960. Data from Dayton Units III and IV did include some beta measurements. Photon exposures were based on the optical density of the monitoring film behind a shield (e.g., brass, Cd, Te, Ta) sufficient to block low-energy radiation, including beta particles; the optical density of the ‘unshielded’ or ‘open-window’ portion of the film could be used to estimate beta doses. However, early beta doses were not read and are not a part of employee records until at least January 1960 (Meyer, 1994, Volume I, p. 164). The reason for this lack of data is that beta dose rates were likely low in the T Building, which was specifically designed to isolate the process solutions. On December 1, 1965, technicians began to read the open-window portion of the film as well as the area behind the shield (and the sensitive and insensitive films as well) as part of the calibration procedure. The purpose of the additional measurements was to permit better evaluation of low-energy gamma photons (Meyer, 1994, Volume I, p. 310). Evaluation of the MESH database for beta results generally supports Meyer’s report of beta monitoring. Though a few results are noted for earlier dates, significant numbers of beta results are not noted until 1968.

Table 6-6 presents a summary of the available external monitoring records. To obtain a count of the minimum number of records believed to be beta-only measurements, the database was queried for the number of beta results that were greater than the recorded deep dose. This resultant yearly count has been included in Table 6-6.

Table 6-6: Summary of External Monitoring Data in the MESH Database
(Table 6-6 spans two pages)

Year	Number of Workers Monitored	Number of Records Available[a]	Number of Beta Records[b]
1949	620	620	1
1950	630	630	0
1951	669	669	0
1952	654	654	0
1953	579	579	0
1954	321	321	0
1955	209	209	0
1956	168	168	0
1957	203	203	0
1958	302	302	0
1959	384	384	0
1960	502	502	0
1961	608	608	1
1962	663	663	1
1963	751	751	1
1964	993	993	1
1965	1036	1036	5
1966	1323	1323	2
1967	1397	1397	2
1968	1436	1436	423
1969	1485	1485	554
1970	1506	1506	1208
1971	1396	1396	835
1972	1412	1412	219
1973	1410	1410	142
1974	1331	1331	866
1975	1539	1539	1075
1976	1059	1059	755
1977	1306	2452	1464
1978	1324	8757	1978
1979	1464	8889	1717
1980	1600	9355	1324
1981	1792	10099	1376
1982	1987	9244	1373
1983	2300	9403	2018
1984	3315	10955	5718
1985	3508	10996	6362
1986	3309	12421	4889
1987	3957	14504	5083
1988	4638	16382	5000

Table 6-6: Summary of External Monitoring Data in the MESH Database
(Table 6-6 spans two pages)

Year	Number of Workers Monitored	Number of Records Available[a]	Number of Beta Records[b]
1989	4386	15769	386
1990	4191	14947	127
1991	4227	13151	166
1992	5036	12958	42
1993	7589	24374	24
1994	6294	17571	18
1995	2246	6182	22
1996	1325	4478	133
1997	1056	3488	125
1998	947	3112	32
1999	1017	3617	84
2000	978	3117	7
2001	846	2617	12
2002	781	2419	29
2003	603	898	0
2004	70	158	3
2005	58	114	0

[a] Prior to 1977, only individual annual summaries are available; therefore, the number of records equals the number of employees. After 1977, dosimeter readings are available. Records typically include both photon and neutron measurement results.

[b] The number of beta records represents the number of results where the beta dose is greater than the recorded deep dose for a given dosimeter.

Table 6-7 summarizes general dosimeter types used and assignment policies.

Table 6-7: Mound Dosimeter Use and Assignment Policies	
Date	**Photon dosimetry**
February 21, 1949	Operations began in T Building. Film badges, one sensitive and one insensitive film, with 1-mm cadmium filter read weekly and two pocket ion chambers read daily. Beta window not read.
December 1951	Film badges read every 2 weeks.
May 1966	Use of pocket ion chambers discontinued.
September 1968	New dosimeters with security credential. Based on Nevada Test Site badges but with different filters. Modified later with TLD photon dosimeters plus Nevada Test Site neutron dose film. In 1977, questions were raised about low-energy photon dose underestimates with tantalum shields.
1972	Routine extremity dosimetry began.
December 1977	All-TLD dosimeters introduced.
October 1986	New soft-pack dosimeters.
June 1991	New hard-pack dosimeters with neutron track etch capability.
June 1993	Added neutron track etch capability for future use.
September 1949	NTA track etch film for fast neutrons first used in T and R Buildings. Read 10 fields at 980 power magnification and averaged readings.
September 1956	Began reading 10 fields at 430-power magnification with projection microscope and averaged values.
December 2, 1957	Returned to using 980-power projection microscope to read NTA film.
January 21, 1963	Began routine monitoring of night maintenance staff in Building P.
March 1963	Began using 400-power projection microscope. Reading 64 fields and averaged.
October 1964	Began using new projection microscope with better light.
March 1966	Began badging all hourly Engineering Department staff members who spent a portion of their time in radiation control areas of plant.
April 1967	Began using another new projection microscope, first at 500-power, then at 1,000-power.
August 1, 1968	Exchange frequency for Buildings R and SW personnel changed to 4 weeks.
Nov./Dec. 1977	All-TLD dosimeters introduced. Began using TLDs for neutron exposure monitoring.
October 1986	New soft-pack dosimeters.
June 1991	New hard-pack dosimeters with neutron track etch capability.
June 1993	Added neutron track etch capability for future use.

Table 6-8 below summarizes the beta-photon dosimeter types, exchange frequencies, and types of workers who were monitored.

Table 6-9 below summarizes the neutron dosimeter types, exchange frequencies, and types of workers who were monitored.

Table 6-8: Beta-Photon Dosimeter Types and Exchange Frequency				
Period	**Dosimeter type**	**Dosimeter holder**	**Exchange frequency**	**Comments**
2/1949–11/1951	DuPont D552	Oak Ridge/steel	Weekly	All radiation workers
12/1951–1957	DuPont D552	Oak Ridge/steel	Biweekly	All radiation workers
1957–1960	DuPont (model unknown)	Oak Ridge/steel	Biweekly	All radiation workers
1961–1962	DuPont 558	Oak Ridge/steel	Biweekly	All radiation workers
1963–1968	DuPont D556	Oak Ridge/steel	Weekly	Some radiation workers
			Biweekly	Most radiation workers
			Monthly	General area workers
1968–1969	DuPont D556	Oak Ridge/steel	Biweekly	Dependent on work area
			Monthly	
			Quarterly	
1970–1977	Kodak Type 3	Mound holder	Biweekly	Dependent on work area
			Monthly	
			Quarterly	
1977–1986	Harshaw 8810 TLD-700	Cycolac	Biweekly	Dependent on work area
			Monthly	
			Quarterly	
1986–1987	Harshaw 8810 TLD-700	Cycolac	Monthly	Dependent on work area
			Quarterly	
1987–1991	Harshaw 8810 TLD-700	Cycolac	Monthly	All employees monitored
			Quarterly	
1991–site closure	Harshaw 8801 TLD-700	Cycolac	Monthly	Dependent on work area
			Quarterly	

Table 6-9: Neutron Dosimeter Types and Exchange Frequency				
Period	**Dosimeter type**	**Dosimeter holder**	**Exchange frequency**	**Comment**
1949–8/1951	Kodak NTA	Oak Ridge/steel	Weekly	All radiation workers
8/1951–1957	Kodak NTA	Oak Ridge/steel	Biweekly	All radiation workers
1957–1960	Kodak NTA	Oak Ridge/steel	Biweekly	All radiation workers
1961–1962	Kodak NTA	Oak Ridge/steel	Biweekly	All radiation workers
1963–1968	Kodak NTA	Oak Ridge/steel	Weekly	Some radiation workers
			Biweekly	Most radiation workers
			Monthly	General area workers
1968–1977	Kodak NTA	Mound holder	Weekly	Dependent on work area
			Biweekly	
			Quarterly	
1977–1986	Harshaw TLD-600 TLD-700	Cycolac	Weekly	Dependent on work area
			Biweekly	
			Quarterly	
1986–1987	Harshaw TLD-600 TLD-700	Cycolac	Monthly	Dependent on work area
			Quarterly	
1987–1991	Harshaw TLD-600 TLD-700	Cycolac	Monthly	Dependent on work area
			Quarterly	
1991–2003	Harshaw TLD-600 TLD-700	Cycolac	Monthly	Dependent on work area
			Quarterly	

Early Mound site neutron dosimeter results were more accurately measured using NTA film than the spectra present at most AEC sites, due to the higher-energy spectrum associated with Po-Be sources. For this reason, Mound neutron doses can be based substantially upon measured doses even in the NTA film era. Periodic health physics reports demonstrate that not all workers were monitored for neutron doses; however, neutron dosimeters were required for work in those areas with significant neutron dose rates. For this reason, those workers with the highest potential neutron doses are assumed to have been monitored, which provides a sufficient basis for estimation of a maximum neutron dose for others workers.

6.3 Mound Air Sampling Data

Mound health physics program records include a number of air samples for alpha- and beta-emitters. Typically, such data are of limited use in dose reconstruction due to the great uncertainties associated with the doses estimated based on measured air concentrations. When possible, dose reconstructions are usually performed based on data related to a specific claim (including bioassay data), which provides a much more direct assessment of the uptake of a given radionuclide and the resulting organ dose. Air concentration measurements are used to assign internal doses from radioactive material in the general environment, in accordance with the Mound Occupational Environmental Dose TBD, (ORAUT-TKBS-0016-4).

Measured air concentrations are useful for estimating maximum doses when bioassay data are unavailable. Performance of routine air monitoring was a feature of the Mound health physics program since the beginning of Mound operations. Air sample results are available in at least summary form for the years 1949 through 1954. This information will be integrated into the revision of the Mound Occupational Internal Dosimetry TBD. In some cases, this information will be used to bound doses for unmonitored internal exposures, as described in Section 7.0 of this report.

7.0 Feasibility of Dose Reconstruction for the Proposed Class

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

In determining feasibility, NIOSH begins by evaluating whether current or completed NIOSH dose reconstructions demonstrate the feasibility of estimating with sufficient accuracy the potential radiation exposures of the class (discussed in Section 9.0 of this report). If the conclusion is one of infeasibility, NIOSH systematically evaluates the sufficiency of different types of monitoring data, process and source or source term data, which together or individually might assure that NIOSH can estimate either the maximum doses that members of the class might have incurred, or more precise quantities that reflect the variability of exposures experienced by groups or individual members of the class as summarized in Section 3.0. This approach is discussed in OCAS's SEC Petition Evaluation Internal Procedures which are available at http://www.cdc.gov/niosh/ocas.

The next four major subsections of this Evaluation Report examine:

- The sufficiency and reliability of the available data. (Section 7.1)
- The feasibility of reconstructing internal radiation doses. (Section 7.2)
- The feasibility of reconstructing external radiation doses. (Section 7.3)
- The bases for petition SEC-00090 as submitted by the petitioner. (Section 7.4)

7.1 Pedigree of Mound Data

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

Since its inception, all Mound radiation monitoring procedures and record-keeping were carried out to comply with Federal radiation protection regulations. Each employee's accumulated radiation exposure, as measured on a continuing basis by various radiation detection dosimeter and assays, was entered into personal radiation records for permanent documentation.

Monitoring record-handling and storage has varied over time, and with changing operators. As discussed in following subsections, specific record maintenance techniques have varied between external and internal data. Individual workers' files have been diligently maintained.

In 1993, the DOE decided to close the Mound Plant pursuant to the DOE Weapons Complex Reconfiguration Program. This was an effort to realign the weapons complex into a smaller, less expensive operation. The focus during the realignment was to maintain the enduring stockpile while retaining necessary resources and sustaining weapons production competency. Records generated in support of past missions were transferred to various receiver sites, or dispositioned per the National Archives and Records Administration (NARA)-approved retention schedules. Receiver sites include the Kansas City Plant, Savannah River Site, Los Alamos National Laboratory, Sandia National Laboratory, associated DOE Operations and Field Offices, the DOE Historian's Office, and the Office of Scientific and Technical Information (OSTI). Transfers of documentary materials also required transfer of document ownership and maintenance responsibilities in order to preserve the existing information assets of the weapons production complex. Details of these records transfers are provided in *Mound Records Transfer History* (Long, 2007). In addition, a description of Mound records disposition to LANL (a petition basis) is included in Section 7.4.1.7.

DOE has completed environmental remediation and restoration of all but one Operable Unit at the site. In May 2006, responsibility for managing Mound records was transferred to the Stoller Corporation/Source One Management contracting team, with oversight by the DOE Office of Legacy Management (DOE/LM).

Upon request (and as applicable), the Stoller Corporation/Source One Management contracting team provides employees' original hardcopy records in addition to database printouts (prior to 1958), which ensures the ability to confirm data. These hardcopy records are in the form of various preprinted forms, cards, or reports (depending on what was in use at the time). Per *Dose Reconstruction Training*, ORAUT-TRNG-0051, when performing dose reconstructions, personnel performing dose compare available hard copy data with database printouts.

The history and general quality of available Mound monitoring record data sets are summarized in following subsections. Dosimeter performance, bioassay procedures, and the QA/QC procedures associated with various monitoring campaigns were quite extensive at Mound and have been described in several documents. The ORAUT internal and external TBDs (ORAUT-TKBS-0016-5, ORAUT-TKBS-0016-6) provide some details. Extensive details of procedures and their evolution are contained within Meyer's external monitoring and bioassay history documents (Meyer, 1992; Meyer, 1994).

7.1.1 Internal Monitoring Data Review

Unless otherwise noted, the following characterizations of Mound internal data have been taken from three documents describing work performed for the Pre-1989 Dose Assessment Project (MJW, 1998; MJW, 2002, Phase I; MJW, 2002, Phase II). Internal monitoring data collection and assessment was a primary goal of Phase I of that project. Below is a summary of more detailed information available in the documents referenced above.

Plutonium Bioassay Data

The PURECON database was established in 1991 by the University of Lowell Research Foundation. This work was undertaken to meet the requirements of DOE Order 5480.11, *Radiation Protection for Occupational Workers* (DOE, 1988), which became effective January 1, 1989. A document entitled *Plutonium Historical Dose Reconstruction Program* provided the historical backdrop for this effort (Meyer and Reeder, 1992). In brief, Mound staff recognized that it needed to develop more reliable internal dosimetry record-keeping with respect to plutonium, which resulted in building the computer database from the original raw data.

As noted above, QA/QC and repair work has been performed on the PURECON database by MJW during its work on the Pre-1989 Dose Assessment Project (MJW, 2002, Phase I; MJW, 2002, Phase II). During its initial assessment of the existing database (5% check), MJW noted that for all PURECON records checked for errors of all types, there was an 8.2 % error rate was observed. This was considered unacceptable because some of these errors dealt with misidentification of bioassay data that could directly affect the results of the MJW dose screening program. Details of these checks are provided in the Phase I Report, Volume I, Appendix II-2 (MJW, 2002, Phase I).

Also provided in Volume II, Appendix A, Subpart 2 of the Phase I Report, is a memo submitted to Mound in September 1997 with recommendations regarding assessment and repair of the entire PURECON (and tritium) databases. The recommendations were approved and a description of the work performed is discussed in Section II(C)(1) of Volume I. In essence, a test plan was devised that allowed continued testing of the PURECON database against a predefined set of test conditions (derived from a proposed Pu-screening algorithm) until a zero error condition was returned.

Questionable results were all checked against original logbook entries. All database alterations identified by the test plan implementation were documented on Form TPOOl-I, MESH Record Quality Assurance Form.

In July 1999, approximately 350 (8 ½" by 11") "KARDEX" cards were discovered among the miscellaneous bioassay records in the Mound Occupational Radiological Exposure (MORE) records cabinets. The existence of these data was mentioned in the Meyer bioassay history document (Meyer, 1992). A thorough search of the record archives revealed their existence. The Meyer document also noted that the KARDEX data were the correct results and should replace any logbook data entered for that time period. Analysis of this new information showed that the KARDEX data took into account background that the logbook entries for the same period did not.

The approximately 2300 data points for 238 individuals for the time period 1960-62 were entered into an Excel spreadsheet, and the pCi value for a 24-hour sample was calculated. This information was then printed out for each individual and placed, along with a copy of the original KARDEX data, in the identified individual's Phase II data packet. In addition, the database was updated to include all new KARDEX data.

In general, the KARDEX data were calculated to be 0.1 to 0.2 pCi lower than the data in the PURECON database for the period 1960 through 1962. In several cases, existing PURECON data that were >MDA were calculated using the new KARDEX data to be <MDA. The net effect of updating the PURECON database with the KARDEX data has been to take into account background data for the period of 1960 to 1962, thus lowering the net result. Comparison of the PURECON database with the KARDEX data for 1962 showed that the majority of results in PURECON had been entered correctly.

As detailed in the Pre-1989 Dose Assessment Project Phase I Final Report (Volume I), the PURECON database for Pu was thoroughly reviewed for errors. A complete QA review of the database was required based on an initial random check of 5% of the existing data. This 100% QA effort corrected approximately 2347 errors in 58,893 records, for an error rate of ~ 4%. All database corrections were recorded. The corrected database was given one additional QA review following completion of all additional data entries; the person performing the initial data entry did not perform the final database QA. During all PURECON database work, the database was maintained on a secure network server located at the MJW offices.

Polonium Bioassay Data

The Po bioassay database for Mound employees contains 207,750 individual sample results spanning from 1944 to 1973. Code-named PORECON, it was created from polonium data cards contained in individual dosimetry files located in MORE records. Since these data cards were transcribed from original logbooks, QA of the database took two forms. The first was the double-key entry process, whereby a data clerk entered the "card" data into a database and a different data entry clerk made a second independent entry. The database creation program automatically checked the two entries and alerted the second clerk if a discrepancy was present. When a discrepancy occurred, the second clerk was required to alert MJW supervisory staff. The supervisor interpreted the data and corrected the discrepancy, at which point the program accepted the data.

Once the database was complete, the second phase of QA was initiated. Supervisory staff compared the results of all 24-hour urine samples entered into the database with the original hard copy logbook results. These samples were chosen for 100% review because 24-hour samples were typically collected following a known or suspected intake, and therefore represented some of the larger results. In addition to this review, 1% of the remaining records were compared to the hard copy results. The goal was to verify that there was less than a 1% error rate in the database construction. If a larger error rate had been found, additional QA would have been performed.

As this data comparison was performed, it turned up gaps of a few weeks to several years in the data of several individuals. This was unusual because samples were typically collected on a weekly basis. These gaps were researched using Microsoft Access to identify gaps by a preset time period such as 30 days, 60 days, etc., up to one year. These data gap printouts showed the length of the gaps, and potentially, the data that were absent. Examples of a data gap printout are shown in Appendix D of the Phase I Final Report (MJW, 2002, Phase I). The data gap research also helped identify those periods of potentially-missing data in an individual's file so that the paper records of weekly reports and logbooks could be searched for the occurrence of a particular name. It should be noted that for the early Po records, only the person's name was used as a means of record identification. In many instances, the name was not complete; in a few cases, only nicknames were entered. Consequently, it is unknown if all records for an individual were reconstructed correctly in that regard.

Once the initial Po database entry work was complete, MJW turned its attention to additional sources of Po data that had not been previously identified. As was previously discussed, the original Po logbooks were consulted throughout the Po data entry process to resolve conflicts found on the Po cards. As a result of continuing to consult these logbooks, additional data were discovered that had never been captured on Po data cards. These new data were input into the Po database as they were discovered.

Additional data added to the PORECON database came from a 3-ring binder containing two sets of 19 microfiche discovered in historical file drawers. Labeled "Po-210 Historical Exposure Data," the data entered on the fiche contained the worker's name, SSN, and Po bioassay data consisting of the sample date and result. Because the origin of these data was unknown, they were treated as potential information which may be missing from the PORECON database. Therefore, a 100% check of the fiche data against the PORECON database was performed. The results showed that a few persons listed on the fiche were not included in the database. They also showed that, for several individuals, the fiche contained more sample information than the database. Finally, in a few instances, the fiche data were in conflict with the database information. In this case, the original Po logbooks were again consulted to resolve any conflicts.

Almost from the inception of the Pre-1989 Dose Reconstruction Project, there were reports by former Mound staff of human bioassay data present in original logbooks sent for classified storage at the Los Alamos National Laboratory (LANL). Discussions were initiated between DOE Mound and DOE LANL in October 1997 regarding a limited search of the Mound logbooks. After several months of discussion, MJW staff spent two days at LANL in March 1998 reviewing approximately 230 classified, potentially radiologically-contaminated logbooks. The results of this review showed that about 10% of the logbooks examined contained human bioassay results for polonium. An additional 5% of the information gathered was also related to Po research, such as nose wipe data, blood sample data, fecal sample data, and various animal studies. Additional discussions were then held between

Mound DOE and LANL DOE to retrieve a selected number of Mound logbooks. A total of approximately 1500 logbooks were returned to Mound following declassification. A complete review of these declassified records was performed and the results of this additional work showed that only about 5% of these logbooks contained human bioassay results for Po with some additional animal data.

After the polonium logbook material from LANL had been declassified and reviewed by MJW staff, Mound staff discovered that not all pertinent Po records had been sent to LANL. Several thousand additional logbooks located on site were identified as potentially containing project-relevant material. Once the scope of the project was defined and funded, a review of the classified records in the logbooks was begun. Five Q-cleared individuals working part-time reviewed approximately 5,300 logbooks. Again, approximately 5% of the logbooks provided information relevant to human Po bioassay data while an additional 5% of the information retrieved related to animal studies using various Po compounds.

It was discovered during MJW's review of logbooks and microfiche that all of the data found in the Mound logbooks retrieved from LANL was recorded on the microfiche. It is likely, therefore, that in reviewing all of the microfilm at Mound related to Po bioassay data, all available data have been reviewed regardless of the location of the hardcopy information.

Tritium Bioassay Data

Mound tritium data reside in the MESH database. Initial review of the data by MJW during the Pre-1989 Dose Reconstruction Project revealed that records entered into the system from 1957 until 1982 only listed the year, the person's social security number (SSN), and a dose in rem. Database information from 1982 to the present consisted of the original tritium bioassay analytical data with sample dates, in addition to the information listed above, with the exception that no annual dose is given in any post-1981 records. No documentation was located in the historical files that described the algorithm used to calculate the dose reported in the database for the earlier years. However, the bioassay methods used throughout the tritium monitoring period, as well as the associated detection limits and accuracy, are known (Meyer, 1992). As noted by Meyer, "urine sampling counting for tritium has been automated since the early days of tritium work and the processing of the data has been handled by computer for many many years…The calculation of whole body exposure has been a routine procedure in tritium dosimetry."

Except for the years 1976 and 1977, primary data for tritium bioassay results are available. Workers involved with the Pre-1989 Dose Reconstruction Project located and used original logbook bioassay data for the highest-exposed employees (pre-1982) for tritium dose algorithm development. The format used for recording primary (and secondary) tritium records has changed many times through the years of tritium bioassay. The tritium dose records available to the dose reconstructor consist, with rare exceptions, of information in the MESH database. Tritium dose records in MESH contain annual totals through 1981, and actual bioassay results for 1982 and after. Dose reconstruction is based on the 'recording level' of 6 µCi/L through the year 1995 unless individual bioassay results (zero or non-zero) are provided. Positive recorded annual doses are modified with the correction factor in accordance with Equation 5-4 in the Mound Occupational Internal Dosimetry TBD (ORAUT-TKBS-0016-5). If the modified dose is greater than the missed dose, based on the recording level, modified dose is assigned. If the missed dose is greater, then missed dose is assigned.

“Other Radionuclides” Bioassay Data

For the purposes of this report, “other” radionuclides are defined as radionuclides other than tritium, Po-210, or plutonium isotopes. Bioassay data for other radionuclides were collected from several sources and compiled into Excel spreadsheets as part of the Pre-1989 Dose Reconstruction Project. Unlike the plutonium (PURECON) database or the polonium (PORECON) and tritium databases, which were created from fairly well-organized individual dosimetry records, the “other radionuclide” information was generally very poorly-documented and the interpretation of the bioassay results were often at best scientific approximations. It appears that because the activities involving the other radionuclides were not large-scale operations, the documentation of associated bioassay sample information was secondary to the larger plutonium, polonium, and tritium sampling and analysis programs.

Logbooks served as the primary source of information MJW used to construct the Excel spreadsheets. Additional results came from Kardex files. A total of 215 records were found in, and extracted from, the PURECON database. The curium and americium data found in PURECON represent the only data discovered to date for those radionuclides.

Difficulties encountered in attempting to interpret available bioassay records are noted in a paper entitled *MJW Corporation Position on “Other” Radionuclides for the Pre-1989 Dose Assessment Project* (MJW, 2002, Phase II). MJW notes therein that gross alpha counting was used to obtain the available results. Some of the results were not associated with a name, social security number, or health physics number. Often, there were no units associated with a result. In many cases, there were results for an element such as radium or thorium, but it was unclear which isotope was intended. There was no information on the age, solubility, or chemical form of the elements. In some cases, it appears bioassay results were repeatedly reported for two, or sometimes three, different radionuclides. For example, a person may have identical results for protactinium and Th-232. In other cases, urine samples may have been analyzed for radium/actinium/thorium by differential decay analysis of the radium fraction. The same urine sample may have also been analyzed for Th-232 by doing a Ra-Th separation. The results of the differential decay analysis appeared to conflict with the Th-232 analysis in that the dominant radium isotope is Ra-223 whereas Ra-224 would be expected. This would seem to indicate that the thorium results should have been interpreted as Th-227.

The methodologies used to reconstruct dose for these radionuclides are discussed in Section 7.2.1.4.

7.1.2 External Monitoring Data Review

After polonium operations began in February 1949, the results of the pocket dosimeter measurements, film badge readings, and neutron doses were entered in each employee’s radiation exposure record on Form 1015-X, which remained in use until December 1959. Beginning in May 1959, neutron exposure data were entered on punch cards and processed by the External Exposure Analysis System (EXAS) program. Beginning on January 2, 1960, results of both photon and neutron monitoring film were entered on punch cards (Meyer, 1994, Volume I, 1960 Appendix I, pp. 133–138). After that time, dose data based on film measurements were entered on Form 1015-X.

Beginning in March 1963 pocket dosimeter results were entered into a file-card system. The use of punch cards for recording pocket dosimeters ended, and a Kardex file cabinet was purchased for the file cards. The file cards were used from March 25, 1963, until December 27, 1963 (Meyer 1994, Volume I, 1963 Appendix III, p. 263). Beginning on December 30, 1963, pocket dosimeter data were entered on Form 1333. This form, which permitted the use of a Rolodex V-File for more efficient handling of daily records, remained in use through May 1966.

The External Radiation Analysis Data (ERAD) program replaced EXAS in 1978, and the Mound Environmental Safety and Health (MESH) program replaced ERAD in September 1989.

The MESH database contains all measured employee radiation doses since 1947, although only the annual summary dose is available for years before 1977. Annual doses are sufficient for overestimation of employee doses; however, the lack of individual dosimeter cycle data requires claimant-favorable assumptions to calculate missed external doses. *Missed* external dose is the potential dose received by an individual below the technological limit of the dosimeter to detect (called the limit of detection, or LOD).

Early neutron dose measurements were made using neutron track emulsion, Type A (NTA) film. These film dosimeters likely responded in a manner proportional to the doses received for early operations at Mound, resulting in neutron doses due to the relatively high-energy spectrum associated with neutrons from Po-Be sources. Other operations had lower average-energy neutron spectra.

Obviously, many changes have occurred over time with regard to Mound's dosimetry program and record-keeping practices. As described by Meyer, the need for a "some day in the future" capability for total program reconstruction was not a well-defined "need," especially in the early decades of operation (Meyer, 1994). In practice, maintaining controlled record storage was more of a challenge than developing the records themselves. Nevertheless, a large number of documents describing the program and dosimetry performance are available. After evaluating these, NIOSH identified no significant administrative practice that would jeopardize the integrity of the recorded external dose. Many of these documents are referenced in ORAUT-TKBS-0016-6, incorporated into the *History of Personnel External Dosimetry Program at the Dayton Project and Mound Laboratory 1946-1993* (Meyer, 1994), and in the SRDB. Program descriptions and assessments for later years are also available in the SRDB.

7.2 Internal Radiation Doses at Mound

The principal source of internal radiation dose for members of the proposed class would have been inhalation and ingestion of radiological contamination during the following operations:

- Research and development (R&D) of fabrication of neutron sources for nuclear weapons initiators and neutron sources for other uses
- Research for alternatives to Po-210 for use in weapons initiators (because the short half-life of Po-210 required the frequent re-manufacture of the initiators)
- Radioisotope thermoelectric generators (RTGs) and radioisotope heat sources, which have been used on a variety of missions to provide heat and electric power
- Tritium-handling technologies that supported weapons and non-weapons programs

- Research on metal tritides and tritium targets
- Recovery and purification of tritium from waste generated by Mound and other DOE sites
- Research into production of alternative reactor fuels such as thorium
- Research and development of the joining of exotic metals
- Research and development of technologies for radioactive waste management

The potential internal sources would have been dependent on the operational area and activities. The major sources of intakes have been polonium, plutonium, and tritium. Bioassay monitoring was typically conducted for the radionuclides determined by the site radiation protection program to be of primary dosimetric concern.

Mound listed the following radionuclides as primary radionuclides because they could deliver relatively high doses to human receptors, had widespread use at the site in multiple buildings and facility processes, and had sufficient site documentation to evaluate internal dosimetry. Tritium was included due to potential absorption via hydrogen exchange across the skin barrier. (ORAUT-TKBS-0016-5)

- Po-210
- Pu-238
- Pu-239
- Pu-240*
- Pu-241*
- Pu-242*
- Pa-231
- H-3

* Pu-240, Pu-241, and Pu-242 are not dosimetrically significant.

Radionuclides of secondary concern to Mound staff were assessed with limited internal dosimetry data due to the limited worker exposures. Short-lived radioactive gases and their respective daughter products were generated at Mound by activities involving uranium and thorium chain extraction and separation activities, as well as by the manufacturing of sealed sources. Exposures to these gases were minimized by a ventilation system installed in 1980 and were largely restricted to the SW building where radium and actinium work took place. The following are the secondary radionuclides in addition to daughter products from the uranium and thorium decay chains:

- Am-241
- Cm-244
- U-238
- U-235
- U-234
- U-233
- Th-232
- Th-230
- Th-228

Comparison results to quantify “short” and “long-lived” radionuclides or specific measurements of “Short-Lived Daughter Products” are contained in health physics periodic reports starting in March 1952.

7.2.1 Process-Related Internal Doses at Mound

The following subsections summarize the extent and limitations of information available for reconstructing the process-related internal doses of members of the proposed class. More detailed information on the individual topics can be found in Section 6.1 of this report and in (Meyer, 1992) and (King, 1995).

7.2.1.1 Tritium

Extensive use of tritium began at Mound in the mid-1950s, and some limited exposure may have been possible prior to that time. Most of the tritium exposure at Mound was assumed to be related to the uptake of tritiated water (HTO), which is effectively monitored using urine bioassay. Tritium dose assessments at Mound were reliably measured using standard assessment methodologies starting in 1957. Measured doses are modified to reflect current dose models as discussed in Section 5.3.1.1 in the Mound Occupational Internal Dosimetry TBD (ORAUT-TKBS-0016-5). Recommended doses for unmonitored exposures are also provided in the referenced section. The quantity and quality of available tritium urinalysis results are sufficient for estimating maximum doses or precisely estimating doses.

7.2.1.2 Polonium-210 Operations

Full-scale separation of Po-210 from irradiated bismuth took place on the second floor of the T Building from 1949 to 1971. Facilities and activities included neutron source calibration, decontamination laboratories, a storage pool for irradiated bismuth slugs, neutron source processing, and analytical laboratories. Po-210 was also present in Building HH from 1949 to 1959, generating sludge materials with 0.02 Ci/l total alpha activity. Use of Po-210 in the R Building involved research and electrodeposition studies from 1948 to 1951, and the manufacturing of Po-Be neutron sources from 1956 to 1961. Po-Be sources were first manufactured at Mound as neutron source initiators to support various weapons programs. Polonium was later used to produce Po-210 heat source generators (King, 1995). Intakes of polonium and the resulting dose may be calculated using bioassay data that existed as early as 1944.

The SW Building was used for counting Po-210 sources, neutron source measurement, source strength verification, and Po-209 and Po-210 retrieval. Aqueous wastes containing Po-208, Po-209, and Po-210 were present in the WD and WDA Buildings beginning in 1949. Chemical forms included polonium nitrate and polonium chloride (Meyer, 1992).

As discussed in Section 6.0 of this report, MJW placed Po-210 bioassay data in the PORECON database during the Pre-1989 Dose Assessment Project after evaluating individual dosimetry files from original logbooks and data cards. PORECON contains over 207,750 individual sample results spanning from 1944-1973.

These data may be supplemented with available process information to estimate a reasonable bounding dose.

7.2.1.3 Plutonium

Pu-238 is the primary radionuclide of concern with respect to internal dose at the Mound site beginning about 1959. The first production RTG, the SNAP-3A, was built in 1958 using Po-210 alpha decay as a heat source. President Eisenhower used the current to generate a radio transmission from the Oval Office in 1959. Subsequently, the SNAP-3 was redesigned to use Pu-238 in order to extend the life of the generator. The SNAP-3B was first launched in the Navy *Transit* satellite program.

Production of Pu-238 was a large-scale project, eventually using the SM and PP buildings, and extending from 1959 through the late 1970s. A number of material forms were used, including Pu-238 metal, plutonium oxide, plutonium dioxide, and plutonium metal ceramic (cermet). The generator projects included a number of spacecraft power sources for satellites, the Apollo program, and planetary and interstellar space exploration programs employing the Pioneer and Voyager spacecraft. Other sources were fabricated for use in buoys, for potential use in pacemakers, and in diving suit heat sources. Production efforts were reduced in the period of the 1970s. During this time, encapsulation of the Pu-238 was moved to the Savannah River Site, and after 1979, unencapsulated Pu-238 was not routinely handled at Mound. The program had an indeterminate status for a number of years, but operations with RTG fuel were officially moved to the INEEL site in 2006.

The Mound site featured only limited exposure to weapons-grade plutonium in small-scale research operations and the preparation of a small number of neutron sources. Weapons-grade Pu-239 used in the Mound plutonium neutron source project (R building, 1956-1958) was reported to be over 95% pure by mass, with trace amounts of Pu-240 and Pu-241, which are not dosimetrically significant (King, 1995). Additional information on Pu-239 feed material characteristics can be found in the Mound site profile.

Plutonium bioassay results are available from 1956 through 1991 in the PURECON database. Subsequent plutonium internal dose monitoring results are listed in the MESH database. Early results were based on gross alpha measurements, and the resulting doses must be calculated based on the potential exposure. Later measurements (1980 and after) were isotopic for Pu-238 and Pu-239. These data may be supplemented with available process information to estimate a reasonable bounding dose.

7.2.1.4 Other Radionuclides with Bioassay Monitoring Data

The Mound site conducted diverse activities in research and chemical engineering; a number of which are discussed in Sections 6.1.4 through 6.1.10. Each process is summarized below with respect to methodology used to reconstruct internal dose.

- Protactinium-231, 1954-1958: This limited program featured bioassay data for the primary radionuclide beginning in 1955, and this value is used to assign missed dose as well as potential dose from intakes implied by positive results. These data may be supplemented with available process information to estimate a reasonable bounding dose.

- Thorium-230, 1954-1956: Programs involving Th-230 featured bioassay data for the primary radionuclide, and this value is used to assign missed dose as well as potential dose from intakes implied by positive results. Air activity measurements are available in periodic health physics reports specific to the ionium program. Along with available process information and bioassay data available from 1956 onward, maximum doses can be estimated, or doses can be estimated more precisely than a bounding dose estimate.

- Thorium-232, 1954-1956 (Research); 1956-1975 (Storage): Programs involving Th-232 featured bioassay data for the primary radionuclide, and this value is used to assign missed dose as well as potential dose from intakes implied by positive results. Small numbers of bioassay results are available from 1951 to 1954, with larger numbers available from 1955 through 1959. Additional bioassay data associated with the periodic re-drumming of material is available prior to and after the time the material was in the Building 21 storage basins. These data may be supplemented with available process information to estimate a reasonable bounding dose.

- Radium-226, Ac-227, and Th-228, 1949-1954 (research and production); 1955-1959 (decontamination and decommissioning): These radionuclides were part of research on production for use of Ac-227 as a substitute for polonium in neutron initiators. The decontamination and decommissioning of the building where the work was done was completed in February 1959 (Meyer, 1992, p.38). NIOSH has access to a limited number of bioassay results for these radionuclides; however, interpretation of the results is uncertain. NIOSH cannot bound the dose for the time period October 1, 1949 through February 28, 1959.

- Uranium: Processes with uranium were associated with reactor fuels research. Existing bioassay results are used to assign missed dose as well as potential dose from intakes implied by positive results. Along with available process information and bioassay data, maximum doses can be estimated or doses can be estimated more precisely than a bounding dose estimate.

- Americium-241 and Cm-244: Limited programs with these materials resulted in a small number of bioassay results. These are used to assign missed dose as well as potential dose from intakes implied by positive results. These data may be supplemented with available process information to estimate a reasonable bounding dose.

7.2.1.5 Other Radionuclides with No Bioassay Data

A number of radionuclides are described in the literature as available through direct exposure during research activities, or as part of the waste disposal system. Small quantities of a variety of radionuclides associated with research-scale activities and their progeny are available in subsequent years to decontamination and decommissioning workers, as listed in the King document (King, 1995). Like most radiation protection programs, the Mound program sampled for those radionuclides having the potential to produce the majority of the internal dose. Radionuclides were considered less significant for several reasons, including:

- Limited amounts of material and limited number of personnel exposed

- Very small doses compared with the primary dose radionuclide. For example, a spectrum of beta- and gamma-emitters associated with the irradiated bismuth feed product for the polonium refinement process is listed in King with the statement that "Polonium-210 is the major radionuclide of concern, with Zinc-65 a distant second" (King, 1995)

- Insignificant dose commitment due to a short effective half-life. An example of this would be La-140, used as a radiotracer

For Mound chemical research operations, descriptions of the process and results exist in Mound progress reports, technical reports, and in peer-reviewed journals. From these documents, the proportions and amounts of radionuclides can be determined with sufficient accuracy to estimate a maximum dose. Another source of information is air monitoring results available for some buildings and time periods.

Examples of other radionuclides for which doses will be calculated based on data other than bioassay results are listed below.

- <u>Fission product dose from 'reactor waste' research (1949-1953</u>. A project was conducted in the R Building to research the feasibility of removing fission products from waste streams, including the bismuth phosphate, tributyl phosphate, and the solvent extraction (Purex) plutonium separation processes. Progress reports, such as *Decontamination of Process Waste Solutions Containing Fission Products by Adsorption and Coprecipitation Methods (Information Report)* (Decon, 1951), contain detailed descriptions of the process, along with chemical composition and radioassay results. Additionally, bioassay was performed for individuals with plutonium as the indicator element. From these, maximum exposures may be determined with sufficient accuracy to determine a maximum dose.

- <u>Separation of yttrium from strontium (1952-1954)</u>. A small research project was conducted to separate Sr-90 from its progeny Y-90 (in secular equilibrium in material aged more than 30 days). No bioassay data exist for this operation; however, a description of the chemical process exists in the document *Preparation of Carrier-Free Yttrium-90* (Yt-90).

- <u>Radiotracers (1949-1954)</u>. The literature suggests that there was some potential for exposure to La-140 and Ba-140 (in secular equilibrium), which was used as a radiotracer to determine the efficiency of the separation process with lanthanum and barium modeling the chemical behavior of radium and actinium. The proportions of the radionuclides in the process material are listed in the progress reports such as *Report for Research on Substitute Materials, October 1, 1951 to December 31, 1951 (Actinium-227)* (Ac-227, 1952). A maximum dose may be estimated for potential exposure to these radionuclides during this activity.

7.2.1.6 Radon

Beginning in 1952, sources of radon (Rn-222), thoron (Rn-220), and actinon (Rn-219) were present at Mound due to radium and thorium processing and separation of Pa-231 and Ac-227. Thorium sludge from Th-232 extraction and purification operations was stored outside in drums from 1954-66. In 1966, drummed thorium sludge was transferred to Building 21.

Table 7-1: Radon Isotope Survey Data by Building and Time Period

Building	Survey dates	Gas concentration (pCi/l)			WL	WLM yr^{-1} (a)
		Radon (Rn-222)	**Thoron (Rn-220)**	**Actinon (Rn-219)**		
SW Tunnel	10/12/79	88,000	28,000	640,000	n/a	n/a
SW-19 before vent	6/79-10/79	67-160				
SW-19 after vent	3/80-4/80	7.7-13.4			0.03	0.4
	12/89	2.6	Not Detected			
	12/99	**1.0-5.8**[b]				
	4/00	**0.7-7.2**				
	1998-2000	5.8-12				
SW-21	5/83	17.5-52.8	n/a	n/a	n/a	n/a
	12/89	**34-118**		0.3-0.7	0.4-1.3 0.85 median	4.7-15.3 10.0 median
	4/90-6/90	117-161				
		125				
SW-22	6/90	**125**	n/a	n/a	n/a	n/a
SW-48	12/89	3.2	n/a	n/a	n/a	n/a
Old SD	12/89	1.5-2.4	n/a	n/a	n/a	n/a
Fire station	12/89	1.2-1.4	n/a	n/a	n/a	n/a
Paint shop	12/89	0.9-1.2	n/a	n/a	n/a	n/a
A	10/88-2/89	**0.1-1.1**	n/a	n/a	n/a	n/a
All other buildings	12/89	5 0.4-0.9	n/a	n/a	n/a	n/a
Outside facilities	5/83	0.24-0.59	n/a	n/a	n/a	n/a
Reported background		0.1 to 2.1 Average = 0.5	n/a	n/a	n/a	n/a

a. Working level months per year (WLM yr^{-1}) were determined as WL (2000 hr yr^{-1}) (1/ 170 hr WLM^{-1}).
b. Bolded concentrations were derived from charcoal canister measurements.

The SW-19 Building had elevated radon concentrations emanating from radium and thorium processing wastes. On October 12, 1979, inert gas concentrations in the SW Building underground tunnel were measured at 88,000 pCi/l Rn-222, 28,000 pCi/l Rn-220, and 640,000 pCi/l Rn-219. A Rn-222 concentration of 88,000pCi/l would correspond to 352 WL, assuming an ICRP 50 indoor mean radon daughter equilibrium factor of 0.45 (ICRP, 1987). The tunnel was not an occupied work area; however, elevated concentrations of radon were transported from the tunnel into SW-19 work areas. Measurements of Rn-222 near an employee's desk ranged from 67 to 160 pCi/l in 1979.

A ventilation system was installed in early 1980 to vent SW Building tunnel air (Meyer, 1992). This system reduced Rn-222 concentrations in SW-19 by a factor of 10 or more. This result was confirmed with continuous measurements from 7.7 pCi/l to 13.4 pCi/l. A working level (WL) measurement by the employee's desk following ventilation system installation was 0.03 WL or 0.03 (12 mo/yr) = 0.4 working level month (WLM) compared with an occupational limit of 4 WLM/yr (King, 1995).

A DOE radon study was conducted from December 12-15, 1989, to measure radon in various Mound buildings (UNC Geotech, 1990). The majority of buildings had radon concentrations below 1.0 pCi/l Rn-222, except SW and Old SD buildings. In June 2000, a radon study summary report was issued based on 1990 and 1999 measurements (BWXT, 2000). Mound site radon background was reported to be 0.5 pCi/l with a range of 0.1 to 2.1 pCi/l.

SW-19 was the only building at Mound identified as an area of potential occupational exposure to Rn-222 and Rn-220 (King, 1995). Rn-220 and Rn-219 measurement results were very limited despite the high concentrations observed in the underground tunnel. The only Rn-219 measurements were made in Building 21 at 0.3 to 0.7 pCi/l, but the holding time before analysis was excessive compared to the four-second half-life of Rn-219. The only Rn-220 measurement in SW-19 was below detection. Rn-220 and Rn-219 exposures would not be detectable in excreta by bioassay due to very short half-lives. (ORAUT-TKBS-0016-5).

The WLM values in Table 7-2 have been used to reconstruct doses for EEOICPA claimants suspected of having been exposed to radon in air. All WLMs have been assumed to be median values of lognormal distributions with a geometric standard deviation (GSD) of 3.0.

To reconstruct missed doses, a background radon concentration of 0.5 pCi/l can be used, which converts to 0.03 WLM indoors assuming 100% occupancy and 0.45 (ICRP, 1987).

Table 7-2: Radon-222 WLM Assumptions for Dose Reconstruction

Building conditions	Period	Radon (pCi/L)	Radon (WL)	Radon (WLM)
SW Tunnel Prior to Ventilation	1949-1979	88,000	352	4,100
SW-19 Ra-Ac Pilot Project	1949-1952	160	0.72	8.5
SW-19 Ra-Ac Old Cave Production	1952-1960	160	0.72	8.5
SW-19 Post Production, Prior to Ventilation	1961-1979	160	0.72	8.5
SW-19 Post Production, Post to Ventilation	1980-1995	0.7-13.4	0.03	0.4
SW-21	1952-1995	17.5-125	0.85	10.0
SW-22	1966-1995	125	0.56	6.6
SW-48	1980-1995	3.2	0.01	0.2

Descriptions of radiation protection activities in periodic health physics report demonstrate that the health physics program was considering short-lived air activity to the extent that this activity was routinely reported through the era of radium and thorium processing, and Pa and Ac separation. For periods outside these years, and for which air concentrations are not available, doses may be estimated based on the measured air concentrations and scaled based on the available source term, as determined in the available process information. Maximum exposures may be determined with sufficient accuracy to determine a maximum bounding dose.

7.2.1.7 Missed Internal Dose

Missed dose is calculated using bioassay data specific to individuals and represents dose from intakes that could have been received, but were not detected by the bioassay method used (urinalysis in most cases for Mound). Missed dose is assigned based on the minimum detectable amounts (MDAs) for each radionuclide and the bioassay method listed in the Mound Occupational Internal Dosimetry TBD (ORAUT-TKBS-0016-5). Missed dose is applied only for monitored individuals. Doses that may have been received, but for which no dose monitoring was performed, are more properly termed "unmonitored dose." Some employees may have received unmonitored exposures to radioactive material. Doses for these individuals may be bounded using process information in the technical reports on Mound research, measured air concentrations, or a combination of the two.

7.2.1.8 Decommissioning and Decontamination

Contractors responsible for performing decommissioning activities were responsible for developing and implementing radiation control programs consistent with DOE requirements in 10 CFR pt. 835. These contractor programs included provisions to monitor external and internal personnel radiation exposures. The potentials for radiation exposure during decommissioning were generally significantly less than those during Mound production operations, and monitoring programs were commensurate with the specific decommissioning operation being performed. Data collected included air monitoring, bioassay, and external exposure monitoring. Personnel monitoring results were provided to the contracting DOE office and included in individual claim files and comprise the external and internal dose monitoring results for each individual. The internal data for these personnel can be extensive in terms of the number of radionuclides for which bioassay was conducted.

7.2.2 Ambient Environmental Internal Radiation Doses at Mound

Unlike some of the other major DOE facilities, Mound did not generally experience significant site-wide ambient contamination, and there was less concern about the potential for internal dose related to ambient working conditions. Nevertheless, the use of facility ambient air monitoring data for purposes of assessing internal radiation doses was evaluated for purposes of performing EEOICPA dose reconstructions. Except for some data for airborne radon and tritium, use of these data was not considered a viable approach due to unknown factors potentially affecting the representativeness of actual breathing zone air concentrations. Personnel ambient exposure/dose is accounted for in the available monitoring data for those personnel and these data can be used to bound the ambient/environmental doses. Further evaluation of these exposures was not performed or required for this evaluation report. In any case, the existing Mound air monitoring data are currently contained in broadly-dispersed record sources.

7.2.3 Internal Dose Reconstruction

For the period October 1, 1949 through February 28, 1959, NIOSH has determined that internal doses from Ra^{226}, Ac^{227}, and Th^{228} associated with the separation operation in SW-19 cannot be determined with sufficient accuracy. This is based on the following factors:

1. NIOSH has access to a limited number of bioassay results for these radionuclides; however, interpretation of the results is uncertain (MJW, 2002).

2. While it is likely that the bioassay results relate to the workers directly involved in this operation, it is not known what fraction of those workers was sampled.

3. There is strong evidence that airborne contamination was produced by this operation, and that this contamination was spread beyond SW-19 to other areas in R and SW Buildings. This situation created significant exposure potential among R and SW Building workers for these radionuclides. The limited number of individuals for whom Ra-Ac-Th bioassay results are available suggests that the larger population in the R and SW Buildings were unmonitored for potential intakes.

4. The reported airborne contamination concentrations throughout R and SW Buildings are relatively high in some cases, suggesting the potential for non-trivial intakes and consequent internal doses.

While it is likely that significant exposure potential resulting from this operation was limited to the R and SW Buildings, it is not clear as of this writing whether access to these buildings was strictly limited to the personnel regularly working in them.

7.2.4 Internal Dose Reconstruction Feasibility Conclusion

Potential for radionuclide intakes existed at Mound. Mound sought to limit internal exposures and maintained a progressive bioassay program throughout its operational history. NIOSH has both demonstrated that employees with the greatest potential for internal intake were monitored, and determined that the available bioassay data can be used to reconstruct or bound potential internal radiation doses for those employees, with the exception of those workers who may have been exposed to Ac-227, Th-228, and Ra-226 from October 1, 1949 through February 28, 1959.

NIOSH can bound the doses arising from exposure to polonium, tritium, plutonium, radon, protactinium, Th-230, and Th-232, uranium, and stable metal tritides using the scenarios described in the previous sections.

NIOSH has established that unmonitored intakes of radionuclides associated with radium-thorium-actinium processing, and purification research and production, may have resulted in unmonitored doses to research and process workers, and workers incidentally exposed in these facilities. For this reason, a class of workers is being proposed for addition to the SEC. For the other periods of Mound site operations, NIOSH has access to sufficient information to either estimate the maximum internal radiation dose for every type of cancer for which radiation dose are reconstructed that could have incurred under plausible circumstances by any member of the class; or estimate the internal radiation doses to member of the class more precisely than a maximum dose estimate.

7.3 External Radiation Doses at Mound

The principal source of external radiation doses for members of the proposed class is associated with Po production operations, which moved from the Dayton Project to the Mound Site in 1949. The narrowly-focused Po production work expanded to the development and production of weapons components. Production of Pu-238 and Pu-239 grew from the early Po work. The principal Mound mission was the research, development, and manufacture of non-nuclear explosive components for nuclear weapons that were assembled at other sites. Research and development included the fabrication of neutron and alpha sources for weapons and non-weapons use. Starting in the 1950s, Mound developed radioisotope thermoelectric generators (RTGs) which have been used on a variety of missions to provide heat and power for spacecraft. Po-210 production declined in the 1960s and was phased out in 1971 (ORAUT-TKBS-0016-2).

External dose monitoring formed a part of personnel protective practice from the early days at Mound, starting with the first operational process, polonium neutron source preparation. External dose monitoring continued throughout Mound's operational history. It is known that employees at the Dayton Laboratory (Units III and IV) were unmonitored for neutron dose; however, neutron dose monitoring forms a part of most early dose monitoring records in Mound employee files. These results reflect measurements with neutron-track emulsion (NTA, for neutron track, type A) which, in contrast with measurements at other sites during that era, likely provided a proportional estimate of neutron doses in the spectrum generated by Po-Be sources. Later measurements were made with thermoluminescent dosimeters (TLDs).

Photon dose monitoring was conducted from the onset of Mound operations using standard film dosimeters and, later, TLDs. Film and TLD dosimeters provided reliable measurements of the photons in Mound work areas. Shallow doses, from beta-emitters and low-energy gammas, were detected on a portion of this dosimeter as well.

7.3.1 Process-Related External Radiation Doses at Mound

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

7.3.1.1 Radiation Exposure Environment

The external dose received by Mound workers was a function of the physical location of the workers on the site, the processes taking place, the types and quantities of material present, and the time spent at each location. Most doses for Mound processing personnel resulted from a mixed field of photons and neutrons. Beta doses or doses from low-energy photons were present in some workplaces. Breakdowns of the workplace radiation field characteristics are given in the relevant tables in the Mound Occupational External Dosimetry TBD (ORAUT-TKBS-0016-6).

The primary sources of external dose at the Mound site are the two major production programs involving polonium and plutonium. Tritium is not a source of external radiation dose. Laboratory dose rates could also result in significant external doses, depending on the process and the amount of material. Photon and neutron doses have been reliably measured using film dosimeters from the first days of Mound operations. A summary of the characteristics of the major external dose sources is presented below:

- Polonium Processing: Polonium is essentially a 'pure' alpha-emitter; however, alpha interactions within the material matrix can generate neutrons with energy proportional to the energy of the alpha particle. These neutrons' energies will be degraded through scattering and moderation. Thermal neutron interactions will include capture with emission of prompt gamma rays. Thus, the polonium production work resulted in both photon and neutron dose rates.

  The average energy of the Po-Be sources fabricated for nuclear weapons and other purposes is reported to be approximately 4.5 MeV. This high average energy is measured with great reliability using the NTA film dosimeters. Photon doses were reliably measured for all Mound employees entering areas where radiation dose fields existed. NIOSH is confident that with the existing data, appropriate neutron-to-photon ratios can be determined to provide a bounding dose estimate.

  Initial polonium processing efforts at the Dayton Laboratory included considerable beta dose, particularly of the extremities. The design process for the T Building, where polonium was processed at Mound, took these high levels of beta radiation into consideration. Rooms 75 and 76, where the loaded bismuth slugs were processed, were equipped with leaded windows (White Paper T, 2002) and an "elevated platform ('Rooms' 275 and 276) was used to access valves and doors by remote operations." (King, 1995, Section 6.2.50). This evidence suggests that the beta dose rates were controlled to a significant extent. That this is the reason that the site did not record beta dose readings is documented in a January 4, 1960 memorandum from the health physics supervisor, W.A. Bigler. The memo requires that open-window portions of the dosimeter film will be read "on any film where the open window is visibly darker than the rest of the film." (Meyer, 1994, Volume I, Page 250) This change was made in response to the fact that health physics personnel had noticed darkening of this portion of the film where it "had not been noted before." (Meyer, 1994, Volume I, page 164). The on-going TBD revision process will evaluate whether an estimated unmonitored exposure will be necessary to bound doses for organs sensitive to non-penetrating radiation (i.e., skin, breast, testes, lip). NIOSH is confident that with the existing data, appropriate neutron-to-photon ratios can be determined to provide a bounding dose estimate.

- Plutonium Processing: Plutonium processing also resulted in mixed-field doses from photons and neutrons. Since Pu-238 was used as a heat source rather than as a neutron source (in the primary processing operation), neutron dose arose from alpha-n interactions of plutonium and its compounds. Most processing took place after the health physics program began reading and recording non-penetrating dose from beta and low-energy gamma radiation, so doses are measured for the most exposed workers.

7.3.1.2 Dosimetry Records

Records of radiation exposures from personnel dosimeters are available from the beginning of operations, and for all years of the proposed class time period. The MESH database serves as the primary electronic repository for these records. As discussed in Section 6.1, annual measured doses are available for all monitored employees. (Guido, 2003; Meyer, 1994)

7.3.2 Ambient Environmental External Radiation Doses at Mound

The ambient environmental external dose is the occupational dose received by individuals while outside operational facilities, such as process buildings. External dose from radioactive materials outside the body may be the result of direct radiation from radioactive materials in soil, from adjacent operational facilities and waste storage areas, from submersion in air containing radionuclides from effluent releases, and from re-suspension from soil. The Mound Occupational Environmental Dose TBD (ORAUT-TKBS-0016-4) and *Occupational Onsite Ambient Dose Reconstruction for DOE Sites* (ORAUT-PROC-0060) provide the historic background, rationale, and data for reconstruction of occupational environmental doses for unmonitored personnel at Mound. The conclusion from the above-mentioned references is that Mound facilities and soil are unlikely to have contributed significantly to the ambient environmental dose. In addition, the TBD evaluates external doses from submersion in air containing radionuclides released in effluents and in resuspended site soil. The annual effective air-submersion external exposures from all radionuclides in these sources during the period 1949 through 2002 were less than 5.0E-10 Sv (ORAUT-TKBS-0016-4). The conclusion of the TBD is that submersion dose from effluents is insignificant and does not need to be considered in dose reconstruction. The ambient environmental dose would be accounted for, and bounded from, the occupational monitoring data for personnel; therefore, further evaluation of the ambient environmental dose is not necessary in this evaluation.

7.3.3 Mound Occupational X-Ray Examinations

Diagnostic X-ray procedures were a contributor to the occupational radiation exposure of Mound workers. In general, the dose from such exposures was not measured, considered, or included as part of the overall occupational exposure of the employee, although it clearly was occupationally-related. Diagnostic medical X-rays administered in conjunction with routine or special physical examinations required for employment are a valid source of occupational exposure. Unlike occupational exposures incurred during normal work processes, individual diagnostic medical X-ray exposures were not monitored, necessitating reconstruction of doses acquired in this manner. (ORAUT-TKBS-0016-3)

Mound employees received posterior–anterior (PA) chest X-rays at hiring, at specified intervals thereafter, and at termination. In 1983, a policy modification required X-rays for terminating employees only if they had not had a chest X-ray within the previous 9 months; this changed to 6 months in 1988. In 1988, a lateral (LAT) view was required for women known to have undergone breast augmentations; the frequency of these examinations is not known. ORAUT-TKBS-0016-3 lists examination frequencies over the years for different groups based on information obtained from the Mound data files. The records returned by DOE include the occupational medical X-rays performed for Mound employees. These are reviewed during dose reconstruction. Typically, the average frequency is less than one per year for most employees. Typically, dose reconstructors assume annual frequencies as an overestimating assumption.

Prior to 1980, details about the X-ray apparatus and technique parameters are not known and default values were used for entrance kerma (ORAUT-TKBS-0003). Since at least 1980, the X-ray apparatus at Mound was a stationary enclosed unit with the control panel separated from the tube head by a wall. From 1980 through 2003, the equipment consisted of a single-phase, TWX-325 control unit with a Eureka Emerald 125 X-ray tube, Eureka Linear II automatic collimator, and S&S 1417B vertical cassette holder (VCH) used with no grid and 14- by 17-in. Kodak X-O-Matic Regular film. Actual measurement data obtained by the Ohio Department of Health were used. ORAUT-TKBS-0016-3 summarizes technique parameters and entrance kerma for PA and LAT views, respectively. For the period before 1980, no external collimation was assumed when converting entrance kerma to organ doses.

Although there is no specific evidence in the history data file (Mound, 2002) to indicate the use of photofluorography at Mound, evidence suggests that General Electric mobile X-ray units might have been used at various U.S. Atomic Energy Commission, Energy Research and Development Administrations, or U.S. Department of Energy sites (NCRP, 1989). A review of files from the 1940s and 1950s reveals that when photofluorography was used, an unusually large number of X-ray examinations would be performed in a given day. Thus, a larger than normal number of X-ray records for a given day might be a positive indicator of the use of photofluorography. However, in the absence of specific data on the use of photofluorography at Mound, or even that such equipment was present on site, this analysis assumes that photofluorography did not occur at Mound. The analysis will be performed in accordance with the guidance in ORAUT-OTIB-0006, *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures*.

7.3.4 External Dose Reconstruction

By December 6, 2007, EEOICPA claims meeting the proposed class definition being evaluated in this report had been submitted to NIOSH. Of those 491 claims, NIOSH has completed dose reconstructions for 348 claims.

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

- Photon Dose
- Electron Dose
- Neutron Dose
- Unmonitored Individuals Working in Production Areas
- Medical X-ray

7.3.4.1 Photon Dose

Photon doses are reliably measured at Mound using the various dose measurement methodologies described in the Occupational External Dosimetry TBD (ORAUT-TKBS-0016-6). Correction and bias factors, as necessary, are applied in accordance with this document.

For external doses based on dosimeter results (zero and non-zero), measured doses can be estimated more precisely than maximum doses. Because individual cycle data are not available for 1977 and before, missed external doses are estimated less precisely than the measured doses. Since some information is available (e.g., routine dosimeter exchange frequencies and minimum levels of detection for Mound dosimeters), missed external doses, though overestimated, are also estimated more precisely than maximum doses. Therefore, NIOSH can bound the dose with sufficient accuracy.

7.3.4.2 Electron Dose

Electron doses are reliably measured using the “open-window” portion of the Mound dosimeters. As stated above, the Mound radiation protection program did not record the measurement from this portion of the dosimeter prior to 1960. However, when darkening of the open-window portion of the film was noted, the site program began reading the affected films. Electron doses can be estimated more precisely than maximum doses in most years at Mound; however, for years when open-window doses were not read or recorded, sufficient information is available to estimate maximum doses to the organs for which shallow dose is calculated. Therefore, NIOSH can bound the dose with sufficient accuracy.

Electron missed doses are applied in accordance with the methodology defined in the technical information bulletin *Interpretation of Dosimetry Data for Assignment of Shallow Dose* (ORAUT-OTIB-0017).

7.3.4.3 Neutron Dose

Neutron dose monitoring was identified as an area requiring improvement during operation of Dayton Units III and IV. When the polonium operation moved to the Mound site, neutron dose monitoring began after August 1949, though operations with polonium began in February of that year. The health physics program did not assume a need for neutron dosimetry prior to the beginning of dose monitoring in late 1949. Once begun, neutron dose monitoring with neutron-track emulsion was likely to measure the neutrons associated with the Po-Be sources with reasonable accuracy, based on the calibration protocol used.

Unmonitored neutron doses may be bounded using neutron-to-photon ratios based on Mound data. NIOSH also has considerable Mound NTA processing data, which provides another option to validate the claimant favorability of the neutron dose calculated using the neutron-photon ratio and the measured photon dose. Mound data includes NTA calibration with the plutonium tetrafluoride source that likely provides a neutron spectrum most similar to the neutron spectra in Mound plutonium facilities. In addition, the earlier doses determined with NTA film, once corrected for energy response limitations (i.e., the fraction of the neutron spectrum that was not measured by the NTA), can be used as another method of validation.

Calculation of missed neutron dose at Mound is more problematic than photon missed dose, which is also based on total annual doses through the year 1977. Claimant-favorable assumptions are used to overestimate the missed dose as with the photon dose; however, correction factors applied to the missed doses in accordance with the Mound Occupational External Dosimetry TBD result in a significant multiplication of the likely missed doses. For this reason, use of a neutron-to-photon ratio will likely result in a more reasonable estimate of neutron missed dose.

Given the fact that reliably-measured photon doses are associated with Mound workers, NIOSH can bound the dose with sufficient accuracy.

7.3.4.4 Unmonitored Individuals Working in Production Areas

The requirement to wear external dosimeters at Mound was based on the areas an employee accessed. This policy is described at several points in the comprehensive history of the Mound site external dose monitoring program (Meyer, 1992). Since this is the case, it is unlikely that individuals routinely entered production areas without dosimeters. Some individuals were not routinely monitored for external dose; however, they were required to use a temporary or “visitor’s” badge upon entry to controlled areas. Discussion of the policies for distributing visitors’ badges is also present in the external dose history. Since all workers entering radiation-controlled areas were required to wear a dosimeter, it is certain that those receiving the highest dose were monitored. For unmonitored individuals, claimant-favorable assumptions for on-site ambient doses are applied as part of the estimate.

Other information in routine health physics reports suggests that only some individuals were monitored for neutron dose. This policy may be based on dosimeters being assigned only to individuals working with neutron sources and initiators, and could result in unmonitored neutron dose from alpha-n reactions associated with Pu-238 and, possibly to a lesser degree, Po-210 in the major Mound processes. Because the workers who were monitored were the most highly-exposed, as well as those most likely to be exposed at all, all worker doses may be bounded by assignment of a proportional dose from neutrons as described in *Neutron Dose*, Section 7.3.4.3.

7.3.4.5 Medical X-ray

In December 2003 and January 2004, an X-ray segregation project was conducted. Due to decomposition, it became necessary to segregate the decomposed X-ray film from the good film. The films which could not be interpreted and posed a health hazard to workers were segregated and destroyed. DOE Administrative Record Retention Schedule 21 Item 21.d provides for the immediate destruction of the decomposed film. (Long, 2007)

In the absence of measurement data or other specific information, a claimant-favorable approach for organ doses for LAT view can be calculated by multiplying the entrance kerma for the PA view by a default value of 2.5 and using this value along with the ICRP (ICRP, 1982) tables to compute the appropriate organ dose. For evaluation purposes, X-ray doses are always considered acute with photon energies in the range of 30 to 250 keV. For actual dose calculations, a normal distribution with an uncertainty of ±30% at the 99% confidence interval can be assumed. However, only the positive uncertainty should be used and a multiplier of 1.3 can be used to include uncertainty at the 99% confidence interval. (ORAUT-TKBS-0016-3)

Based on the information available to NIOSH, the medical X-ray dose for the class under evaluation can be reconstructed with sufficient accuracy.

Missed Dose

Calculation of missed external dose at Mound is problematic because only annual dose results are available, in almost all cases through the year 1977. For the year 1978 and after, actual zero and non-zero results are used. If cycle data are not available for the earlier period, then missed doses are necessarily overestimated. In most cases, annual total doses are assumed to have been received in a single cycle, and the balance of the results is assumed to be zero dosimeter results; monitoring frequency assumptions are based on Table 6-11 in the Mound Occupational External Dosimetry TBD, or assumed to be the maximum routine dosimeter exchange frequency. This is known to be an overestimating practice. Other cases may require less overestimating assumptions; however, for individual cases, the method of arriving at the assumed number of zero dosimeter results is explained in the dose reconstruction report.

7.3.5 External Dose Reconstruction Feasibility Conclusion

NIOSH has established that it has access to sufficient information to: (1) estimate the maximum external 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 external radiation doses to members of the class more precisely than a maximum dose estimate.

7.4 Evaluation of Petition Basis for SEC-00090

The following subsections evaluate the assertions made on behalf of petition SEC-00090 for the Mound Site.

The petitioner provided four affidavits, one from herself and three from former EEs. Two of the affidavits describe contamination in Building 61, a non-radiologically controlled building.

The other two affidavits do not provide any supporting information regarding the petition. One affidavit is a work summary and the other is a copy of a letter sent to the petitioner from the U.S. Department of Labor in regard to her personal dose reconstruction.

The petitioner provided an affidavit contending that contaminated items were moved to areas of Building 61, a non-radiological controlled area, for disposition to other government agencies and eventually to public sale and/or auction, and that the workers in Building 61 had no follow-up monitoring when the contaminated equipment was found. In addition, concern was raised about other incidents of radiological contamination continuing throughout the plant and that as many as one incident per week occurred after serious decommissioning work began. The petitioner contends that most of the incident critiques found violations of radiological procedures or lack of radiological control.

> SEC-00090: The last item in the petitioner affidavit states that many Mound records were shipped to Nevada for burial because it was decided that the monitoring and decontamination processes *"were too costly to pursue"*. The contents of the *"records would provide valuable data regarding the change in Mound culture from Safety First to Cut Costs and Get Out"*.

A second affidavit provided by a former employee lists several points of concern, including a change in policy regarding the use of dosimeters and whole-body count requirement, incidents of contaminated material outside of radiological controlled areas, an employee with a full body burden as a result of an accident, reports of exposure to radioactive material and documents taken from Mound by an employee and the retrieval of these documents by Babcock and Wilcox.

The petitioner also included a letter sent to the U.S. Department of Labor in response to the denial of her claim. Three discussion points, as paraphrased by NIOSH, included:

1. Monitoring of potentially-radioactive material was done in a haphazard way and eventually monitoring of personnel via dosimeter, urinalysis, etc., was even more sporadic and eventually administratively denied to all except those employees chosen by Rad Control;

2. Mound Plant Employee Health Records are not available. The records were removed from the Mound Plant in 2005 and buried at LANL without the knowledge and permission of the DOL due to radioactive contamination;

3. Mound Plant Employee Health Records were removed from their storage site and kept in Building 61 prior to shipment.

The letter, as written by the petitioner, can be found in petition SEC-00090 (OSA Ref ID: 103188).

SEC petitions 00090 and 00091 were merged. Both petitions listed concerns regarding records disposal at LANL and NTS. The History of Mound (Long, 2007) provides in-depth review of the records history and the records disposal at LANL and NTS.

In November 1989, the U.S. Environmental Protection Agency (EPA) placed the Mound Site on the National Priorities List (CERCLIS No. OH6890008984). In 1993, DOE made a decision to close the Mound Site under the DOE Weapons Complex Reconfiguration Program. The reconfiguration was an effort to realign the weapons complex into a smaller, less-expensive operation. The realignment focus was to maintain the stockpile while retaining the required resources. Records generated in support of past missions were transferred to various receiver sites, or dispositioned per the National Archives and Records Administration (NARA)-approved retention schedules. Receiver sites include the Kansas City Plant, Savannah River Site, Los Alamos National Laboratory, Sandia National Laboratory, associated DOE Operations and Field Offices, the DOE Historian's Office, and the Office of Scientific and Technical Information (OSTI).

Mound Data Buried at the Nevada Test Site (NTS)

There are 1,639 potentially-contaminated lab notebooks that were buried at NTS after they were electronically imaged using Image Alchemy Software. These lab notebooks were indexed as part of the Classified Document Consolidation Project (CDCP) to a Searchable Classified Records Database (SCRD). Emergency disposal approval was granted by NARA in August 1999. Images were transferred to CD-ROMs which then became the official record, and the contaminated notebooks were destroyed per an approved DOE method.

Mound Data Buried at the Los Alamos National Laboratory (LANL)

The issue of Mound records buried at LANL was a topic of discussion at the ABRWH meeting on February 7, 2007. Glen Podonsky of the Department of Energy participated in this discussion, as well as members of the Board. In the intervening months, NIOSH has interviewed individuals with direct knowledge of this issue, and reviewed all available pertinent documentation.

There were 458 boxes of inactive classified contaminated and potentially-contaminated records shipped from Mound's classified Long Term Storage facility and the T Building classified vault to LANL at the direction of DOE Albuquerque Weapons Quality Division and supported by DOE/MEMP. Copies of receipts for contaminated or potentially-contaminated records shipped to LANL in August 1995 were sent to DOE/MEMP. These boxes were never formally inventoried at folder or document level. They were not included in the tracking database because of the classification. This collection contains classified R&D notebooks created in the 1950s and 1960s, financial and program records including detonator assembly, acceptance, surveillance reports, and reservoir R&D and engineering reports.

Forty-three of the 458 boxes were returned to Mound to support the Pre-1989 Dose Reconstruction Project being performed by MJW Corporation because it was believed that bioassay data were contained within them (see Section 7.1.1 for more details). The boxes contained photocopies, printouts, and excerpted or redacted formerly-classified laboratory notebooks. The record copies of the returned notebooks were scheduled, imaged, indexed with the Document Control classified collection, and included in the hard drive and CD shipments. Two sets of the hard drive and CDs were created; one set was sent to NNSA, and the second to OSTI in 2003. LANL was to image the remaining 415 boxes of contaminated, classified documents to make them available electronically. Per the Records Manager at the time, LANL never received the DOE funding to image the collection. In 2002, the DOE OFO General Counsel informed the BWXT Records Manager that LANL had requested approval to destroy the collection, but no further communication regarding the subject was located. DOE/LM recently received documentation validating the request and authorization for destruction of the collection.

7.4.1 Evaluation of Major Topics Detailed in Petition SEC-00090

The following major topics were detailed in Petition SEC-00090. Italicized statements are from the petition; the comments that follow are from NIOSH. Please note that the petitioner made statements in the petition, attached a letter that was included in the petition, dated May 15, 2007, and provided an affidavit. All three of these comments made by the petitioner covered the same issues, but were worded differently. One wording was chosen to answer the issue of concern.

7.4.1.1 Monitoring of Workers

SEC-00090: *Mound developed a culture of haphazard, administrate* [sic] *very controlled monitoring of workers with regard to the employee input.* [Another similar statement was made in a letter dated May 15, 2007, and attached to the petition. It reads:] *Monitoring of potentially radioactive materials and Mound Plant Employees was done in a haphazard way, with changing criteria almost daily. Monitoring of personnel via dosimeter, urinalysis, etc. was even more sporadic and eventually administratively denied to all except those employees chosen by "Rad Control". In place Administrative Controls prohibited the collection of Radiological data for most all Mound employees.*

Historical documents exhibit an on-going program of evaluation and modification of the internal and external monitoring programs. Changes were made to the program based on changing workplace conditions and resulting changes in the character of the potential exposures. Changes were also made to take advantage of new technology in order to obtain more accurate measurements. Finally, changes were required over the years to ensure compliance with contractual radiation safety requirements and, later, with federal radiation safety regulations. Data are available in archived records and, in most cases, electronic databases containing transcription of the archived records. Information sources include film badge and TLD readings, air monitoring data, and results from bioassay programs, nose swipes, fecal analyses, whole-body counts, and chest counts. There have been concerns expressed by numerous former workers about whether the bioassay requirements matched the exposure potential to workers during the D&D era. In addition, there were several Price Anderson Act violations and fines during this period. NIOSH continues to investigate whether these occurrences compromise its ability to perform dose reconstructions with sufficient accuracy.

7.4.1.2 Incident Occurrence and Reporting

SEC-00090: *Incident occurrence and critique reporting will show a pattern of one incident after another of radioactively contaminated materials in non-controlled areas for storage and shipment.*

Incidents at the Mound Site were reported in the Corrective Action Reporting System (CARS) and could potentially have been reported in the ORPS (DOE) system, as discussed in Section 5.4.5. Undetected or unmonitored intakes occur at many DOE facilities, and dose estimates can be completed using any number of methods. Estimates of the unmonitored dose can be made by using either co-worker data or by using the approximated recorded doses for a specific worker of interest occurring prior to or following a period of unmonitored dose. OCAS-PR-004 describes several different options for calculating unmonitored dose in various situations. A definitive intake date, while helpful, is not necessary for dose reconstruction. In cases where a definite intake date cannot be ascertained, claimant-favorable assumptions may be made in lieu of specific information. Claimant-favorable assumptions may include using the absorption type that results in the highest dose when the type associated with the intake is not known; use of an intake rate (acute or chronic) based on the higher dose; or assignment of an arbitrary date for an assumed acute intake based on a date that results in the maximum dose.

7.4.1.3 Employees Prohibited from Receiving Monitoring

SEC-00090: *Employees working in non-controlled areas were prohibited from receiving monitoring.*

The basic principle of dose reconstruction is to characterize the occupational radiation environment to which a worker was exposed using available worker and/or workplace monitoring information. In cases where radiation exposures in the workplace environment cannot be fully characterized based on available data, default values based on reasonable, claimant-favorable scientific assumptions are used as substitutes. EEOICPA recognized that the process of estimating radiation doses would require dealing with uncertainties and limited data, and thus, methods were established for arriving at reasonable, claimant-favorable estimates of radiation dose received by an individual who was not monitored or inadequately monitored for exposures to radiation, or for whom exposure records are missing or incomplete. To the extent that the science and data involve uncertainties, these uncertainties are typically handled to the advantage, rather than to the detriment, of the claimant. NIOSH has used the best available science to develop the methods and guidelines for dose reconstruction.

For unmonitored individuals, on-site ambient doses or claimant-favorable dose estimates derived from co-worker dose distributions are assigned as appropriate.

7.4.1.4 Mound Documentation

SEC-00090: *Mound Lab documentation was very closely guarded by management and procedure(s). They even went so far as to send Mound security to the home of* [employee's name removed] *to retrieve documents that he took home in an attempt to provide himself defense in the case of future health issues. Therefore any documentation is only within Dept. of Energy Records.*

In an interview with the Records Manager at the time of this incident, she was told by the employee that he had taken records from the site to his home. The Records Manager told him that he needed to bring the records back to the site where he could copy them so he could take home the copies. After several days, he had not done this. At this time, the Records Manager reported the event to the company attorney who called Security and requested the dispatch of security personnel to the employee's home to retrieve the records. This is not an SEC issue.

7.4.1.5 Occurrence Reporting

SEC-00090: *The (DOE) (ORPS) Occurrence reporting and processing system will contain some historic data. It is of course "not" an open record. These records were removed from the Mound site to the desert due to being radioactive.*

Incidents at the Mound Site were reported in the Corrective Action Reporting System and could potentially have been reported in the ORPS (DOE) system. In addition, incident reports were filed with the employee dosimetry records. Regarding the buried records, refer to Section 7.4.1.7 for a complete discussion on the buried records.

7.4.1.6 The "Rad" Database

SEC-00090: *The "rad" data base which did exist was not a well designed software and the integrity of the data that does exist has no value.*

The Mound Site has used several databases over the course of its history to record both internal and external employee doses. Databases such as PORECON and PURECON for internal exposures, and the External Exposure Analysis System (EXAS) and External Radiation Analysis Data (ERAD), were all merged into the Mound Environmental, Safety, and Health system (MESH) database as of September 1989. Data input to MESH is accomplished either via manual entry of data using application forms or via a number of automated data upload procedures within the application. MESH contains the following information:

- Employee data (HR): 1944 - present (in various levels of detail)
- External exposure data (ES&H): 1947 – present (in various levels of detail)
- Internal exposure data (ES&H): 1946 – present (in various levels of detail)
- Medical data (ES&H) 1990s only: some audio data from 2000-2002
- Safety data (ES&H): 1979-2003
- Environmental data (ES&H): 1992-1995 only

See Section 6.0 for a full discussion on data integrity.

7.4.1.7 Mound Plant Employee Health Records Removed to LANL

SEC-00090: *Mound Plant Employee Health Records are not available. These records were removed from the Mound Plant site in 2005 and buried in the Los Alamos, N.M. desert without the knowledge and permission of the Dept. of Labor (Energy Compensation Program) due to radioactive contamination.*

NIOSH and the ORAU Team have reviewed existing documentation relative to this concern, and interviewed three former workers involved with the records transfer to LANL. These workers include two former Mound Records Managers and a researcher who reviewed the records. In addition, NIOSH reviewed the *Mound Records Transfer History* (Long, 2007), which discusses the Mound Records Transfer History. Based on its investigation, NIOSH has determined that the records did not contain data related to employees' health records that would prevent the reconstruction of doses with sufficient accuracy.

From 1992-1995, as part of the Non-Nuclear Reconfiguration Project, all types of records were identified and shipped to six different DOE facilities/ Federal Records Centers. These records included classified, unclassified, active, and inactive records. In 1994, in preparation for the transfer of records, random sample radiation contamination surveys were performed on the inactive classified record collection located in the vault of the T-building at Mound. Some of these records were found to be contaminated with several different radionuclides. As a result, the entire collection in the T Building vault was declared contaminated and the vault subsequently designated as a Radiological Control Area. LANL ultimately agreed to accept the classified, contaminated records with the intent to image them, destroy the originals, and administer access to the imaged data. DOE Weapons Quality Division agreed and directed Mound to transfer the collection to LANL. Shipment occurred in 1995. LANL had planned to inventory the records upon their arrival because many of the boxes contained records supporting DOE nuclear production and would likely have been classified as DOE Schedule 3 (Nuclear Records). Based on the available information, NIOSH has found no evidence indicating that the collection contained primary, employee-specific dosimetry records. The original employee- specific health physics records were filed by employee name within the Mound Occupational Radiological Exposure (MORE) Records Center.

In preparation for shipment, boxes from the T Building were brought to the entrance of the classified vault. The Records Manager at Mound identified the box contents from the affixed label and documented the contents on the Reconfiguration Records Transfer sheet. Each sheet represented a box and a copy of all completed Reconfiguration Records Transfer sheets were sent to LANL. Approximately 458 cubic feet of classified, contaminated records were shipped to LANL. Items in the boxes included production records for classified programs, industrial X-rays, classified material accounting, health physics log books and a substantial number of uniquely numbered research log books. The researcher's laboratory notebooks were primarily filled in during the 1950s and 1960s. They are not believed to be the kind of files that would have recorded radiation exposure information in them, but instead, dealt with the details of their particular research project's progress. (Long, 2007 p. 164, 168) The Classified Document Control function maintained a file index that cross-referenced the employee name who received the log notebook. This file index was eventually scanned and is retrievable at OSTI.

On May 13, 2003, LANL requested and received approval from NNSA/AL to destroy and dispose of (i.e., bury) the T Building collection.

Laboratory notebooks were part of the burial that may have included information on personal dosimetry or bioassay results. The information in the notebooks is not believed to be the primary dosimetry information because all health physics-related information was kept in the MORE records database. Therefore, any included information would not be considered primary data. The buried data are not crucial to complete a dose reconstruction with sufficient accuracy. Bioassay and dosimetry records are routinely in the individual's personal dosimetry file. MORE (established in the late 1980s) kept all employee-specific exposure records, radiological incident reports, and visitor exposure records.

Approximately two years after the T Building collection was shipped to LANL (~1998), Mound contracted with MJW Corporation to perform a Pre-1989 Dose Reconstruction Project. A scientist from MJW Corporation went to LANL and reviewed a selection of the T Building records. The selected laboratory notebooks were thought to be potentially useful for the pre-1989 project. However, once the boxes were reviewed by the scientist, it was determined that bioassay data retrieved from LANL had already been at Mound in the form of microfilms or other records. The retrieved data were only used for cross-referencing existing data. As a result of the review, 43 boxes containing laboratory notebooks were returned from LANL to Mound for use in the dose reconstruction project. These boxes were incorporated into the A-basement classified scanning project (once scanned, the originals were packed into LSA drums ultimately shipped to NTS for burial).

In 1999, Mound Security began consolidating the classified repositories within the site as Mound began to work towards site closure. Eventually, all classified documents were moved to A-basement. The combined collections (now ~100,000 documents) were scanned using Image Alchemy software. Two sets of the hard drive and DVDs were created; one set was sent to NNSA/AL and the second set went to OSTI in 2003.

After the Non-Nuclear Reconfiguration ended, all remaining unclassified records were transferred to the Dayton Federal Record Center.

7.4.1.8 Mound Plant Employee Health Records Kept in Building 61

SEC00090: *Mound Plant Employee Health Records were removed from their storage site at Mound and kept in Building 61 prior to their shipment to the desert site. I was the Supervisor over the crews that were involved with the removal and shipments of these records (materials). These materials sat in Building 61 for a period of time prior to their shipment to Nevada.*

1,639 potentially-contaminated lab notebooks were buried at NTS after they were electronically imaged using Image Alchemy Software. These lab notebooks were indexed as part of the Classified Document Consolidation Project (CDCP) to a Searchable Classified Records Database (SCRD). Emergency disposal approval was granted by NARA in August 1999. Images were transferred to CD-ROMs which then became the official record, and the contaminated notebooks were destroyed per an approved DOE method.

In the affidavit provided by the petitioner, she also states: *Building 61 was a non radiological building controlled building* [sic]. *Dosimetry and other monitoring processes were systematically reduced and eventually eliminated for most employees stationed in this building. When contaminated equipment was discovered in this building, no follow-up monitoring was provided to employees working in the area.*

At the time of this writing, NIOSH has not yet been able to verify a contamination incident for Building 61 that would impact NIOSH's ability to bound the dose for the proposed class. Attempts were made to contact the SEC-00090 petitioner. NIOSH was able to contact another person listed in Petition SEC-00091 to discuss this incident; however, this person could not remember the details or the approximate date of this issue.

Air concentration measurements can be used to assign internal doses from radioactive material in the general environment, in accordance with the Mound Occupational Environmental Dose TBD (ORAUT-TKBS-0016-4), as discussed in Section 6.3 of this evaluation. While this is an important issue, NIOSH believes that this issue does not have SEC implications. NIOSH does not consider this exposure scenario an example of a maximum or bounding-exposure scenario. In the case of an unmonitored worker who had the potential for radiation exposure, NIOSH could provide a bounding dose estimate (i.e., assign dose based on the air sample data or based on the maximally-exposed, monitored worker groups) for the proposed worker class definition.

7.4.2 Evaluation of Specific Petitioner Statements in SEC-00090

This subsection presents specific affidavit statements made by workers on behalf of petition SEC-00090. The italicized statements are from the petition; the comments that follow are from NIOSH.

7.4.2.1 Employee badges

SEC-00090: *1) When I joined Mound in 1981all employees were give* [sic] *dosimeter badges. The badges were read on a periodic basis and all employees were also given a periodic whole body count. 2) Shortly after Babcok* [sic] *and Wilcox assumed control of Mound they, as a cost savings effort, removed dosimeters from all personnel who did not immediately work in radiological areas. As an attempt to provide some minimal of* [sic] *radiological monitoring dosimeters were hung around the plant, but no effort was made to track or monitor the movement of individuals into those various areas, so any attempt to tie those reading to individuals was impossible. 3) If an employee made a special request for a dosimeter badge, it was denied out of hand, as an unnecessary expense.*

Historical documents exhibit an on-going program of evaluation and modification of the internal and external monitoring programs. Changes were made to the program based on changing workplace conditions and resulting changes in the character of the potential exposures. Changes were also made to take advantage of new technology in order to obtain more accurate measurements. Finally, changes were required over the years to ensure compliance with contractual radiation safety requirements and, later, with federal radiation safety regulations. Data are available in archived records and, in most cases, electronic databases containing transcription of the archived records. Information sources include film badge and TLD readings, air monitoring data, and results of bioassay programs, nose swipes, fecal analyses, whole-body counts, and chest counts.

7.4.2.2 Contamination Incidents

SEC-00090: *I have specific recollection of several instances of radiological materials moving outside of the controlled areas. In one instance contaminated computers were moved through Building 61 and actually sold on the public market only to have Mound personnel have to go into the buyer's warehouse and recover those computers after they had left the Mound site. In addition, I have a specific recollection of handling an incident report where a worker in the dosimeter processing lab was contaminated by radiological material that accidentally got into her lab.*

Although no specifics are given in this example, it is clear that contamination incidents occurred throughout the operating history of Mound. It has been demonstrated that the doses resulting from such incidents can be estimated. Doses from internally-deposited radionuclides are estimated from bioassay results, and external doses are measured using film badges or TLDs. While this is an important issue, NIOSH believes that such issues do not have SEC implications. In the case of an unmonitored worker who had the potential for radiation exposure, NIOSH could estimate unmonitored dose based on co-worker data. This does not prevent NIOSH from bounding the dose for the proposed class.

7.4.2.3 Plutonium through Ventilation Ducts

SEC-00090: [Employee name removed], *now deceased, told me that he had a full body burden as a result of an accident where a failure to properly control radiological material allowed plutonium to move through ventilation ducts and into his office, contaminating him. He also told me of one particularly hot area where he worked where the dosimeter badges were always completely exposed. No effort was ever made to determine of* [sic] *the badges were just barely fully exposed or if they had been exposed to ten times the radiation necessary to fully expose the film. He went on to relate that despite his complaints, management never made any effort to adjust the dosimeter reading schedule or to determine by other means the actual exposure.*

There were certainly incidents throughout the operational history of Mound. However, the occurrence of such incidents does not prevent NIOSH from conducting dose reconstructions of sufficient accuracy. Film badge dosimeters in use at the Mound site contained both a sensitive and an insensitive element. Occupational-range measurements were made on the sensitive element, and the insensitive element had a much higher-response range. It is unlikely that any occupational exposure at Mound would fully expose the insensitive element. On the other hand, neutron film emulsions, which measure neutron doses by accumulating damage tracks, can also be darkened by gamma radiation to the extent that the damage tracks are difficult to read. When this occurs, the dose is very likely to be estimated by the health physics program personnel; for any such occurrence in the record, the neutron dose may be estimated by a proportional neutron dose based on the recorded photon dose.

7.4.2.4 Reports

SEC-00090: *As a quality engineer and a member of the Mound audit staff, I constantly handled reports relating to people being exposed to radioactive materials because of system and management failures. Through I do not have any specific details, all these reports were carefully submitted to the Department of Energy and, in theory, corrective actions were taken, but exposure incidents were a constant occurrence.*

Although no specifics were given in this example, incidents did occur throughout the operating history of Mound. It has been demonstrated that the doses resulting from such incidents can be estimated. Doses from internally-deposited radionuclides are estimated from bioassay results, and external doses are measured using film badges or TLDs. While this is an important issue, such issues do not have SEC implications. In the case of an unmonitored worker who had the potential for radiation exposure, NIOSH could estimate unmonitored doses. This does not prevent NIOSH from bounding the dose for the proposed class.

7.4.2.5 Documents taken from Mound

SEC-00090: *I am intimately familiar with the story of the documents that* [employee name removed] *took from Mound and that Babcock and Wilcox so desperately wanted to recover, as those documents were stored, for some period, in my basement because of* [employee name removed] *concerns about how Babcock and Wilcox would react to those documents, which clearly demonstrated their mis-management would be perceived and received by responsible regulatory authority.*

In an interview with the Records Manager at the time of this incident, she was told by the employee that he had taken records from the site to his home. The Records Manager told him that he needed to bring the records back to the site where he could copy them and take home the copies. After several days, he had not done this. At this time, the Records Manager reported the event to the company attorney who called Security and requested the dispatch of security personnel to the employee's home to retrieve the records. This is not an SEC issue.

7.4.3 Evaluation of General Concerns

7.4.3.1 Various Contamination Incidents

SEC-00091 presented a list of general statements by a former worker. She listed many concerns which included: use of special clothing while mixing MOCA and not always wearing a radiation badge, repeated showering, work with Be, travel from building to building for different jobs, death of a young man from radiation in the T Building in the medical facility, persistent contamination in her hair, radiation in her right arm so she could not touch her husband for three weeks, chemical storage areas, and a resume of some of her job duties.

The substance MOCA is a polyurethane elastomer used in fabricating weapons components and is not a radioactive material. Personnel working with non-radioactive weapons components (sometimes called "small parts workers") were often not monitored for radiation dose due to the lack of radiation fields in these workplaces. Although no specifics are given in this example, it is clear that contamination incidents occurred throughout the operating history of Mound. It has been demonstrated that the doses resulting from such incidents can be estimated. Doses from internally-deposited radionuclides are estimated from bioassay results, and external doses are measured using film badges or TLDs. While this is an important issue, such issues do not have SEC implications. In the case of an unmonitored worker who had the potential for radiation exposure, NIOSH can estimate unmonitored dose based on co-worker data. Regarding the concern about a young man who died from radiation in the T Building, current research has not, to date, resulted in the discovery of a record of such an incident.

Approximately 400 NOCTS files were reviewed for incident reports. Approximately one-third of the files contained incident reports describing the incident, the date of the incident, and what measures were taken (e.g., nose swipe, urine samples). The bioassay results are also found in the individual employee's file. The dates of the incidents spanned the entire period under evaluation and included spills, contamination of personnel and equipment, glovebox issues, and elevated air samples.

7.4.3.2 Inadequate Monitoring and Protection

The SEC-00091 petitioner presented several non-specific concerns, including inadequately monitored and inadequately protected radiation workers, large quantities of several radionuclides that were processed without engineering controls or protection as would be expected by today's standards, non-uniformity of radiation monitoring, manufacture of Po-Be neutrons, and research and development of radionuclides, including Ra-226, Ac-227, Th-228, Th-230, Pa-231, and U-233. The claimant clearly states that these comments can be referred to as radiation exposures and radiation doses were not monitored, either through personal monitoring or through area monitoring.

NIOSH is aware that the engineering controls of the past can be quite different from the standards of today. In addition, NIOSH is aware of the processes that occurred at Mound during its operational history and can estimate doses based on internally-deposited radionuclides from bioassay results. The other radionuclides, as mentioned above, have been discussed in Section 6.1.

7.4.3.3 Actinium-227 Urine Samples

During interviews with former Mound workers, a concern was raised regarding Ac-227 urine bioassay samples collected from employees involved in a 1991 R-Building Corridor 5 D&D job. These samples were not analyzed for a number of years, and there were apparently quality control issues with them once they were analyzed. This situation resulted in Price-Anderson Act violations (PAAA, 2006). NIOSH is continuing to investigate this issue for impact on our ability to conduct dose reconstructions with sufficient accuracy for this situation.

7.4.3.4 Neutrons

The workers associated with polonium research and neutron source production during the very early years of Monsanto (1943-1949) were not monitored for neutrons. SEC-00049 qualified as a Special Exposure Cohort based on insufficient data available to support internal dose construction.

The potential for exposure to neutrons existed for workers during the early years of Mound, and personal monitoring for neutrons started in September 1949 (Meyer, 1994; ORAUT-TKBS-0016-6). NIOSH can now estimate the potential neutron exposures with sufficient accuracy. The *Documentation of Variables in the Assessment of Neutron Doses at Mound Laboratory* (Variables, 1977), discusses track fading and NTA film sensitivity to low-energy neutrons. According to that document:

> *Prior to the production of Radioisotopic Thermoelectric Generators (RTG) at Mound Laboratory, polonium-beryllium (PoBe) neutron sources were used for film calibration. The energy spectrum from these neutron sources, having an average energy of about 4.5 MeV, corresponded to the spectrum of neutrons in the radiation areas.* (Variables, 1977, pdf page 3).

In addition, the document goes on to say:

> *Since track fading is of significance in deriving dose determinations for personnel working in our areas with low energy neutron spectrums, calibration procedures utilizing the PuF4 sources were devised to incorporate corrections for track fading. Dosimeter badges of personnel have always been exchanged on varying frequencies based on the employee's degree of involvement and potential exposure. Exchanges have been made for periods of one or more days, one week, two weeks, and four weeks. Predominantly, most badges are routinely exchanged on either a two week or four week basis. The calibration procedure involves the exposure of film in badges to determine film response to known exposure for any increment of time up to four weeks. Each calibration exercise involves exposing different sets of badges to the same total dose, but at different rates over a four week period. All badges are processed at the same time on the Monday following the four week period. We typically expose 5 sets of badges to total dose of 1.0 rem. The badges, assuming we expose all to 1.0 rem, are exposed as follows:*
>
> *Set 1 - Exposed to 250 rem per week for 4 consecutive weeks*
> *Set 2 - Exposed to 333 rem per week for 3 consecutive weeks prior to process date*
> *Set 3 - Exposed to 500 rem per week for 2 consecutive weeks prior to process date*
> *Set 4 - Exposed to 1.0 rem during the week prior to the process date.*
> *Set 5 - Exposed to 1.0 rem on the process date.*
>
> *The response for each batch in tracks is plotted versus time and appropriate factors derived for dose evaluation for any segment of time up to four weeks. In routine operations, the assumption is made that exposures have been uniformly received by the employee during the time period the badge was worn. Health Physics survey groups closely review scheduled operations for non-routine special operational activities. Personnel performing special operations are monitored with badges for the exact period of the activity and appropriate factors are used for evaluating dose received.* (Variables, 1977, pdf pages 5-6)

NIOSH concludes that NTA film sensitivity to low-energy neutrons and track fading are not SEC issues at Mound.

7.4.3.5 D&D Era Bioassay

There have been concerns expressed by numerous former workers about whether the bioassay requirements matched the exposure potential to workers during the D&D era. In addition, there were several Price Anderson Act violations and fines during this period. NIOSH continues to investigate whether these occurrences compromise its ability to perform dose reconstructions with sufficient accuracy.

7.5 Summary of Feasibility Findings for Petition SEC-00090

This report evaluates the feasibility for completing dose reconstructions for employees at the Mound Plant from February 1, 1949 through August 17, 2007. NIOSH found that the available monitoring records, process descriptions and source term data available are sufficient to complete dose reconstructions for the proposed class of employees, with the exceptions listed below.

Table 7-3 summarizes the results of the feasibility findings at the Mount Plant for each exposure source during the time period February 1, 1949 through August 17, 2007.

Table 7-3: Summary of Feasibility Findings for SEC-00090

February 1, 1949 through August 17, 2007

Source of Exposure	Reconstruction Feasible	Reconstruction Not Feasible
Internal [1]		
Actinium-227	X (Mar 1, 1959 – Aug 17, 2007)	X (Oct 1,1949 – Feb 28, 1959) [2]
Americium-241	x	
Curium-244	x	
Plutonium-238	x	
Plutonium-239	x	
Plutonium-240	x	
Polonium-210	x	
Protactinium- 241	x	
Radium-223	x	
Radium-224	x	
Radium-226	X (Mar 1, 1959 – Aug 17, 2007)	X (Oct 1,1949 – Feb 28, 1959) [2]
Radon-220	x	
Radon-222	x	
Thorium-228	X (Mar 1, 1959 – Aug 17, 2007)	X (Oct 1,1949 – Feb 28, 1959) [2]
Thorium-230	x	
Thorium-232	x	
Uranium-233	x	
Uranium-234	x	
Uranium-235	x	
Uranium-238	x	
External		
- Gamma	x	
- Beta	x	
- Neutron	x	
- Occupational Medical x-ray	x	

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

[2] K-65 sludge (the source of Ac-227, Ra-226, and Th-228 concerns) did not arrive on site until October 1949; therefore, these radionuclides are not relevant from the beginning of the evaluation period (February 1, 1949) until October, 1949. The related area of work was decontaminated and decommissioned on February 28, 1959; sufficient monitoring was in place from that time forward.

As of December 6, 2007, a total of 491 claims have been submitted to NIOSH for individuals who worked at Mound and are covered by the proposed class definition evaluated in this report. Dose reconstructions have been completed for 348 of those individuals (71%).

8.0 Evaluation of Health Endangerment for Petition SEC-00090

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 has insufficient information regarding internal Ra-Ac-Th exposures at Mound from the arrival of K-65 sludge in October 1949 through February 28, 1959, when the related area of work was decontaminated and decommissioned and sufficient monitoring was in place. NIOSH's evaluation determined that it is not feasible to estimate radiation dose for members of the proposed class with sufficient accuracy based on the sum of information available from available resources. Modification of the class definition regarding health endangerment and minimum required employment periods, therefore, is required.

9.0 NIOSH-Proposed Class for Petition SEC-00090

Based on its research, NIOSH reduced the petitioner-requested class to define a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all employees of the Department of Energy (DOE), its predecessor agencies, and DOE contractors and subcontractors, who were monitored or should have been monitored, for internal Ra-Ac-Th exposures while working in all areas of the Mound site for a number of work days aggregating at least 250 work days from October 1, 1949 through February 28, 1959, or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

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) and several Mound databases, for information relevant to SEC-00090. 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 has complied with these standards of performance in determining that it would be feasible to reconstruct the dose for the class proposed in this petition.

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10.0 References

42 C.F.R. pt. 81, *Guidelines for Determining the Probability of Causation Under the Energy Employees Occupational Illness Compensation Program Act of 2000;* Final Rule, Federal Register/Vol. 67, No. 85/Thursday, p 22,296; May 2, 2002; SRDB Ref ID: 19391

42 C.F.R. pt. 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000*; Final Rule; May 2, 2002; SRDB Ref ID: 19392

42 C.F.R. pt. 83, *Procedures for Designating Classes of Employees as Members of the Special Exposure Cohort Under the Energy Employees Occupational Illness Compensation Program Act of 2000*; Final Rule; May 28, 2004; SRDB Ref ID: 22001

42 U.S.C. §§ 7384-7385 [EEOICPA], *Energy Employees Occupational Illness Compensation Program Act of 2000*, as amended

OCAS-IG-001, *External Dose Reconstruction Guideline*, Rev. 2; National Institute for Occupational Safety and Health (NIOSH); Cincinnati, Ohio; August 25, 2006; SRDB Ref ID: 29929

OCAS-PR-004, *Internal Procedures for the Evaluation of Special Exposure Cohort Petitions*, Rev. 0, National Institute for Occupational Safety and Health (NIOSH); Cincinnati, Ohio; September 23, 2004; SRDB Ref ID: 32022

ORAUT-OTIB-0002, *Maximum Internal Dose Estimates for Certain DOE Complex Claims*, Rev. 02; Oak Ridge Associated Universities; February 7, 2007; SRDB Ref ID: 29947

ORAUT-OTIB-0006, *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures*, Rev. 03 PC-1; Oak Ridge Associated Universities; December 21, 2005; SRDB Ref ID: 20220

ORAUT-OTIB-0017, *Interpretation of Dosimetry Data for Assignment of Shallow Dose,* Rev. 01; Oak Ridge Associated Universities; October 11, 2005; SRDB Ref ID: 19434

ORAUT-OTIB-0018*, Internal Dose Overestimates for Facilities with Air Sampling Programs*, Rev. 01; Oak Ridge Associated Universities; August 9, 2005; SRDB Ref ID: 19436

ORAUT-OTIB-0049, *Estimating Doses for Plutonium Strongly Retained in the Lung*, Rev. 00; Oak Ridge Associated Universities; February 6, 2007; SRDB Ref ID: 29975

ORAUT-OTIB-0060, *Internal Dose Reconstruction*, Rev. 00, Oak Ridge Associated Universities; February 6, 2007, SRDB Ref ID: 29984

ORAUT-OTIB-0061, *Internal Dosimetry Coworker Data for the Mound Site,* Rev. 00, Oak Ridge Associated Universities; June 22, 2007; SRDB Ref ID: 32524

ORAUT-OTIB-0066, *Calculation of Dose from Intakes of Special Tritium Compounds*, Rev. 00; Oak Ridge Associated Universities; April 26, 2007; SRDB Ref ID: 31421

ORAUT-PROC-0006, *External Dose Reconstruction, Attachment A*; Rev. 0, Oak Ridge Associated Universities; June, 27, 2003; SRDB Ref ID: 20211

ORAUT-PROC-0060, *Occupational Onsite Ambient Dose Reconstruction for DOE Sites*, Rev. 01; Oak Ridge Associated Universities; June 28, 2006; SRDB Ref ID: 29986

ORAUT-PROC-0061, *Occupational X-Ray Dose Reconstruction for DOE Sites*, Rev. 01; Oak Ridge Associated Universities; July 21, 2006; SRDB Ref ID: 29987

ORAUT-TKBS-0003, *Technical Basis Document for the Savannah River Site*, Rev. 01, Oak Ridge Associated Universities; August 21, 2003; SRDB Ref ID: 20178

ORAUT-TKBS-0016-1, *Technical Basis Document for the Mound Site – Introduction*, Rev. 00; Oak Ridge Associated Universities; September 9, 2004; SRDB Ref ID: 19784

ORAUT-TKBS-0016-2, *Technical Basis Document for the Mound Site – Site Description*, Rev. 00 PC-1; Oak Ridge Associated Universities; July 7, 2006; SRDB Ref ID: 30057

ORAUT-TKBS-0016-3, *Technical Basis Document for the Mound Site – Occupational Medical Dose*, Rev. 01 PC-2; Oak Ridge Associated Universities; March 31, 2006; SRDB Ref ID: 30059

ORAUT-TKBS-0016-4, *Technical Basis Document for the Mound Site – Occupational Environmental Dose*, Rev. 00; Oak Ridge Associated Universities; October 6, 2004; SRDB Ref ID: 19789

ORAUT-TKBS-0016-5, *Technical Basis Document for the Mound Site – Occupational Internal Dosimetry*, Rev. 00; Oak Ridge Associated Universities; September 9, 2004; SRDB Ref ID: 19790

ORAUT-TKBS-0016-6, *Technical Basis Document for the Mound Site – Occupational External Dosimetry*, Rev. 00; Oak Ridge Associated Universities; August 11, 2004; SRDB Ref ID: 19791

ORAUT-TRNG-0051, *Dose Reconstruction Training*, Rev. 03; Oak Ridge Associated Universities; March 1, 2007; SRDB Ref ID: Not currently in SRDB

Ac-227, 1952, *Report for Research on Substitute Materials, October 1, 1951 to December 31, 1951 (Actinium-227)*, Mound Laboratory; MLM- 650; February 4, 1952; SRDB Ref ID: 24671

Bismuth, 1952, *Bismuth Recovery Process, Engineering Research Final Report*; Mound Laboratory; MLM-734, August 5, 1952; SRDB Ref ID: Not currently in SRDB

BWXT, 2000, Radon Study Summary Report; 2000; Document search underway; SRDB Ref ID: Not currently in SRDB

Decon, 1951, *Decontamination of Process Waste Solutions Containing Fission Products by Adsorption and Coprecipitation Methods (Information Report)*, Mound Laboratory; C. S. Lowe, et al.; MLM-621; November 13, 1951; SRDB Ref ID: 24668

DOE, 1988, *Radiation Protection for Occupational Workers*, DOE Order 5480.11, U.S. Department of Energy; Washington, D.C.; SRDB Ref ID: 8073

Evaluation, 1970, *Evaluation of Accidental Personnel Exposures to Plutonium-238: Whole Body Counting and Bioassay Results*, H. F. Anderson; W. E. Sheehan; J. R. Mann; R. W. Bistline; Health Physics 18(6):631-639; June 1970; SRDB Ref ID: 8752

Guido, J., 2003, Response to Beverly Long Concerning A Response To NIOSH Request for Additional Personnel Exposure Information and personnel communication with Wes Proctor, May, 2004; SRDB Ref ID: Not currently in SRDB

ICRP, 1959, *Recommendations of the International Commission on Radiological Protection*, Publication 2; International Commission for Radiological Protection; Pergamon Press; Oxford, England; SRDB Ref ID: 11106

ICRP, 1975, *Report of the Task Group on Reference Man*, Publication 23, International Commission for Radiological Protection; Pergamon Press; Oxford, England; 1975: SRDB Ref ID: 22735

ICRP, 1982, *Limits for Intakes of Radionuclides by Workers,* Publication 30, International Commission for Radiological Protection; Pergamon Press; Oxford, England; 1982: SRDB Ref ID: 22733

ICRP, 1987, *Lung Cancer Risk from Indoor Exposure to Radon Daughters*, Publication 50, International Commission for Radiological Protection; Pergamon Press; Oxford, England; Commonly available

Incident Reports, 1973-81, Monsanto Research Corporation; SRDB Ref ID: 25502

King, 1995, *Mound Site Radionuclides by Location*, W. King; MD-22153 Issue 1; U.S. Department of Energy; Miamisburg, Ohio; 1995; SRDB Ref ID: 3240

Kirby, 1952, *Tentative Procedure for the Analysis of Mixtures Containing Radium-226, Actinium-227 and Thorium-228*, H. W. Kirby; AEC Research and Development Report MLM-773, Mound Laboratory, Miamisburg, Ohio; 1952; SRDB Ref ID: 1962, page 512.

Kirby, 1954, *Determination of Radium-226, Actinium-227 and Thorium-228 in Human Urine (Ad Interim Report)*, H. W. Kirby and R. M. Brodbeck; AEC Research and Development Report MLM-1003; Mound Laboratory; Miamisburg, Ohio; 1954; SRDB Ref ID: 1962, page 522

Kirby, 1959, *The Radiochemistry of Protactinium*, H. W. Kirby; U.S. Energy Commission Report NAS-NS 3016; Subcommittee on Radiochemistry; National Academy of Sciences-National Research Council; Washington, D.C.; December, 1959; Commonly available

Long, 2007, *Mound Records Transfer History,* Beverly Long; January 3, 2007: SRDB ID 36234

Meyer, 1992, *History of Mound Bioassay Programs*, H. E. Meyer; MLM-MV-93-93-0003; EG&G Mound Applied Technologies; Miamisburg, Ohio; 1992; SRDB Ref ID: 1962

Meyer, 1994, *History of Personnel External Dosimetry Program at the Dayton Project and Mound Laboratory 1946-1993*; H. E. Meyer; Mound Laboratory; SRDB Ref IDs: 3268, 3276, 3281, 3297, 3299, 3303, 3315

Meyer and Reeder, 1992, *Plutonium Historical Dose Reconstruction Program*, Herbert E. Meyer and Dianne L. Reeder; Mound Laboratory; July 31, 1992; SRDB Ref ID: Not currently in SRDB

Meyer, date unknown, *Enclosure #6: Thorium 232 - Mound Facility*, by H. E. Meyer; Mound Laboratory; historical overview; date unknown; SRDB Ref ID: 12700

MJW, 1998, *Pre-1989 Dose Assessment Project, Phase I Interim Report*, Volume I; MJW Corporation, Inc.; June 15, 1998; SRDB Ref ID: 8667

MJW, 2002, Phase I, *Pre-1989 Dose Assessment Project, Phase I Final Report*, Volume I; MJW Corporation, Inc.; April 2002; SRDB Ref ID: 8745

MJW, 2002, Phase II, *Pre-1989 Dose Assessment Project, Phase II Final Report*, MJW Corporation, Inc.; June, 2002; SRDB Ref ID: 8738

Monex, 1955, *Development of the Monex Thorium Refining Process through the Pilot Plant Stage, Final Report*, by F. C. Mead, et al.; MLN-1072; Mound Laboratory; December 31, 1955; SRDB Ref ID: 12798

Mound, 1999, *Work Plan for Environmental Restoration of the DOE Mound Site, The Mound 2000 Approach*, Final, Rev. 0; Feb 1999; SRDB 12624

Mound, 2002, *Mound External Dosimetry Data*, Cincinnati Operations Center Terminal Server, O:\DOE Site Images\Mound\07-25-03-Data Capture\010000993.pdf, downloaded September 9, 2003, ORAU Cincinnati Operations Center, Cincinnati, Ohio.

Mound Laboratory, 1968, *Bioassay Group Analytical Procedures*, Technical Manual MD, Issue 1 (TM-20736); Miamisburg, Ohio; 1968; SRDB Ref ID: 4097

Mound Laboratory, 1981, *Tritium in Water*, Technical Manual PD-80030, Issue 1 (TM-80030), Environmental Analytical Procedures; Miamisburg, Ohio; 1981; SRDB Ref ID: 1962, page 688

Mound Laboratory, 1996, *Internal Dosimetry Technical Basis Manual-Appendix D*, Technical Manual MD-10435, Issue 4, (TM-10435), Miamisburg, Ohio; 1996; SRDB Ref ID: 2537

Mound Po, various dates, *Information File #2: Misc. Po-210 Documents*; various authors; various dates; Mound Laboratory; SRDB Ref ID: 8746

NBS, 1953, *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*, Handbook 52; National Bureau of Standards; U.S. Department of Commerce, Washington, D.C.; SRDB Ref ID: 12332

Neutron, 2001, *Validation of Personnel Neutron Dosimeters in the Workplace at Mound*, R. I. Scherpelz, et al; Pacific Northwest National Laboratory; PNWD-3118; September, 2001; SRDB Ref ID: 35720

ORAU, 2003a, *Processes and Characteristics of Major Isotopes Handled at Mound*, ORAU file locator, DOE Site Images, Mound Laboratory, Data Capture 11-18-03, Folder 2311, pp. 65-126; Oak Ridge Associated Universities for NIOSH Office of Compensation Analysis and Support; Cincinnati, Ohio; SRDB Ref ID: 12328

ORAU, 2003b, *Appendix A: Detectable Amounts for Urinalysis*, ORAU file locator, DOE Site Images, Mound Laboratory, Data Capture 11-18-03, Folder 2311, p.1; Oak Ridge Associated Universities for NIOSH Office of Compensation Analysis and Support; Cincinnati, Ohio; SRDB Ref ID: 8641 pg 2

ORAU, 2003c, *Specific 24-Hour Fecal Records*, ORAU file locator, DOE Site Images, Mound Laboratory, Data Capture 11-18-03, Folder 2311; Oak Ridge Associated Universities for NIOSH Office of Compensation Analysis and Support; Cincinnati, Ohio; SRDB Ref ID: 8641

ORAU, 2003d, *Database of Ra-Ac-Th Excretion Data*, ORAU file locator, DOE Site Images, Mound Laboratory, Data Capture 09-24-03, Folder 1805; Oak Ridge Associated Universities for NIOSH Office of Compensation Analysis and Support; Cincinnati, Ohio SRDB Ref ID: 8754

ORAU, 2003e, *Database of Excretion Data for Other Radionuclides*, ORAU file locator, DOE Site Images, Mound Laboratory, Data Capture 09-24-03, Folder 1806; Oak Ridge Associated Universities for NIOSH Office of Compensation Analysis and Support; Cincinnati, Ohio; SRDB Ref ID: 8757

PAAA, 2006, *Price Anderson Amendments Act (PAAA) Documents Regarding Fines Levied Against Mound from 1990 to Present*, Department of Energy, Office of Legacy Management; SRDB Ref ID: 37733

Personal Communication, 2007, ORAU interview with Joyce Massie, S. M. Stoller Corporation, October 25, 2007; SRDB Ref ID: 37339

Polonium, 1956, *Polonium*, book by H. V. Moyer of The Ohio State University for the U. S. Atomic Energy Commission; July 1956; SRDB Ref ID: 12703

Spitz, 1989, *Retrospective Analysis of Polonium-210 Urinalysis Data Collected as Part of a Routine Occupational Monitoring Program Between 1943 and 1965*, H. B. Spitz; Quality Assurance Report; EG&G, Mound Technologies, Radiological Science; Miamisburg, Ohio; February 28, 1989; SRDB Ref ID: Not currently in SRDB

Ten-Year Plan, 1977, *Ten-Year Plan for Decontamination and Decommissioning for Mound Laboratory*, Sam S. Freeman; Monsanto Research Corporation; MLM-MU-77-66-0001; June 30, 1977; SRDB Ref ID: 33360

UNC Geotech, 1990, *DOE Indoor Radon Study*, Office of Projects and Facilities Management, UNC Geotech; Grand Junction, Colorado; April 12, 1990; SRDB Ref ID: 13191

Variables, 1977, *Documentation of Variables in the Assessment of Neutron Doses at Mound Laboratory,* W. A. Bigler; Mound Laboratory; June 17, 1977; SRDB Ref ID: 3144

White Paper T, 2002, *T Building Structural History and Process History Summary Background Document* (unpublished) BWXT of Ohio, November 2002; SRDB Ref ID: 25941

Yt-90, *Preparation of Carrier-Free Yttrium-90*, Document search underway; SRDB Ref ID: Not currently in SRDB