SEC Petition Evaluation Report
Petition SEC-00189

Report Rev #: 0

Report Submittal Date: August 15, 2012

Subject Expert(s):	Michael Domal, Roger Halsey Ray Clark, Keith Varnado
Site Expert(s):	N/A

Petition Administrative Summary

Petition Under Evaluation

Petition #	Petition Type	Petition Receipt Date	Qualification Date	DOE/AWE Facility Name
SEC-00189	83.13	July 18, 2011	October 11, 2011	Oak Ridge National Laboratory (X-10)

Petitioner-Requested Class Definition

All contractor employees, subcontractor employees, and AEC employees who were monitored or should have been monitored for any of the various radionuclides and fission products present at the X-10 plant while working in all areas at the Oak Ridge National Laboratory (X-10) from January 1, 1943 through December 31, 1952.

Class Evaluated by NIOSH

All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area at the Oak Ridge National Laboratory (X-10) in Oak Ridge, Tennessee, from January 1, 1943 through July 31, 1955.

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

All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area at the Oak Ridge National Laboratory (X-10) in Oak Ridge, Tennessee, from June 17, 1943 through July 31, 1955, for a number of work days aggregating at least 250 work days, occurring either solely under this employment, or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort.

Related Petition Summary Information

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

Related Evaluation Report Information

Report Title	DOE/AWE Facility Name
N/A	N/A

ORAU Lead Technical Evaluator: Michael Domal

ORAU Peer Review Completed By: Michael Kubiak

Peer Review Completed By:	[Signature on File] *Timothy D. Taulbee*	8/16/2012 *Date*
SEC Petition Evaluation Reviewed By:	[Signature on File] *J. W. Neton*	8/17/2012 *Date*
SEC Evaluation Approved By:	{Signature on File] *Stuart L. Hinnefeld*	8/17/2012 *Date*

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Evaluation Report Summary: SEC-00189
Oak Ridge National Laboratory (X-10)

This evaluation report by the National Institute for Occupational Safety and Health (NIOSH) addresses a class of employees proposed for addition to the Special Exposure Cohort (SEC) per the *Energy Employees Occupational Illness Compensation Program Act of 2000*, as amended, 42 U.S.C. § 7384 *et seq.* (EEOICPA) and 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*.

Petitioner-Requested Class Definition

Petition SEC-00189 was received on July 18, 2011, and qualified on October 11, 2011. The petitioner requested that NIOSH consider the following class: *All contractor employees, subcontractor employees, and AEC employees who were monitored or should have been monitored for any of the various radionuclides and fission products present at the X-10 plant while working in all areas at the Oak Ridge National Laboratory (X-10) from January 1, 1943 through December 31, 1952.*

Class Evaluated by NIOSH

Based on its preliminary research, NIOSH expanded the petitioner-requested class. NIOSH evaluated the following class: All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area at the Oak Ridge National Laboratory (X-10) in Oak Ridge, Tennessee, from January 1, 1943 through July 31, 1955.

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

Based on its full research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area at the Oak Ridge National Laboratory (X-10) in Oak Ridge, Tennessee, from June 17, 1943 through July 31, 1955, for a number of work days aggregating at least 250 work days, occurring either solely under this employment, or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort.

Feasibility of Dose Reconstruction

Per EEOICPA and 42 C.F.R. § 83.13(c)(1), NIOSH has established that it does not have access to sufficient information to: (1) estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class; or (2) estimate radiation doses of members of the class more precisely than an estimate of maximum dose. Information available from the site profile and additional resources is not sufficient to document or estimate the maximum internal and external potential exposure to members of the proposed class under plausible circumstances during the specified period.

- NIOSH determined that radioactive materials did not arrive on site until June 17, 1943 at the earliest. Principal sources of internal and external radiation for members of the proposed class included exposures to plutonium, uranium, thorium, mixed fission products, and various cyclotron-related radionuclides. Principal sources of external radiation also included reactors that operated during the proposed class period.

- NIOSH determined in its evaluation that it did not locate sufficient data, including bioassay results and air monitoring concentrations, to estimate with sufficient accuracy the total internal dose from exposures to all the principal sources of internal radiation during the period from June 17, 1943 through July 31, 1955.

- NIOSH found that it may be feasible to reconstruct internal doses to plutonium for employees during the period from January 1, 1944 through July 31, 1955. It may also be feasible to reconstruct the following internal exposures for a portion of the evaluation period:

  - Internal exposures to thorium from January 1, 1944 through December 31, 1947.

  - Internal exposures to uranium from January 1, 1949 through July 31, 1955.

  - Internal exposures to mixed fission products from January 1, 1950 through July 31, 1955.

- NIOSH has determined that cyclotron-related radionuclides produced at the nearby Y-12 Facility were processed at the ORNL facility during the period under evaluation. To allow cyclotron-related operations and exposures at the two sites to be collectively evaluated, NIOSH has reserved the evaluation of ORNL exposures to various radionuclides produced as a result of Y-12 cyclotron operations.

- The availability of ORNL (X-10) internal monitoring data is summarized in the following table.

<table>
<tr><th colspan="15">Summary Section: Available ORNL (X-10) Internal Monitoring Data</th></tr>
<tr><th rowspan="2">Internal Sources</th><th colspan="14">Year</th></tr>
<tr><th>1943</th><th>1944</th><th>1945</th><th>1946</th><th>1947</th><th>1948</th><th>1949</th><th>1950</th><th>1951</th><th>1952</th><th>1953</th><th>1954</th><th colspan="2">1955</th></tr>
<tr><td>Plutonium</td><td></td><td>Air</td><td>Bio</td><td>Air</td><td colspan="10">Bioassay</td></tr>
<tr><td>Uranium</td><td colspan="6">No Data</td><td colspan="8">Bioassay</td></tr>
<tr><td>Thorium</td><td></td><td colspan="4">Air Data</td><td colspan="8">No Data</td><td>Bio</td></tr>
<tr><td>Fission Products</td><td></td><td colspan="6">No Data</td><td colspan="7">Bioassay</td></tr>
<tr><td>Reactor/Cyclo-tron/Accelerator</td><td colspan="14">Reserved for a joint ORNL (X-10) and Y-12 evaluation</td></tr>
</table>

- NIOSH found that external exposures could be reconstructed for all employees during the period from June 17, 1943 through July 31, 1955.

- Prior to October 3, 1947, occupational medical X-rays were performed at Oak Ridge Hospital (an EEOICPA-covered site located on what was then the Clinton Engineering Works site). Starting October 3, 1947, occupational X-rays were performed on the ORNL site. Therefore, NIOSH has determined that it is applicable and feasible to reconstruct occupational medical X-ray exposures for ORNL (X-10) workers during period from June 17, 1943 through July 31, 1955.

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

- Although NIOSH found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any internal and external monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at ORNL (X-10) during the period from June 17, 1943 through July 31, 1955, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

Health Endangerment Determination

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

NIOSH did not identify any evidence supplied by the petitioners or from other resources that would establish that the proposed class was exposed to radiation during a discrete incident likely to have involved exceptionally high-level exposures, such as nuclear criticality incidents or other events involving similarly high levels of exposures. However, evidence indicates that some workers in the proposed class may have accumulated substantial chronic exposures through intakes of radionuclides, combined with external exposures to gamma, beta, and neutron radiation. Consequently, 42 C.F.R. § 83.13(c)(3)(ii) requires NIOSH to specify that health was endangered for those workers covered by this evaluation who were employed for at least 250 aggregated work days either solely under this employment or in combination with work days within the parameters established for one or more other SEC classes.

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SEC Petition Evaluation Report for SEC-00189

ATTRIBUTION AND ANNOTATION: This is a single-author document. All conclusions drawn from the data presented in this evaluation were made by the ORAU Team Lead Technical Evaluator: Michael Domal, MJW Corporation. The rationales for all conclusions in this document are explained in the associated text.

1.0 Purpose and Scope

This report evaluates the feasibility of reconstructing doses for all employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area at the Oak Ridge National Laboratory (X-10) in Oak Ridge, Tennessee, from January 1, 1943 through July 31, 1955. It provides information and analyses germane to considering a petition for adding a class of employees to the congressionally-created SEC.

This report does not make any determinations concerning the feasibility of dose reconstruction that necessarily apply to any individual energy employee who might require a dose reconstruction from NIOSH. This report also does not contain the final determination as to whether the proposed class will be added to the SEC (see Section 2.0).

This evaluation was conducted in accordance with the requirements of EEOICPA, 42 C.F.R. pt. 83, and the guidance contained in the Division of Compensation Analysis and Support's (DCAS) *Internal Procedures for the Evaluation of Special Exposure Cohort Petitions*, DCAS-PR-004.[1]

2.0 Introduction

Both EEOICPA and 42 C.F.R. pt. 83 require NIOSH to evaluate qualified petitions requesting that the Department of Health and Human Services (HHS) add a class of employees to the SEC. The evaluation is intended to provide a fair, science-based determination of whether it is feasible to estimate with sufficient accuracy the radiation doses of the class of employees through NIOSH dose reconstructions.[2]

42 C.F.R. § 83.13(c)(1) states: *Radiation doses can be estimated with sufficient accuracy if NIOSH has established that it has access to sufficient information to estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class, or if NIOSH has established that it has access to sufficient information to estimate the radiation doses of members of the class more precisely than an estimate of the maximum radiation dose.*

[1] DCAS was formerly known as the Office of Compensation Analysis and Support (OCAS).
[2] NIOSH dose reconstructions under EEOICPA are performed using the methods promulgated under 42 C.F.R. pt. 82 and the detailed implementation guidelines available at http://www.cdc.gov/niosh/ocas.

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

NIOSH is required to document its evaluation in a report, and to do so, relies upon both its own dose reconstruction expertise as well as technical support from its contractor, Oak Ridge Associated Universities (ORAU). Once completed, NIOSH provides the report to both the petitioner(s) and the Advisory Board on Radiation and Worker Health (Board). The Board will consider the NIOSH evaluation report, together with the petition, petitioner(s) comments, and other information the Board considers appropriate, in order to make recommendations to the Secretary of HHS on whether or not to add one or more classes of employees to the SEC. Once NIOSH has received and considered the advice of the Board, the Director of NIOSH will propose a decision on behalf of HHS. The Secretary of HHS will make the final decision, taking into account the NIOSH evaluation, the advice of the Board, and the proposed decision issued by NIOSH. As part of this decision process, petitioners may seek a review of certain types of final decisions issued by the Secretary of HHS.[3]

3.0 SEC-00189 ORNL (X-10) Class Definitions

The following subsections address the evolution of the class definition for SEC-00189, Oak Ridge National Laboratory (ORNL), also known as the X-10 Facility. When a petition is submitted, the requested class definition is reviewed as submitted. Based on its review of the available site information and data, NIOSH will make a determination whether to qualify for full evaluation all, some, or no part of the petitioner-requested class. If some portion of the petitioner-requested class is qualified, NIOSH will specify that class along with a justification for any modification of the petitioner's class. After a full evaluation of the qualified class, NIOSH will determine whether to propose a class for addition to the SEC and will specify that proposed class definition.

3.1 Petitioner-Requested Class Definition and Basis

Petition SEC-00189 was received on July 18, 2011, and qualified on October 11, 2011. The petitioner requested that NIOSH consider the following class: *All contractor employees, subcontractor employees, and AEC employees who were monitored or should have been monitored for any of the various radionuclides and fission products present at the X-10 plant while working in all areas at the Oak Ridge National Laboratory (X-10) from January 1, 1943 through December 31, 1952.*

[3] See 42 C.F.R. pt. 83 for a full description of the procedures summarized here. Additional internal procedures are available at http://www.cdc.gov/niosh/ocas.

The petitioner provided information and affidavit statements in support of the petitioner's belief that accurate dose reconstruction over time is impossible for the ORNL (X-10) workers in question. NIOSH deemed the following information and affidavit statements sufficient to qualify SEC-00189 for evaluation:

> The petition basis was the assertion that radiation exposures and radiation doses were not monitored, either through personal or area monitoring. It cited information from three ORAUT documents as the basis for the claim:

- ORAUT-TKBS-0012-5, *ORNL Site - Occupational Internal Dose*, was cited because it states that internal monitoring records are limited or do not exist for most radionuclides during this timeframe because internal monitoring as a form of personnel monitoring was just starting to be developed in the mid-to-late 1940s. As such, the petitioner indicates that the applicability for use of this document starts in 1947.

- ORAUT-OTIB-0034, *Internal Dosimetry Coworker Data for X-10*, was cited because it is only applicable starting in 1951 due to the lack of internal dosimetry data prior to 1951.

- ORAUT-OTIB-0018, *Internal Dose Overestimates for Facilities with Air Monitoring Programs*, was cited because it is only applicable starting in 1953.

Based on its ORNL research and data capture efforts, NIOSH determined that it has access to urine, fecal, air monitoring, film dosimeter badge, pocket dosimeter, and Neutron Track Emulsion Type A (NTA) film data for ORNL workers during the time period under evaluation. However, NIOSH also determined that bioassay and air monitoring records are not complete for all time periods or for all radionuclides. NIOSH concluded that there is sufficient documentation to support, for at least part of the requested time period, the petition basis that internal radiation exposures and radiation doses were not adequately monitored at ORNL, either through personal monitoring or area monitoring. The information and statements provided by the petitioner qualified the petition for further consideration by NIOSH, the Board, and HHS. The details of the petition basis are addressed in Section 7.4.

3.2 Class Evaluated by NIOSH

Based on its research, NIOSH expanded the time period of the petitioner-requested class because NIOSH was unable to obtain the data necessary to estimate doses with sufficient accuracy until August 1, 1955. Therefore, NIOSH defined the following class for further evaluation: All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area at the Oak Ridge National Laboratory (X-10) in Oak Ridge, Tennessee, from January 1, 1943 through July 31, 1955.

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

Based on its research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class to be added to the SEC includes All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area at the Oak Ridge National Laboratory (X-10) in Oak Ridge, Tennessee, from June 17, 1943 through July 31, 1955, for a number of work days aggregating at least 250 work days, occurring either solely under this employment, or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort. The start date for the NIOSH-proposed class to be added to the SEC was changed from January 1, 1943 to June 17, 1943 because NIOSH obtained documentation showing that construction at the site did not start (i.e., ground-breaking) until February 1943, and the first uranium slug shipment left Aluminum Company of America for the site on June 17, 1943 (Alcoa, 1944). Thus, ORNL first had radioactive materials on site sometime after June 17, 1943.

4.0 Data Sources Reviewed by NIOSH to Evaluate the Class

As is standard practice, NIOSH completed an extensive database and Internet search for information regarding ORNL (X-10). The database search included the DOE Legacy Management Considered Sites database, the DOE Office of Scientific and Technical Information (OSTI) database, the Energy Citations database, and the Hanford Declassified Document Retrieval System. In addition to general Internet searches, the NIOSH Internet search included OSTI OpenNet Advanced searches, OSTI Information Bridge Fielded searches, Nuclear Regulatory Commission (NRC) Agency-wide Documents Access and Management (ADAMS) web searches, the DOE Office of Human Radiation Experiments website, and the DOE-National Nuclear Security Administration-Nevada Site Office-search. Attachment 1 contains a summary of ORNL documents. The summary specifically identifies data capture details and general descriptions of the documents retrieved.

In addition to the database and Internet searches listed above, NIOSH identified and reviewed numerous data sources to determine information relevant to determining the feasibility of dose reconstruction for the class of employees under evaluation. This included determining the availability of information on personal monitoring, area monitoring, industrial processes, and radiation source materials. The following subsections summarize the data sources identified and reviewed by NIOSH.

4.1 Site Profile Technical Basis Documents (TBDs)

A Site Profile provides specific information concerning the documentation of historical practices at the specified site. Dose reconstructors can use the Site Profile to evaluate internal and external dosimetry data for monitored and unmonitored workers, and to supplement, or substitute for, individual monitoring data. A Site Profile consists of an Introduction and five Technical Basis Documents (TBDs) that provide process history information, information on personal and area monitoring, radiation source descriptions, and references to primary documents relevant to the radiological operations at the site. The Site Profile for a small site may consist of a single document.

As part of NIOSH's evaluation detailed herein, it examined the following TBDs for insights into ORNL operations or related topics/operations at other sites:

- *Technical Basis Document for the Oak Ridge National Laboratory – Introduction*, ORAUT-TKBS-0012-1; Rev. 0; August 11, 2004; SRDB Ref ID: 20132
- *Oak Ridge National Laboratory – Site Description*, ORAUT-TKBS-0012-2; Rev. 02; August 17, 2007; SRDB Ref ID: 34367
- *Oak Ridge National Laboratory – Occupational Medical Dose*, ORAUT-TKBS-0012-3; Rev. 02; October 1, 2007; SRDB Ref ID: 35194
- *Technical Basis Document for the Oak Ridge National Laboratory – Occupational Environmental Dose*, ORAUT-TKBS-0012-4; Rev. 0; May 7, 2004; SRDB Ref ID: 20136a
- *Oak Ridge National Laboratory – Occupational Internal Dose*, ORAUT-TKBS-0012-5; Rev. 01; October 1, 2007; SRDB Ref ID: 35195
- *Oak Ridge National Laboratory – Occupational External Dose*, ORAUT-TKBS-0012-6; Rev. 01; September 10, 2007; SRDB Ref ID: 34945

4.2 ORAU Technical Information Bulletins (OTIBs) and Procedures

An ORAU Technical Information Bulletin (OTIB) is a general working document that provides guidance for preparing dose reconstructions at particular sites or categories of sites. An ORAU Procedure provides specific requirements and guidance regarding EEOICPA project-level activities, including preparation of dose reconstructions at particular sites or categories of sites. NIOSH reviewed the following OTIBs as part of its evaluation:

- *OTIB: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures*, ORAUT-OTIB-0006, Rev. 04; June 20, 2011; SRDB Ref ID: 98147
- *OTIB: Internal Dose Overestimates for Facilities With Air Sampling Programs*, ORAUT-OTIB-0018; Rev. 01; August 9, 2005; SRDB Ref ID: 19436

- *OTIB: Technical Information Bulletin – External Coworker Dosimetry Data for the X-10 Site*, ORAUT-OTIB-0021, Rev. 00; December 29, 2004; SRDB Ref ID: 19442

- *OTIB: Internal Dosimetry Coworker Data for X-10*, ORAUT-OTIB-0034; Rev. 00; December 13, 2005; SRDB Ref ID: 20222

- *OTIB: Guidance on Assigning Occupational X-ray Dose Under EEOICPA for X-rays Administered Off Site*, ORAUT-OTIB-0079, Rev. 00; January 1, 2011; SRDB Ref ID: 89563

4.3 Facility Employees and Experts

To obtain additional information, NIOSH interviewed eight current or former ORNL (X-10) employees in five interviews.

- Personal Communication, 2006, *Personal Communication Regarding Activities in the ORNL Biology Buildings Located at Y-12*; Interview by ORAU Team; April 12, 2006; SRDB Ref ID: 22812

- Personal Communication, 2012a, *Personal Communication with One Individual Regarding Thorium Operations at the X-10 Facility*; Interview by ORAU Team; March 14, 2012; SRDB Ref ID: 109522

- Personal Communication, 2012b, *Personal Communication with Two Individuals Regarding Thorium Operations at the X-10 Facility*; Interview by ORAU Team; March 22, 2012; SRDB Ref ID: 109819

- Personal Communication, 2012c, *Personal Communication with Three Individuals Regarding Radiation Monitoring at ORNL (X-10)*; Interview by ORAU Team; June 13, 2012; SRDB Ref ID: 116011

- Personal Communication, 2012d, *Personal Communication with One Individual Regarding Bioassay Sampling at ORNL*; Interview by ORAU Team; June 14, 2012; SRDB Ref ID: 115274

- Personal Communication, 2012e, *Personal Communication with One Individual Regarding Reporting of Neutron Doses*; Interview by ORAU Team; July 3, 2012; Ref ID: 115899

4.4 Previous Dose Reconstructions

NIOSH reviewed its NIOSH DCAS Claims Tracking System (referred to as NOCTS) to locate EEOICPA-related dose reconstructions that might provide information relevant to the petition evaluation. Table 4-1 summarizes the results of this review. (NOCTS data available as of July 10, 2012)

Table 4-1: No. of ORNL Claims Submitted Under the Dose Reconstruction Rule

Description	Totals
Total number of claims submitted for dose reconstruction	2036
Total number of claims submitted for energy employees who worked during the period under evaluation (January 1, 1943 through July 31, 1955).	1302
Number of dose reconstructions completed for energy employees who worked during the period under evaluation (i.e., the number of such claims completed by NIOSH and submitted to the Department of Labor for final approval).	1074
Number of claims for which internal dosimetry records were obtained for the identified years in the evaluated class definition	236
Number of claims for which external dosimetry records were obtained for the identified years in the evaluated class definition	668

4.5 NIOSH Site Research Database

NIOSH also examined its Site Research Database (SRDB) to locate documents supporting the assessment of the evaluated class. As of the issuance of this report, there are 16,929 documents and subdocuments in the SRDB identified as pertaining to ORNL. These documents were evaluated for their relevance to this petition. The documents include historical background on monitoring, program descriptions, air monitoring data, urinalysis data, fecal data, film badge data, radiological control programs, medical monitoring, process materials, and process descriptions.

4.6 Documentation and/or Affidavits Provided by Petitioners

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

- *Form B with Lecture Notes, Health Physics Training Lectures, 1948-49*, AECU-817, Health Physics Division, Oak Ridge National Laboratory; September 29, 1950; Form B received on July 18, 2011; DSA Ref ID: 114345 (Form B)

- *Health Physics Division Quarterly Progress Report for Period Ending October 20, 1951*, ORNL 1174 Progress, Health Physics Division, Oak Ridge National Laboratory; 1951; DSA Ref ID: 114348 (Progress Report, Oct1951a)

- *Oak Ridge National Laboratory – Occupational Internal Dose*, ORAUT-TKBS-0012-5; Rev. 01; October 1, 2007; SRDB Ref ID: 35195

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

- *Internal Dosimetry Coworker Data for X-10,* ORAUT-OTIB-0034; Rev. 00; December 13, 2005; SRDB Ref ID: 20222

5.0 Radiological Operations Relevant to the Class Evaluated by NIOSH

The following subsections summarize both radiological operations at the ORNL from January 1, 1943 through July 31, 1955 and the information available to NIOSH to characterize particular processes and radioactive source materials. From available sources NIOSH has gathered some process and source descriptions, information regarding the identity of each radionuclide of concern, and limited information describing processes through which radiation exposures may have occurred and the physical environment in which they may have occurred. The information included within this evaluation report is intended only to be a summary of the available information.

5.1 ORNL Plant and Process Descriptions

The Oak Ridge National Laboratory is located on about 4470 acres of the 34,000-acre Oak Ridge Reservation in eastern Tennessee's Anderson and Roane counties. The general area where the main ORNL facilities are now located was known as Bethel Valley, Kingston, Tennessee. In the latter part of 1942, the Army organized a new Manhattan Engineer District (MED) under the U.S. Army Corps of Engineers to manage the activities directed toward producing an atomic bomb. The Corps of Engineers started construction of a town and administrative office buildings in 1942 under the name Clinton Engineer Works (CEW). This was the area planned for the large-scale production activities required to produce an atomic bomb. The original plan called for all atomic bomb project activities to be carried out at this site (Thompson, 1963).

The entire facility known as the Clinton Engineer Works was bounded by security fences from February 1943 through March 1949. Within the facility were the processing plants, known as K-25 (for uranium enrichment), X-10 (for plutonium production), and Y-12 (for uranium enrichment). Each plant had its own security fence. (Each plant has been designated separately for the purposes of EEOICPA.) During this time, Roane Anderson Company managed, operated, and maintained for the CEW the residences, apartments, dormitories, guest houses, barracks, hutments, trailers, restaurants, cafeterias, buses, roads, streets, sidewalks, garbage and sewage disposal, heating plants, and more. However, Roane did not operate the processing plants and laboratories. The CEW gates came down in March 1949. This meant that people no longer needed a security clearance to enter the CEW, although clearances were still required to enter the plants and laboratories. The fences surrounding the processing plants remained. It was also in 1949 that privatization began of what today is known as the City of Oak Ridge.

DuPont agreed to accept the responsibility for the plutonium production plant, and because of this, also accepted responsibility for the design and construction of the pilot plant at CEW. Although the pilot plant was to be operated by the Metallurgical Laboratory of the University of Chicago, it was expected that DuPont would train personnel at the pilot plant for later assignment to the production facilities. Construction of the pilot plant started on February 1, 1943, the first plant construction in the CEW. Because of the location in the CEW, the name Clinton Laboratories was chosen for the pilot plant (Thompson, 1963). MED security required that the lab operator not be linked to these laboratories. Thus, a separate organization, the Clinton Laboratories, was created to obfuscate that link. In early 1947, those facilities were named the Clinton National Laboratory, which became the Oak Ridge National Laboratory on February 1, 1948.

The main ORNL site is frequently known as "X-10." That name had its origins in late 1942 as a code name for the initial product of the Graphite Reactor and chemical processing plant at Oak Ridge (i.e., plutonium). ORNL and its predecessors have been operated, successively, by the University of Chicago's Metallurgical Laboratory (March 17, 1943 - June 30, 1945), the Monsanto Chemical Company (July 1, 1945 - February 29, 1948), divisions or subsidiaries of Union Carbide and Carbon Corporation and Union Carbide Corporation (March 1, 1948 - March 31, 1984), subsidiaries of Martin Marietta Company and Lockheed Martin Company (April 1, 1984 - March 31, 2000), and UT-Battelle, LLC, a partnership between the University of Tennessee and Battelle (April 1, 2000 - present) (Quist, 2000).

For the period under evaluation, the ORNL workforce varied, ranging from approximately 953 workers in 1943 to 4024 in 1955. A tabulation of workers compiled for an ORAU epidemiological study yielded widely-varied numbers, as indicated in Table 5-1. The database used for ascertaining the ORNL employment for 1943-1955 was the same database used by the ORAU Center for Epidemiological Research. (ORAU CER).

Table 5-1: Number of ORNL Workers by Year

Gender	**Year**												
	1943	**1944**	**1945**	**1946**	**1947**	**1948**	**1949**	**1950**	**1951**	**1952**	**1953**	**1954**	**1955**
Female:	205	455	405	577	705	706	481	504	632	636	624	601	617
Male:	748	1891	1726	1926	2222	2211	1833	2484	2929	3128	3085	3243	3407
Total:	953	2346	2132	2504	2927	2917	2314	2988	3561	3764	3709	3844	4024

Source: ORAU CER database. ORAU CER was one of the three DOE epidemiological research centers that collected data on ORNL, including employment data which was used to determine when a person was employed.

The original general purpose of the facilities that became ORNL was to provide the MED with its pilot plutonium-production plant. Those ORNL pilot facilities included a graphite-moderated, air-cooled, natural-uranium, nuclear-fission reactor to produce plutonium and pilot-plant chemical-processing facilities for separating and purifying that plutonium. Subsequently, the large plutonium-production reactors and chemical facilities that were built at Hanford, Washington provided the plutonium for the atomic device tested at Alamogordo, New Mexico in July 1945, and for the atomic bomb dropped on Nagasaki, Japan in August 1945 (Quist, 2000).

The four specific original purposes of ORNL were: (1) to operate a small, graphite-moderated, air-cooled, natural-uranium-fueled, nuclear-fission reactor to produce small amounts of plutonium; (2) to operate a chemical pilot plant to separate plutonium from uranium and its fission products using the bismuth phosphate carrier process; (3) to operate a training school for technical personnel who would form the nucleus staff for operating Hanford's production plants; and (4) to perform research and development related to nuclear fission, nuclear reactors, and plutonium-separation processes. The first two items, the engineering scale-up of laboratory processes, were the most important purposes followed by (3) and then (4). A fifth purpose may have been to evaluate the health hazards from fission and fission-product radioactivity. The oldest ORNL facilities are the Graphite Reactor and the chemical-processing facilities. DuPont provided a total of 337 employees, all of whom were experienced in some phase of plant operations. Personnel who initially operated the Hanford plant were trained at those ORNL facilities (Quist, 2000; Thompson, 1963).

Since operations began in 1943, ORNL's mission has been research and development and production missions in support of the Department of Energy (DOE) and its predecessor agencies. Much of the earliest site work was devoted to the development and operation of the original graphite reactor which was designed as a pilot plant for the larger production reactors scheduled for the Hanford site. The graphite reactor was used to produce gram quantities of plutonium, and later, fission products (radioactive lanthanum and all other types of radioactive materials were separated in other ORNL site facilities).

A large part of ORNL activities and operations has been research and development of chemical technologies for separation of materials from irradiated nuclear fuels and liquid waste streams. ORNL developed many of the solvent extraction processes adopted at U.S. plutonium production facilities, and at one time, the facility was a substantial provider of radioisotopes for industry and research. ORNL also produced stable isotopes using Calutrons at the Y-12 National Nuclear Security Complex. Isotope sales were eventually scaled back to only highly-specialized materials, such as Cf-252 from the High Flux Isotope Reactor, which was separated and packaged in the Radiochemical Engineering Development Center.

Between 1944 and 1956, the Radioactive Lanthanum (RaLa) program was carried out at ORNL to produce large quantities of Ba-140/La-140 for use in weapons dynamic studies at the Los Alamos National Laboratory. The RaLa program involved dissolving short-decay uranium fuel slugs irradiated in either the ORNL Graphite Reactor or the production reactors at the Hanford site.

The ORNL site was also used for developing new reactor technologies. Various reactor designs (pool, pressurized-water, boiling-water, liquid metal, gas-cooled) were designed and, in most cases, tested at ORNL. They were then either scrapped or further developed elsewhere. Reactors operated by ORNL include the Low Intensity Test Reactor (LITR), Critical Experiments Facility (CEF at Y-12), Bulk Shielding Reactor (BSR)/Pool Critical Assembly (PCA), ORNL Research Reactor (ORR), Tower Shielding Reactor (TSR), Health Physics Research Reactor (HPRR), Homogeneous Reactor Experiment (HRE), Aircraft Nuclear Propulsion (ANP) Program, the High Flux Isotope Reactor (HFIR), and the Molten Salt Reactor Experiment (MSRE). These reactor technologies and associated facilities are discussed later in this report.

In 1947, several ORNL divisions moved to the Y-12 complex (while remaining as ORNL divisions). These divisions were responsible for conducting research in biological sciences, production of stable isotopes, and engineering technology.

The Oak Ridge Graphite Reactor, intended as a pilot plant for the larger plutonium production reactors at the Hanford site, achieved initial criticality on November 4, 1943. The Graphite Reactor served only briefly in its role as a pilot plant, and quickly became an essential tool for basic research and radioisotope production. The Graphite Reactor was the first of many reactors to operate at the site as the laboratory expanded its reactor research into a number of domains, including energy, propulsion systems, materials research, and radioisotope production. In addition, ORNL operated the Critical Experiments Facility (CEF) at the Y-12 site from mid-1950 until 1987. The CEF supported experiments with various reactor designs at ORNL and elsewhere.

ORNL has operated several accelerators including the 86-inch cyclotron at the Y-12 complex, the Oak Ridge Isochronous Cyclotron, the Holifield Heavy Ion Research Facility, and the Oak Ridge Electron Linear Accelerator. Other smaller accelerators have also been used for such applications as dosimetry research and waste assay research.

Waste-handling practices at ORNL evolved as the scope and duration of its mission expanded. Gaseous wastes were initially discharged via local stacks and vents before a centralized off-gas treatment system began operating in 1950. Liquid wastes were originally handled using a system of tank farms and settling basins to treat wastes before discharge into White Oak Creek. More liquid waste treatment facilities were added over time. A number of trenches, burial grounds, and Solid Waste Storage Areas have been at ORNL for the disposal of solid wastes.

5.1.1 Major Facilities and Radionuclides of Concern

The original building identification numbers from the 1940s were different than they are today. In the beginning, buildings were given three-digit numbers (e.g., 105, 225, 706). In the early 1950s, the building numbering nomenclature was changed to one with predominantly four digits. A March 1, 1953, document from the ORNL Facilities and Operations Directorate, *Oak Ridge National Laboratory Building List* (ORAUT-TKBS-0012-2), indicated a cross-linking from the old and new building numbering nomenclature at that time. Numbers 0000 through 5999 are located on the main plant site. Numbers 6000-7499 are further east of the main plant site in Bethel Valley, numbers 7500-7999 are in Melton Valley, and the ORNL facilities in the Y-12 National Security Complex begin with the 9000 numbers. During the more than 60 years of site operations, facilities have been constructed, operated, decontaminated, and decommissioned based on need.

Table 5-2 shows the major ORNL facilities with their former and current building numbers as well as the associated radionuclides of concern.

Table 5-2: Major ORNL Facilities and Radionuclides of Concern
(This table spans two pages)

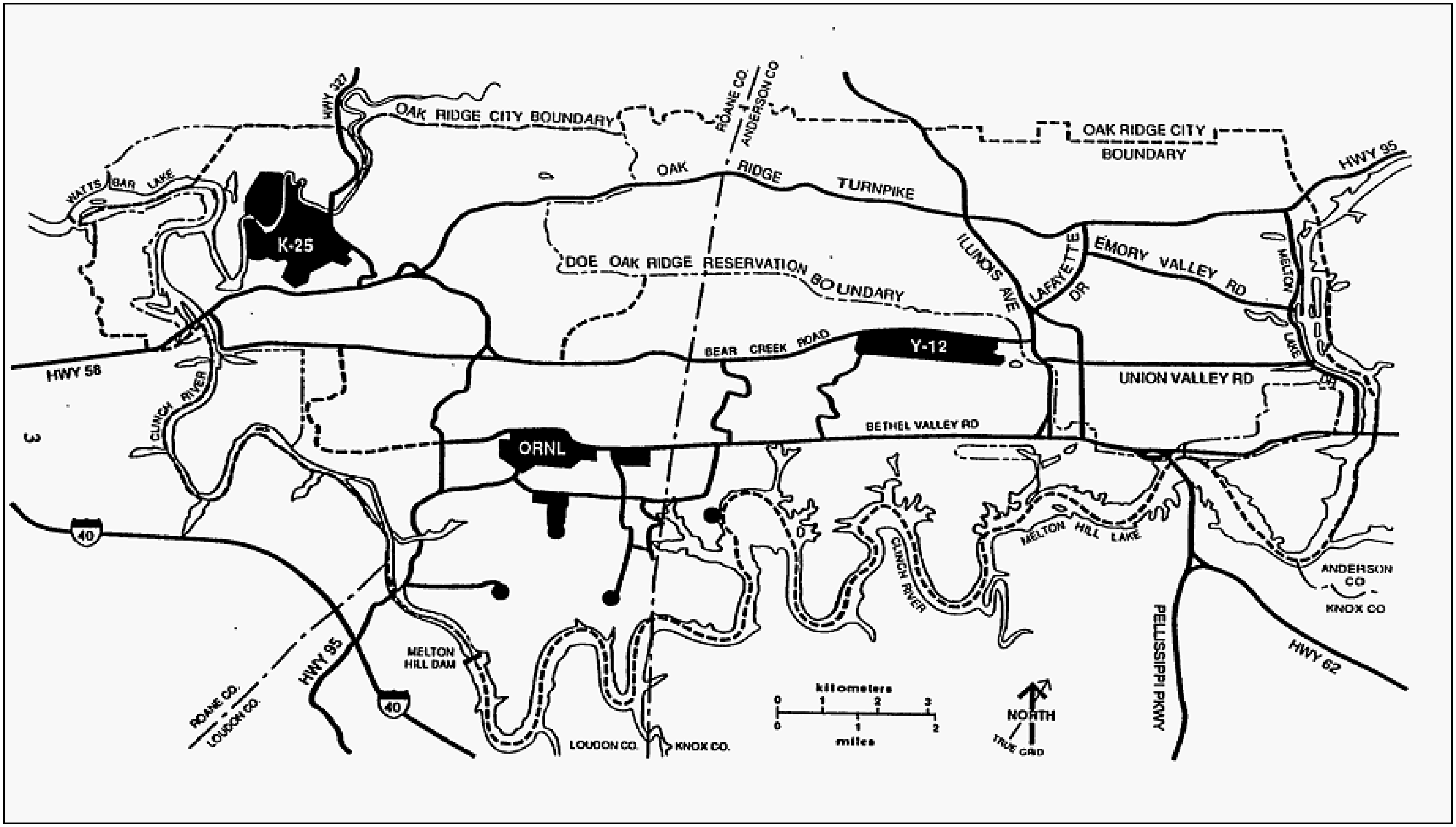
Current Building Number	Former Building Number	Facility Name or Description	Dates of Operation	Principal Radionuclides of Concern
3001	105	Graphite Reactor	Nov. 1943–Nov. 1963	Mixed fission/activation products, natural uranium
3005	106	Low-Intensity Test Reactor	1949–Oct. 1968	Volatile fission products, Na-24, N-16
3010		Bulk Shielding Reactor/Pool Critical Assembly	1951–1987	Volatile fission products, Na-24, N-16
3019	205	Pilot Plant (Solvent Extraction Facility)	Dec., 1943–present (partly inactive and pending D&D)	Mixed fission/activation products, natural uranium, Th-232, U-233, TRU (liquid forms)
3023	206	North Tank Farm	1943–1986	Mixed fission/activation products, natural uranium, Th-232, U-233, TRU (liquid forms)
3026-C	706-C	Radiochemistry Laboratory (original RaLa building); Kr-85 enrichment facility	1944–circa 1997 (pending D&D)	Mixed fission products, I-131, Kr-85 (liquid and gaseous forms)
3026-D	706-D	Radiochemistry Laboratory (RaLa building from May 1945 until 1958); Segmentation Facility	1945– (pending D&D)	Mixed fission products, I-131, Ru-106, noble gases (liquid and gaseous forms); uranics/TRU (segmentation facility)
3028	910	Radioisotope Processing Building A/Alpha Powder Facility	1950–1985	Mo-99, I-131, Xe-133, Pm-147, Cm-242/244
3029	909	Source Development Laboratory	1952–late 1980s	Fission/activation products
3030	908	Radioisotope Processing Building C	circa 1950–late 1980s	Fission/activation products
3031	907	Radioisotope Processing Building D	circa 1950–late 1980s	Fission/activation products
3032	906	Radioisotope Processing Building E	circa 1950–late 1980s	Fission/activation products
3033	905	Radioisotope Processing Building F, Radioactive Gas Processing Facility	circa 1950–1990	H-3, C-14, Kr-85 (gaseous forms)
3038	902	Isotope Research Materials Laboratory/Alpha Handling Facility	1949–1990	Fission/activation products, uranics, TRU
3042		Oak Ridge Research Reactor	March, 1958–ca. 1987	Volatile mixed fission products; Na-24, N-16
3505		Metals Recovery Facility	1952–1960	Mixed fission products, uranics, TRU (liquid form)
3507	206	South Tank Farm	1943–1978	Mixed fission/activation products, natural uranium, Th-232, U-233, TRU (liquid form)
3508		Alpha Isolation Laboratory	1952–ca. 1976	TRU, U-233 (gram quantities); mixed fission products
3515		Fission Product Pilot Plant	1948–1958	Mixed fission products, uranics, TRU (liquid form)

Table 5-2: Major ORNL Facilities and Radionuclides of Concern
(This table spans two pages)

Current Building Number	Former Building Number	Facility Name or Description	Dates of Operation	Principal Radionuclides of Concern
3517		Fission Product Development Laboratory	1958–1975	Mixed fission products, uranics, TRU (liquid form)
3525		High Radiation Level Examination Laboratory	1963–present	Fission/activation products
3550	706-A	Research Materials Preparation Facility (706 Chemistry Bldg)	1943-no end date known	Mixed fission products, uranics, TRU
4501		High Level Radiochemistry Laboratory	1951–present	U-233 (OREX process)
4507		High-Level Chemical Development Facility	1957– (pending D&D)	Mixed fission products (liquid forms)
7500		Homogeneous Reactor Experiment, Homogeneous Reactor Test	1952–April, 1961	Mixed fission/activation products, uranyl sulfate

Source: ORAUT-TKBS-0012-2

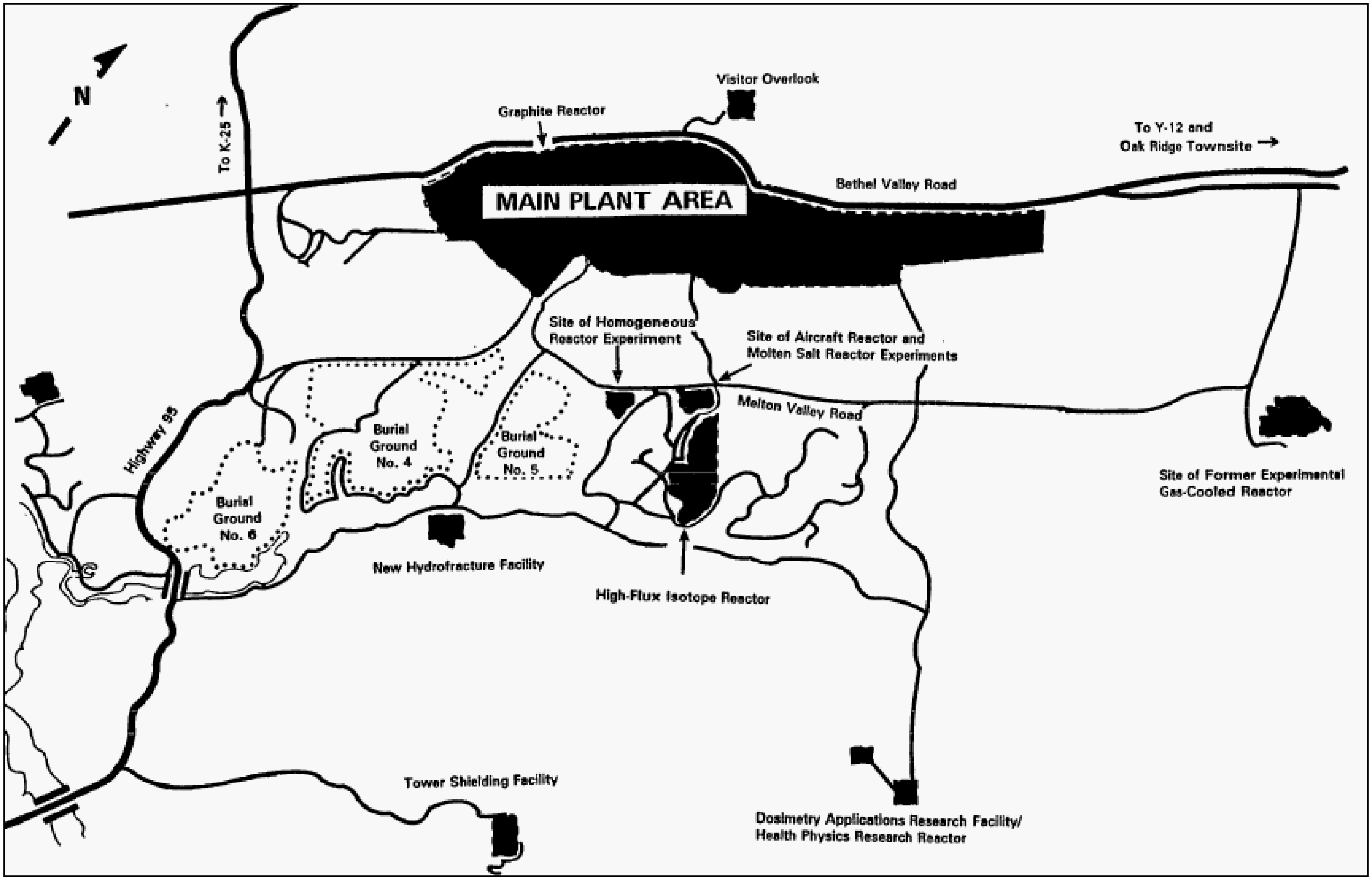
Figure 5-1 shows a view of the Oak Ridge Reservation and main DOE facilities.



Source: ChemRisk, 1993

Figure 5-1: The Oak Ridge Reservation and Main DOE Facilities

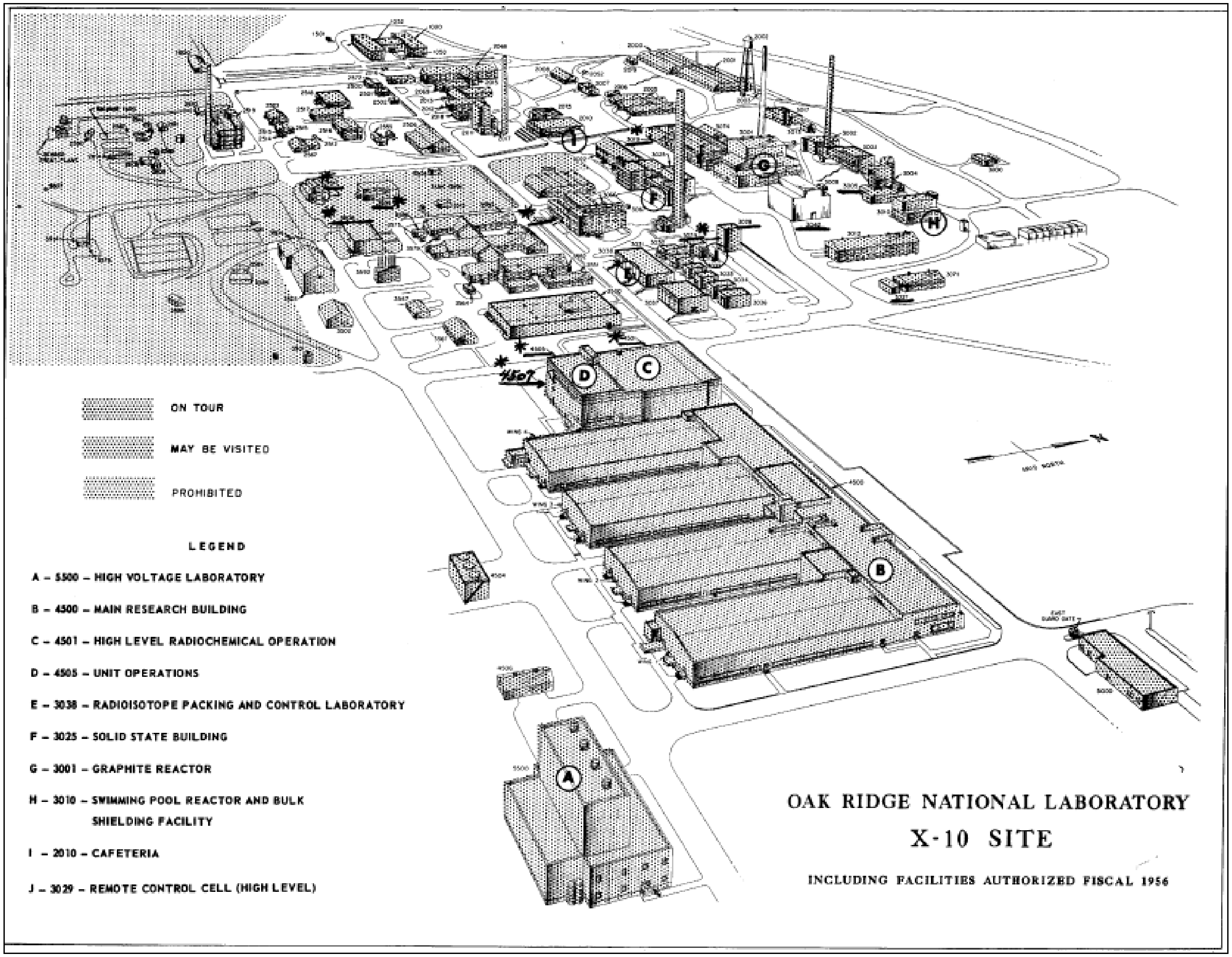
Figure 5-2 shows a view of ORNL Outlying areas.



Source: ChemRisk, 1993

Figure 5-2: Map of ORNL Outlying Areas

Figure 5-3 shows a view of the ORNL site in 1956.



Source: ORNL Site Map, 1955

Figure 5-3: Map of Oak Ridge National Laboratory in 1956

5.1.2 Reactors and Critical Assemblies

The Graphite Reactor (Pile)

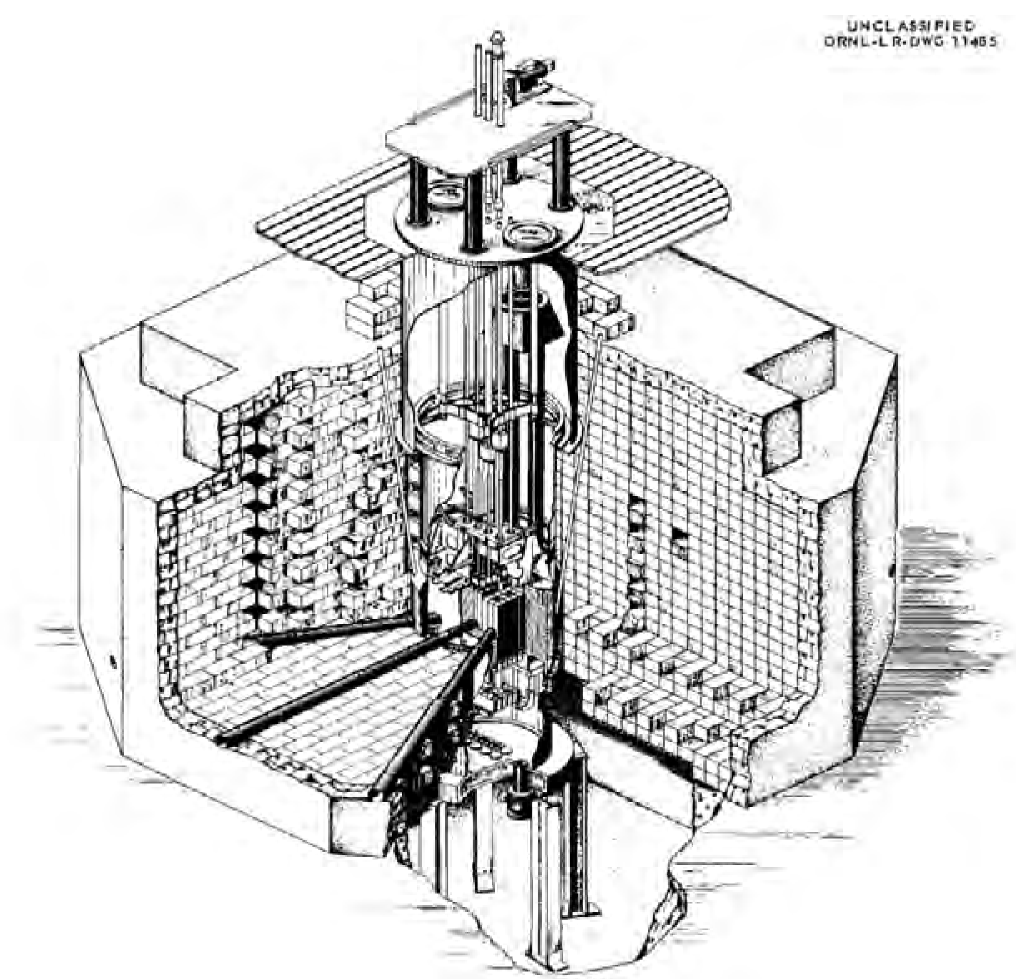
The Graphite Reactor, Building 3001 (originally 105), operated from November 1943 to November 1963. The reactor was designed and built as a pilot plant to test the control and operating procedures of the proposed larger production reactors and to provide needed quantities of plutonium for the MED. The reactor was designed to operate at a thermal power rating of 1,000 kW, but with subsequent modifications reached at least 4,400 kW. There were 7 ft. of concrete shielding between the reactor and the front wall of the shield that operators would work from (5 ft. of barites concrete with 1 ft. of structural concrete on each side as retaining walls). Natural uranium fuel slugs (4 in. long by approximately 1.1 in. in diameter) were loaded in the reactor by inserting them through holes in the front face into horizontal channels in the graphite matrix. Following irradiation, the slugs were pushed out the back side of the reactor into a water-filled transfer canal. (ORAUT-TKBS-0012-2)

Low Intensity Test Reactor (LITR)

The Materials Test Reactor (MTR) was designed by ORNL and built at the National Reactor Test Site in Idaho (now the Idaho National Laboratory). This was a high-power, enriched-uranium core cooled and moderated by ordinary water.

In 1949, a full-scale mock-up of the MTR’s major components was built at ORNL in Building 3005 to check out mechanical and hydraulic operation and provide training for operators. After the mock-up was running, ORNL argued that it should be made critical with real fuel plus beryllium reflector elements, which would allow nuclear measurements and testing of instruments and controls. This was done, and in 1950, many low-power measurements for the final MTR design were made. In 1952, it was a small step to add shielding and a heat exchanger, thus providing the Laboratory with the 1500 kW Low-Intensity Test Reactor (LITR). Later, after the addition of shielding and other modifications, the LITR was operated at 3 MW (Rosenthal, 2009).

Originally, LITR stood for the Low Intensity Training Reactor, and later, the Low Intensity Test Reactor. This reactor used MTR-type, enriched-uranium fuel elements and beryllium-reflector pieces in a 5-element x 9-element lattice with moderation and cooling provided by forced circulation of demineralized water. The reactor tank was surrounded with concrete block shielding. Control-rod drives were mounted on the top of the reactor tank. The reactor was flanked on the sides with two large rooms for housing experimental equipment. The beam holes opened into these rooms. Two higher levels around the tank, called the “midriff” and the “top level,” were enclosed to shelter the experiments and operating personnel (George, 1962). Figure 5-4 shows a diagram of the LITR.



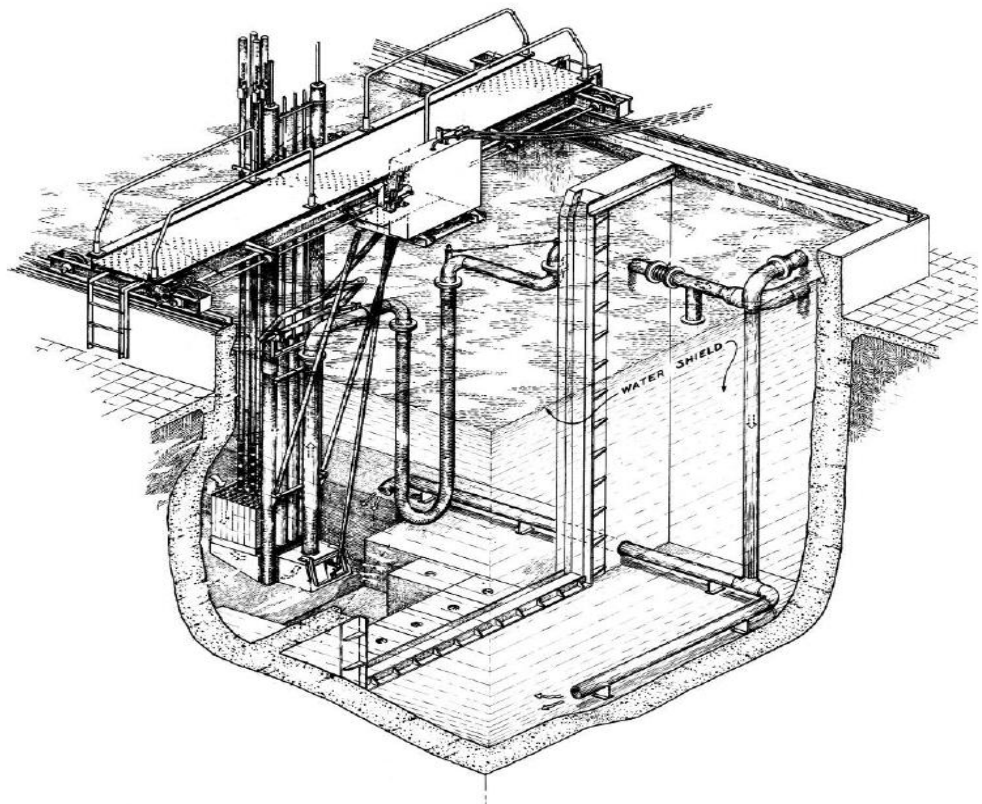
Source: George, 1962

Figure 5-4: Cross-sectional Diagram of the LITR

Bulk Shielding Reactor (BSR)

The BSR was originally a 10-kilowatt research reactor that was operated in the Bulk Shielding Facility, Building 3010. The reactor, a two-foot cube, was submerged in a pool 40 feet long, 20 feet wide and, at its deepest point, 27 feet deep. It was operated seventeen feet below the surface of the water shield (ORNL, 1958).

The BSR achieved criticality on December 17, 1950 and was in operation through 1963. The reactor was known as the "Swimming Pool" reactor and served as the model for university, industry, and government research reactors. Figure 5-5 shows a diagram of the BSR.



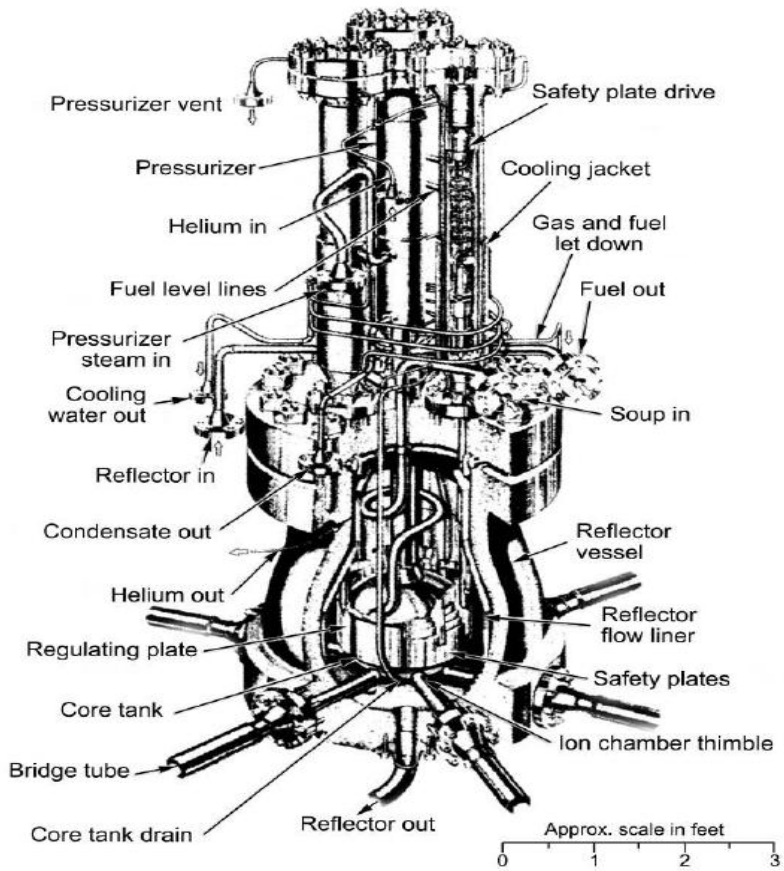
Source: Rosenthal, 2009

Figure 5-5: Cross-section of the BSR Pool

Homogeneous Reactor Experiment (HRE)

The Homogeneous Reactor Experiment was the first reactor prototype incorporating a circulating homogeneous aqueous fuel operating at high specific power and temperature with the reactor coupled to a steam turbine generator. The reactor was built for the purpose of demonstrating the feasibility of this concept; primarily, to show that the reactor was self-regulating and inherently stable.

The reactor achieved criticality on April 15, 1952 and was in operation until April 1954. The reactor essentially consisted of an 18-inch diameter spherical core inside a 39-inch diameter reflector vessel, a circulating pump, and a heat exchanger where steam was produced for the operation of the turbine generator. The design conditions were 250°C temperature, 1000 psig pressure, and 1000 kilowatt reactor power. The material of construction was Type 347 stainless steel. A low pressure system contained dump tanks for the storage of fuel solution, an evaporator and condensate tanks for changing concentration, and recombiners for the decomposition gases released in the core. The fuel was a light water solution of UO_2SO_4 with a U-235 enrichment of 93 percent and the reflector was heavy water (Campbell, 1956; Visner, 1957). Figure 5-6 shows a diagram of the HRE.



Source: Rosenthal, 2009

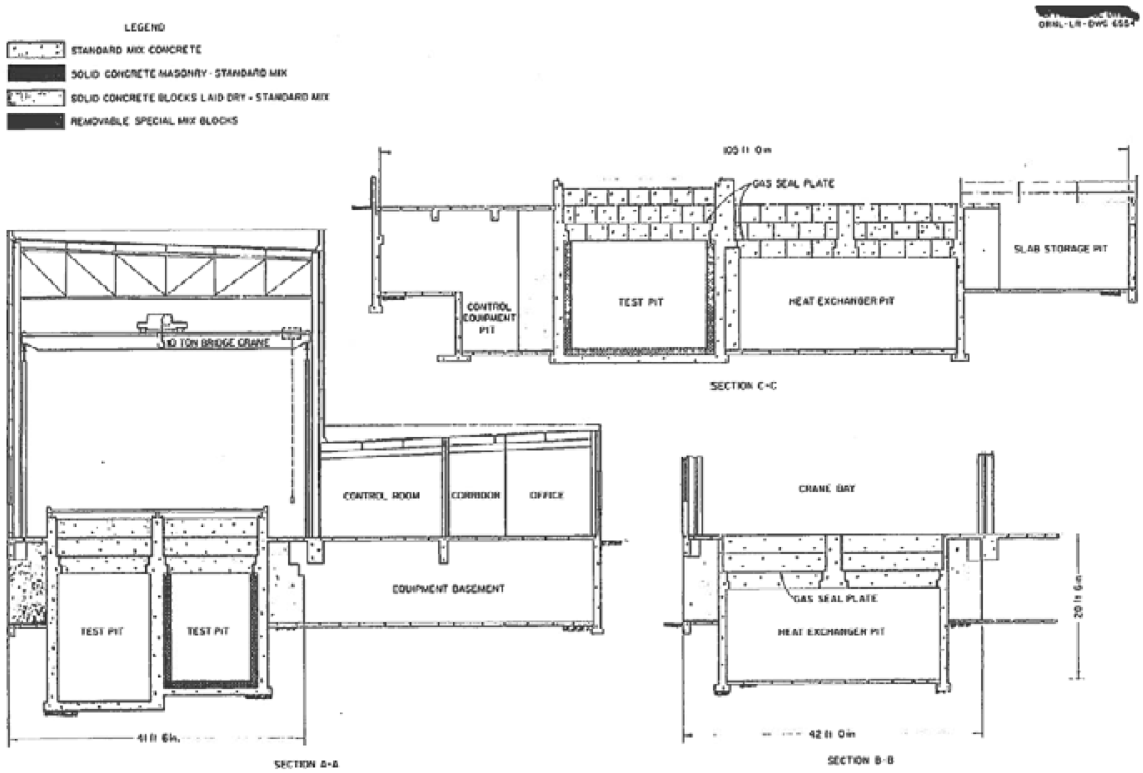
Figure 5-6: Cross-section of the HRE

Aircraft Reactor Experiment (ARE)

In 1953, ORNL erected Building 7503 to house the Aircraft Reactor Experiment (ARE) in Melton Valley about a half mile south of the ORNL main facilities complex. The entire reactor system was contained in three interconnected pits: one for the reactor, one for the heat exchangers and pumps, and the third for the fuel dump tanks.

The ARE was an experiment to build and operate a high-temperature, low-power, circulating-fuel reactor using materials that would be amenable to a high-power aircraft-type reactor. The fuel was UF_4 dissolved in molten salts, a mixture of sodium and zirconium fluorides.

The reactor achieved criticality on November 3, 1954. The experiment was concluded on November 12 when the reactor was shut down permanently. During its short run, the reactor logged a little over 100 megawatt-hours and achieved a maximum power level of 2.5 megawatts (Meem, 1954; Rosenthal, 2009). Figure 5-7 shows a layout of Building 7503.



Source: Cottrell, 1955, pdf p. 239

Figure 5-7: Building 7503 Layout

Tower Shielding Reactor (TSR)

In 1952, ORNL proposed to address air scattering and shielding problems arising from the development of a reactor-powered aircraft by hanging full-scale reactor and shield models high in the air. Approval was received and the Tower Shielding Facility (TSF) was built on Copper Ridge in a remote area south of the main laboratory area. The TSF (see Figure 5-8) was formed from four 315-foot towers, separated by 200 feet in one dimension and 100 feet in the other. Cables attached to the towers could hoist the reactors and shields to 200 feet above the ground. The facility was operated from an underground building and a fence kept people and animals away.

The first Tower Shielding Reactor (TSR) was essentially a BSR (bulk-shielding reactor). It was tested in a 12-foot diameter water-filled tank and in specially designed shield assemblies into which the core was lowered. When the core was in the tank, the reactor support system could rotate or move it to any position within a horizontal plane for measurements. Cooling was by forced convection. When testing began in 1954, the initial power limit was 100 kW, but permission was soon obtained for operation at up to 500 kW. When not in use, the reactor was stored in a deep pool between the towers (Rosenthal, 2009).

Source: Rosenthal, 2009

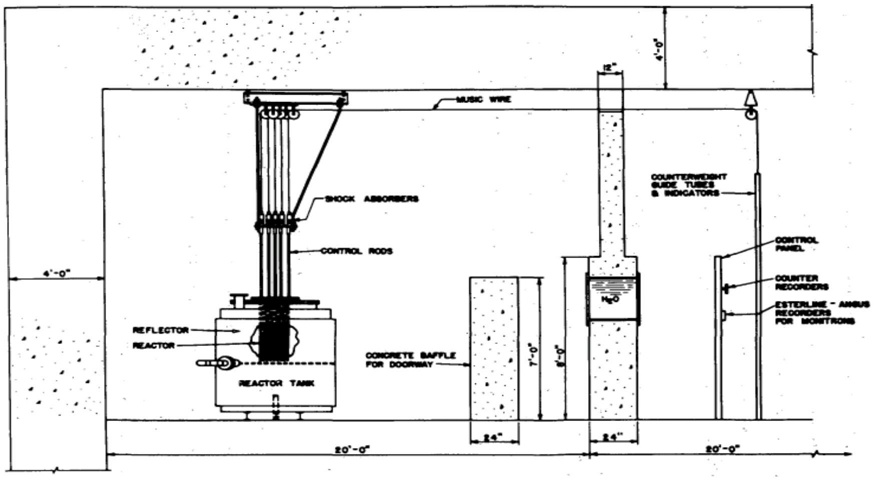
Figure 5-8: Completed Tower Shielding Facility

Critical Experiments

These were a series of three small reactor assemblies for testing enrichments, moderators, and reflector configurations that operated between 1945 and 1950 in Building 3019. After 1950, the Critical Experiments were moved to Y-12 (ORNL, 1967).

The first configuration tested enriched uranium in a small reactor using an aluminum-water moderator and deuterium oxide, beryllium, and ordinary water reflectors (Mann, 1947). The assembly was later modified for a series of experiments using only beryllium reflectors by the removal of the liquid storage and piping systems. This assembly was placed on an aluminum floor supported by cast iron and had plates and cross bars installed to accurately position fuel tubes and control rods. This rearrangement included the installation of improved radiation monitoring equipment (Martin, 1948).

The assembly was further modified to test a more complex arrangement in support of the design of the MTR. It was used to measure the critical mass of a slab as a function of its geometry, the change in reactivity arising from holes through the reflectors and absorbers within these holes, gamma-produced heat in the reflector, the neutron flux through the core and reflector, and the effectiveness of control rods of various materials (ORNL, 1948). Figure 5-9 shows a diagram of the Critical Experiments.



Source: Mann, 1947

Figure 5-9: Diagram of a Critical Experiments Assembly and Control Rooms

5.1.3 Radiochemical Development Facility and Other Separations Facilities

Construction activities for Building 3019 (originally 205) began in March 1943. Primary construction included six hot cells: one for dissolution of uranium from irradiated fuel slugs, four that housed equipment for successive chemical treatment of the uranium (precipitation, oxidation, and reduction); and one that stored contaminated equipment removed from the other cells. The cell area was within a frame structure that also contained the operating gallery and office areas. This facility, known as the Pilot Plant, was where various new chemical separations processes were tested (e.g., bismuth phosphate, reduction-oxidation [REDOX], Hexone-25, TBP [tributyl phosphate]-25, plutonium-uranium extraction [PUREX], fluoride volatility chemical process, and thorium extraction [THOREX]). (ORAUT-TKBS-0012-2)

Because of the variety of processes that took place in the building, many different radioisotopes were present in the facility. This facility conducted much of the research and development operations for separations at the site. Several of the processes are described below (ORAUT-TKBS-0012-2).

<u>Bismuth Phosphate Process</u>

From 1943 until 1945, the Bismuth Phosphate Process took place in Building 3019 using the bismuth phosphate “co-precipitation” process to recover plutonium. Processing began in December 1943, using uranium irradiated at the Washington University cyclotron in St. Louis. By the end of 1944, this chemical pilot plant was processing one-third ton of Graphite Reactor uranium fuel per day. By the time operations ceased in early 1945, a total of 326 grams of plutonium had been separated from 299 batches of irradiated uranium fuel slugs (ChemRisk, 1993).

The process took place in six hot cells. The fuel slugs were transported from the Graphite Reactor through an underground water-filled canal. The process involved the slugs being dissolved in acid in the initial cell. The remaining cells housed the equipment used in precipitating the plutonium from the dissolved fuel slugs and oxidation and reduction of the uranium. This batch process is based on the fact that plutonium will co-precipitate with bismuth phosphate in the +4 valence state, but not in the +6 valence state. Aluminum cladding was dissolved away from the fuel elements using boiling sodium hydroxide solution. The bare uranium was then dissolved in concentrated aqueous nitric acid and plutonium was separated and concentrated by many cycles of precipitation and dissolution using bismuth phosphate. The bismuth-phosphate process could only extract plutonium; the uranium remained as a waste product.

Radionuclides of concern include: U-234, U-235, Pu-238, Pu-239, and mixed fission products.

REDOX Process

The REDOX Process took place in Building 3019 from 1945 until 1951. The REDOX facility was a pilot plant for the Argonne National Laboratory REDOX Processing Plant. REDOX was a method of extracting uranium and plutonium from reactor fuel using solvents.

Radionuclides of concern include: U-234, U-235, Pu-238, Pu-239, and mixed fission products.

PUREX Process

PUREX processing took place in Building 3019 from 1949 to 1960. The PUREX process involved the use of TBP for solvent extraction. The TBP was used in organic and hydrocarbon diluents to isolate plutonium, uranium, zirconium, niobium, and ruthenium from fission product wastes.

Radionuclides of concern include: U-234, U-235, Pu-238, and mixed fission products.

Fluoride Volatility Process

Building 3019 housed the fluoride volatility chemical process. This process used the volatility of uranium hexafluoride to separate U-235 from molten salt fuels and other fuels that were soluble in molten salt.

Radionuclides of concern include: U-234, U-235, Kr-85, Xe-133, Te-127, Te-129, I-131, Ru-103, Ru-106, and Pu-238.

THOREX Process

The THOREX process was used in Building 3019 to separate U-233, Th-232, Th-233, and Pa-233 from irradiated thorium metal and other fission products. During 1956 and 1957, the thorium metal was decayed at shorter periods than normal to test the equipment and processes under high radiation conditions. In 1959, an explosion in the THOREX pilot plant released 0.6 g of plutonium from a hot cell, spreading it onto the street and the Graphite Reactor.

Radionuclides of concern include: Pu-238, Pu-239, U-233, Th-232, Th-233, Kr-85, Zr-95, Nb-95, Ru-103, Ru-106, I-131, I-132 (Te-132), Xe-133, Ba/La-140, Ce-141, Ce-144, and Pa-233.

Other Separations-Related Activities

Building 3019 also originally housed the Fuel Cycle Alpha Facility (FCAF) in a basement area before it was relocated to Building 4508. The FCAF fabricated PuO and (Pu,U)O fuel pellets and was used for coating sol-gel-derived microspheres with pyrolytic carbon. Special target materials for the High Flux Isotope Reactor were also developed and fabricated in this facility. Two additional and unique fuel-rod-loading techniques (vibratory compaction and slug injection) were also studied in the FCAF.

Wastes generated from Building 3019 operations flowed to the underground storage tanks in the North and South Tank Farm area, Buildings 3023 and 3507. At times, volatile gases were released from the head space of the tanks when liquids were being filled in the tanks.

Other buildings in the Main Plant Area where radioisotopic separations were conducted using slugs irradiated in the Graphite Reactor included: 3026C, 3026D, 3505, 3515, and 3517. The Building 3505 Metal Recovery Facility received irradiated fuel slugs from 1952 to 1960 and reprocessed the slugs to produce 320,662 kg of uranium, 184 kg of plutonium, 1,344 kg of neptunium, and 55 kg of americium (Peretz, 1982). Radiological fission products would have been present during the reprocessing of the irradiated fuel. A radiological survey conducted in 1981 indicated that the facility had widespread presence of residual fission products (Cs-137 and Sr-90) and uranic and transuranic radioisotopes. The building was demolished and removed from the site in the 2000 timeframe.

Buildings 3515 (Fission Product Pilot Plant) and 3517 (Fission Product Development Laboratory) were used in the further separation of fission products from the waste solutions that came from Building 3505. Building 3515 operated from 1948 to 1958 and was originally known as the Ru-106 Tank Arrangement. It was used to extract radioisotopes of ruthenium, strontium, cesium, cerium, and other fission products (ORAUT-TKBS-0012-2). In 1948, the facility consisted of a concrete pad with tanks surrounded by stacks of concrete blocks three rows deep. The pad was once covered by a tent. In 1950 or 1951, an 18-inch-thick, walled concrete hot cell with a 2-ft-thick concrete roof was constructed. Numerous spills occurred in the building over the years, and the internal structure, particularly the concrete floor, was frequently soaked with contaminated waste. The building was posted as a high radiation area. Operations in Building 3515 were moved to Building 3517 in 1958.

The hot cells in Building 3517 processed kilocurie amounts of fission products from REDOX and PUREX waste streams. A total of 1E+6 Ci of fission products were processed until building operations ended in 1975. The radioisotopes separated during the late 1950s and early 1960s included Ce-144, Cs-137, Sr-90, Pm-147, Ru-106, and Tc-99, but some uranic and transuranic isotopes would have been present in the waste as well as other fission products.

5.1.4 Radioactive Lanthanum Activities

During mid-1942, much research at the Metallurgical Laboratory at the University of Chicago was being directed at small-scale studies of various radioisotopes. While most of the radiological research was focused on the production of fissionable material for use in weapons manufacturing, some was conducted on other radioisotopes (i.e., activation and fission products) to determine their potential value to the war effort. While the Graphite Reactor was still being conceptualized by its designers, special attention was being given to barium, strontium, and lanthanum separation chemistry. Though initially-purified Ba-140 had little gamma activity, the activity of La-140 growing into the purified

Ba-140 created much interest due to the presence of a 1.6-MeV gamma emitted from La-140. Production activities were called the RaLa Project. In the fall of 1943, much of the Metallurgical Laboratory moved to ORNL to continue the research on fission products. This research was initiated at ORNL in Building 3550 (706-A) and soon (October 21, 1943) a request to construct a larger production facility was made. During the following year, Building 3026-C (originally 706-C) was designed and constructed with larger containers and equipment; the new facility's initial production run began on September 10, 1944 (ORAUT-TKBS-0012-2).

The 3026-C facility was designed to handle 1-Ci to 10-Ci amounts of radioactivity; however, due to time constraints and unusual circumstances, the facility was producing greater-than-100-Ci amounts of product upon start-up. The 3026-C facility processed irradiated slugs from the Graphite Reactor. In addition, nine production runs of RaLa were completed for shipment to Los Alamos, for a total of 3,852 Ci in the building (Thompson, 1949). Multiple batches of irradiated slugs were dissolved to make up a completed run. The last run in Building 3026-C was conducted on May 28, 1945.

After the second successful RaLa run in Building 3026-C, discussions were held indicating the need to further increase production rates. Although the use of existing facilities in the Pilot Plant (Building 3019) was discussed and evaluated, it was determined that a new facility annexed to the current facility would be needed. Building 3026-D (originally 706-D) was designed to process much larger (up to 1,000 Ci) amounts of radioactivity and was attached to the east end of the existing 3026-C facility. As in the construction of Building 3026-C, time constraints caused the design and development work for the new facility to coincide with facility construction. The first production run occurred on May 26, 1945 as the ninth and final run of RaLa was being completed in Building 3026-C. This facility also processed much higher activities than were designed for the facility (ORAUT-TKBS-0012-2).

Around 1948, the AEC decided to use irradiated slugs from the Hanford production reactors as feed for RaLa. The higher power of the Hanford reactors (relative to the Graphite Reactor) meant much larger quantities of RaLa could be produced in a shorter time even after the slugs were shipped across the country. A total of 68 RaLa runs had been completed at ORNL when operations ended in October 1956 (ChemRisk, 1999; Thompson, 1949). The RaLa program was subsequently transferred to the Idaho Chemical Processing Plant.

Due to the relatively short half-life of the parent Ba-140, the freshly-irradiated fuel slugs used in the RaLa process still contained relatively large quantities of short-lived fission products, most notably noble gases and radioiodines. Much of the iodine volatilized during the slug-dissolving process was effectively removed from the dissolver off-gas stream by the reflux condenser and chemical scrubber that were in line before the gaseous waste went to the stack. Dissolver off-gas from RaLa production was vented to the 3020 stack from 1944 to 1950 and to the 3039 stack from 1950 to 1956. From 1944 to 1950, other airborne wastes were withdrawn from the building's two process cells to a 30-ft stack adjacent to the building until this stream too was routed to the 3039 stack (ORAUT-TKBS-0012-2).

5.1.5 Isotope Production Areas

Following the small-scale production of plutonium from the Graphite Reactor and large-quantity production of RaLa in Buildings 3026-C and -D, site facilities were built to produce other radioisotopes. Table 5-3 lists facilities involved in the ORNL isotope production program and radioisotopes that would have been present. Building 3026-C was the initial facility for commercial isotope production at ORNL (Kuhaida, 1997). Most of the other isotope production facilities were built in the early 1950s. Some facilities have not produced any material since the 1960s, and some are used for storage. The following paragraphs contain information on several isotope production buildings.

Building 3028

Building 3028 was constructed in 1950 to house the I-131 processing facility and the separation facility for Pm-147 (ORNL, 1997a).

Building 3029

Building 3029 was constructed in 1952 to support the Isotopes Program (ORNL, 1997b). A small manipulator cell (now called Cell 4) and a system of remotely-operated barricades supported source fabrication of Ir-192. In addition, small Co-60 sources were fabricated. In 1955 and 1956, an additional cell (Cell 1) was built to handle large amounts of Co-60 for source fabrication. The amount of Co-60 sources fabricated in the facility diminished in the late 1950s. Major operations in Building 3029 included Co-60, Cs-137, and Sr-90 source fabrication, and Ir-192 processing. A Co-60 storage and irradiation facility, called the Co-60 Garden, is below the floor of the east wing (Kuhaida, 1997). The exact dates of operation of this facility are unknown, but the program ended in the late 1980s.

Building 3030

Building 3030 was constructed in 1950 to produce and develop radioisotopes for industry, medicine, and research (ORNL, 1997c). The building contained a hot cell for processing irradiated cyclotron and reactor targets to produce, purify, and separate radioisotopes such as Co-56, Co-57, Au-198, Fe-55, and Ir-192. These isotopes were processed primarily from irradiated targets from the HFIR (High Flux Isotope Reactor), ORR (Oak Ridge Reactor), and 86-inch Cyclotron. The exact dates of operation are not known. The program the facility supported began in the late 1940s and ended in the late 1980s.

Building 3031

Building 3031 was constructed in 1950 as part of the Isotopes Program and used for storage, purification, processing, and dispensing radioisotopes that were processed primarily from irradiated targets from the HFIR, ORR, and 86-inch Cyclotron (ORNL, 1997d). The hot cell was used for the final separation of gadolinium (Gd-103).

Building 3032

Building 3032 housed the analytical facility for radiochemical support of Isotopes Production activities (ORNL, 1997e). It has a laboratory with five hoods on the north side and an office on the south side connected by an open passageway. It was used for storage, purification, processing, and dispensing radioisotopes that were processed primarily from irradiated targets from the HFIR, ORR, and 86-inch Cyclotron. The exact dates of operation are unknown. The program it supported began in the late 1940s and ended in the late 1980s.

Building 3033

Building 3033 was used for processing C-14, Kr-85, and H-3. Processing of C-14 ended in 1975 (ORNL, 1997f). Radioactive gas processing of tritium and krypton took place in this facility. Bulk tritium shipments from the Savannah River Site were received, purified, loaded in shipping canisters, and shipped around the world. Krypton from Idaho was received and purified (Kr-85) for sale to private industries or used as feed to the thermal diffusion columns in Building 3026-C. The exact dates of operation are unknown. The program it supported began in the late 1940s. Processing of H-3 ended in 1990. The last Kr-85 was produced in September 1989.

Building 3033-A

Building 3033-A housed facilities for the fabrication of ceramic oxide wires and the loading of these wires, oxide powder, or metal into small metal capsules for use as in-core reactor neutron dosimeters (ORNL, 1997f). It also housed facilities for the fabrication of mono-energetic gamma sources, weighing and packaging of milligram-to-gram quantities of actinide materials, preparation of nanogram-to-milligram actinide samples for alpha counting, decontamination of nuclear material shipping containers, and storage of radioactive materials. All production operations ended in January 1990.

Building 3034

Building 3034 houses the electrical distribution system for the isotopes area and serves as a storage area and drop point for supplies. It also contains office space. No radioactive operations took place in the building; however, 1995 radiological surveys indicated several limited locations of elevated fixed beta/gamma contamination. An exhaust duct on the west wall of the second floor also indicated elevated beta/gamma measurements (ORAUT-TKBS-0012-2).

Building 3038

Building 3038 was used from 1949 until 1990 for radioisotope packaging, inspection, and shipping activities. It contained five hot cells shielded by water-filled steel tanks. The operating face of each cell consisted of 3 ft. of shielding, a viewing window, and manipulator ports. Each cell was 10 ft. deep. From 1968 until 1990, the western portion (the Alpha Handling Facility [AHF]) was used for the target fabrication. The center portion (3038-M) contained radioactive isotope shipping operations. The east end (3038-E) contained analytical chemistry laboratories that supported isotope shipping activities (DOE, 1996). The northwest corner (3038-W) contained a storage area and an isotope technology low-level laboratory.

Building 3118

Building 3118 was constructed to cover and enclose entries made in the hot cells in Buildings 3030 and 3031. It was used as a temporary storage shed for drums and containers of hazardous and radiological waste, radioactive shielding materials, and casks (ORAUT-TKBS-0012-2).

Table 5-3. Radioisotopes of Concern in Isotope Production Facilities

Building name	Building No.	Isotopes Formerly Stored, Used, or Produced
Krypton-85 Enrichment Facility	3026-C	I-129, I-131, Se-79, Pd-107, Pm-147, Cs-137, Sr-90, actinides, Kr-85, U, Tc-99, Co-60, Pu, H-3
Alpha Powder Facility	3028	I-131, Xe-133, Cm-242/244, Pm-147, Mo-99, Pu-238
Source Development Laboratory	3029	Ir-192, Co-60, Cs-137, Sr-90, I-131, I-CH3131, C-14, Tc-99
Radioisotope Production Laboratory–C	3030	Co-56/57, Au-198, Fe-55, Np-234, Se-75, Sr-90 nitrate, Sn-111, U-237, P-33, Ir-192, Ni-63, Pd-103
Radioisotope Production Laboratory–D	3031	Y-90, Gd-153
Radioisotope Production Laboratory–E	3032	Am-241, U-235, Pu-233, Eu-152,154, Gd-153, Co-56, Co-57, Au-198, Fe-55, Np-234, Se-75, Sr-90, Cs-137, Sn-111, U-237, P-33, Ir-192, Cm-244, Xe-131, I-131, Mo-99, Pm-147
Radioactive Gas Processing Facility	3033	H-3, Kr-85, C-14
Radioactive Production Laboratory Annex	3033-A	C-14, Am-241, Np-237, Pu-238, highly enriched actinide isotopes
Radioisotopes Area Services	3034	Not established – former field shop for Plant and Equipment Division support
Alpha Handling Facility	3038-AHF	Cf-252, Cm-244, Am-241, Pu-238, U-234, Np-237, Pa-231, others
Isotope Materials Laboratory	3038-E	Transuranics, Y-90, U-235, Pm-147, Sr-90, Cm-244, Am-241
Radioisotope Packaging and Shipping Facility	3038-M	I-129, Cs-137, Co-60, Sr-90, Tc-99, Mn-89, Ru-106, Cl-36
Isotope Technology Building	3047	C-14, Eu-152,154, Co-60, Gd-153, Am-241, Cm-242/243
Storage Cubicle	3093	Kr-85
Storage Pad	3099	N/A
Radioisotope Production Laboratory–H	3118	Not established
Fission Products Development Laboratory	3517	Sr-90, Cs-137, Ce-144, Pm-147, Ru-106, Tc-99, Co-60, Ir-192, U-235, Eu-152,154, Am-241
Tritium Target Preparation Facility	7025	H-3, ThO2, UO2, Sr-90, Cs-137, Cm-244

Source: ORAUT-TKBS-0012-2

5.1.6 ORNL Facilities at the Y-12 National Nuclear Security Complex

NOTE: Radiation exposures received by ORNL (X-10) employees while located on the Y-12 Facility are not part of this ORNL (X-10) evaluation. Information in this section is meant to describe the radionuclides produced at the Y-12 facilities, but often transferred to ORNL (X-10) for processing and experimentation. Evaluation of ORNL cyclotron and accelerator operations on the Y-12 site is reserved for this evaluation report because such operations at both ORNL (X-10) and Y-12 will be addressed in a future combined evaluation effort.

Due to a moratorium on construction activities immediately after World War II, insufficient space at ORNL caused the Biological Sciences Division to move to space at the Y-12 National Nuclear Security Complex, which included Buildings 9207, 9208, 9210, 9211, 9220, 9224, 9743, 9767-3, 9767-5, 9982, and several cooling towers. The Biological Sciences Division conducted animal research, typically using low-strength radiological sources for carcinogenic research, determination of the relative biological effectiveness of differing radiation types and source strengths, and dosimetry in space flight. Many of the studies were conducted in Building 9210, known as the Mouse House (ORAUT-TKBS-0012-2).

Space at Y-12 was used by the ORNL Research and Development divisions for several other projects. Three of the projects included the beta calutrons, the 86-inch cyclotron, and the 5-MeV Van de Graff Accelerator, all of which are briefly summarized below. Several of these projects involved the production and/or separation and purification of both stable and radioactive isotopes. Generally, the radioactive isotopes were produced in small quantities and/or had short half lives.

Work performed at these facilities presented external and internal radiation exposure potential. At times, Y-12 workers supported efforts at the facilities and, in some cases, Y-12 employees were administratively transferred to ORNL.

Figure 5-10 shows the productions flow between X-10, Y-12, and off-site locations. Certain radionuclides were produced at ORNL Graphite Reactor, the Cyclotron, and the Calutrons. Some materials containing these radionuclides were shipped off site, while other materials underwent further processing at X-10 before being shipped off site. Other source material was produced at the Low Intensity Test Reactor (ORNL) and off-site locations such as Hanford, University of Pittsburg, and Arco Idaho.

A decision was made to reserve the radionuclides created by cyclotrons, accelerators, and reactors for this evaluation report due to the complexity and interdependency involved in transferring materials between two DOE-covered facilities (X-10 and Y-12). The operational complexity involved both the graphite pile (X-10) and the cyclotron (Y-12) and included the transfer of some manufactured radionuclides from Y-12 to X-10 for further processing while others were manufactured at Y-12, packed at Y-12, and shipped out of the Oak Ridge area from Y-12. An evaluation of potential exposures from these activities was being initiated for Y-12 when this interdependency was discovered; therefore, the decision was made to combine the Y-12 and X-10 radionuclide research efforts for a better understanding of the overall operations and also enhanced efficiency of evaluation. This planned evaluation of radionuclides produced by cyclotrons, accelerators, and reactors will commence following the issuance of this current evaluation report.

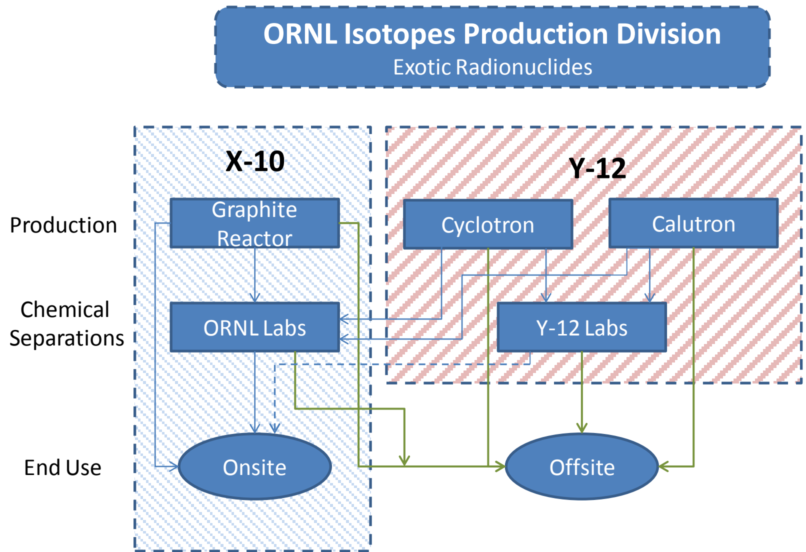


Figure 5-10: ORNL Isotopes Production Flow

Calutrons

The Stable Isotopes Program emerged at the end of World War II when site personnel stopped using calutrons to separate uranium isotopes for atomic weapons. The initial primary location for the effort was Building 9731 (Calutron Pilot Plant) starting in 1946 (Savage, 1950; Wilcox, 1997). During the 1950s, the Y-12 Beta calutrons (Building 9204-3) were used for the production, enrichment, and purification of an extensive list of stable and radioactive isotopes for worldwide medical research. Researchers at first used four calutrons salvaged from electromagnetic equipment. Copper isotopes were the first to be collected, followed by isotopes of iron, platinum, lithium, and mercury. These were separated and shipped to universities, governments, and national laboratories.

Based on a series of about 30 progress reports produced by the Electromagnetic Research Division and subsequent organizations, it is evident that plutonium isotopic enrichment work was occurring in 1952 and 1957. Documents also show that plutonium urinalyses were performed from 1952 through at least 1965, air monitoring was performed, and personnel protection was addressed through clothing and respiratory protection. Calutron facilities provided for double containment of the calutron(s) and glove-box handling of collection pockets (Progress Report, Dec1961; Progress Report, Oct1957).

86-inch Cyclotron

The 86-inch cyclotron began operation in November 1950 and was used for isotope production and to perform radiation damage studies for the Nuclear Aircraft Project (Ball, 1971). As the world's largest fixed-frequency proton cyclotron, it produced a proton beam four times more intense than any other cyclotron. One of the original uses of the Oak Ridge 86-inch cyclotron was the production of Po-208

(Livingston, 1952; Progress Report, Jul-Oct1962; Johnson, 1994). Polonium was produced in the 86-inch cyclotron as early as 1951 (ORNL, 1951). In 1952, internal revisions of the position and mounting of the ion source resulted in proton energy of 23 MeV.

<u>5-MeV Van de Graff Accelerator</u>

In the early 1950s, a 5-MeV Van de Graff accelerator operated for about one year in the east end of Building 9202-2 while a permanent structure was being built for the accelerator at the X-10 site. The 5-Me V Van de Graff Accelerator was an X-10 project and the health physicists and all other workers involved with the Van de Graff were X-10 employees (ChemRisk, 1993; Progress Report, Jan-Jun1951; Progress Report, Jul-Dec1951).

5.1.7 Waste Areas and Processes

According to the ORNL Site Description TBD (ORAUT-TKBS-0012-2), waste-handling practices at ORNL evolved as the scope and duration of its mission expanded. Gaseous wastes were initially discharged via local stacks and vents before a centralized off-gas treatment system began operating in 1950. Liquid wastes were originally handled using a system of tank farms and settling basins to treat wastes before discharge into White Oak Creek. More liquid waste treatment facilities were added over time. A number of trenches, burial grounds, and Solid Waste Storage Areas at ORNL have served as locations for disposal of solid wastes.

The Central Exhaust Facility (Building 3039), built in 1950, is the major exhaust stack in the Main Plant Area. The 3039 Stack Ventilation System off-gas and cell-ventilation facilities include cell ventilation, off-gas scrubber, and waste systems. Because of the diversity of activities in the buildings that the system serves, any gaseous waste stream can contain TRU or fission product radioisotopes. Building operators, in their role as waste generators, are responsible for keeping radionuclides in the gaseous waste streams discharging to the Stack Ventilation System at levels that limit risk to the health and safety of the public and employees. This mitigation occurs through a combination of administrative controls, input controls, application of health physics procedures, and treatment of the gaseous waste stream before discharge to the Stack Ventilation System (usually by HEPA filters).

Due to the varied history and growth of operations at ORNL, several waste disposition areas have been used. Early sites in or near the Main Plant Area accepted solid and liquid production wastes. In later years (after the period under evaluation), disposal areas moved south of the Main Plant Area across Haw Ridge to Melton Valley. The following paragraphs describe the information available to NIOSH regarding the areas and amounts of radioactive materials present.

The ORNL site was originally intended to operate for a short period to develop processes for use at other MED facilities. Because of this short-term focus, maintenance of much of the wastes was expected to be in consolidation areas. The North and South Tank Farms were established for temporary storage of liquid wastes. Processing included treatment and precipitation of solids and drainage of the supernatant. The waste was sent to the waste-holding basin and then to White Oak Creek. The holding areas treated the liquids and precipitated much of the radioactivity out of solution prior to off-site release. However, sediments in White Oak Creek and Lake contain radioactive materials that settled from the process liquids.

The North Tank Farm (Facility 3023), which was built in 1943, included four large concrete (gunite) underground tanks (W-1, W-2, W-3, and W-4) to store liquid chemical and radioactive wastes. In 1950, four stainless-steel underground tanks (W-1A, W13, W-14, and W-15) were built in the same general area. An extensive underground piping system transported liquid waste from Buildings 3019 and 3026 to the tanks.

The South Tank Farm (Facility 3507) is a series of six 170,000-gallon underground gunite storage tanks placed in service in 1943. The farm was part of the LLLW system for collection, neutralization, storage, and transfer of aqueous radiological and chemical wastes generated at ORNL.

The Waste Holding Basin (Facility 3513) was built in 1944 by scooping a depression in the native clay and constructing earthen berms to contain the liquids. The unlined disposal area measured 220 ft. by 220 ft. by 6.5 ft. deep. Supernatant wastes from the South Tank Farm were piped to the northern end of the basin. Water from the process waste treatment plant that had been treated with fly ash and lime was discharged to the holding basin before discharge to White Oak Creek. The basin was removed from service in 1976, but still contains water and contaminated sediments.

The contaminants in these three waste storage areas consisted of soluble and insoluble radioisotopes that flowed from the chemical separations areas. The liquid wastes were often treated with caustic material to increase the pH and prompt the radioactive material to settle out. Once treated, liquid waste could be transferred to make room for additional waste. The treated waste liquid was initially pumped into White Oak Creek. Liquid wastes were later transported by truck to Melton Valley, where they were poured into pits and trenches in which the liquid evaporated and chemically combined with the soil.

The Old Hydrofracture Facility (Building 7852) disposed of LLLWs deep in geological faults that are separate from sources of drinking water.

There are additional underground storage tanks in the main plant area (thorium tanks, Area 4500 tanks, and several tanks near the South Tank Farm).

Solid wastes were originally placed in Solid Waste Storage Areas on or near the Main Plant site (SWSA's 1, 2, and 3). Solid wastes were later transported to Melton Valley where other landfills operated. The following paragraphs describe SWSAs 1 to 6. NOTE: SWSAs 5 and 6 were opened after the SEC evaluation period and are not included in this discussion.

- <u>SWSA 1</u>: A 1.5-acre site on the north side and at the foot of Haw Ridge and immediately southeast of White Oak Creek in Bethel Valley. Solid waste was buried in this area in trenches south of Incinerator Drive beginning in April 1944. More waste was added in 1944, but the site was abandoned later that year due to water accumulating in the trenches. The area contains only a small amount of solid radioactive waste because fissionable material was maintained in the main plant site. At the time of waste generation, site operations did not include isotope separation and concentration of waste. Analyses from ground-water wells show low concentrations of Sr-90, but no indication of Cs-137 or transuranic elements.

- SWSA 2: Approximately 3.6 acres north of the location where the East Vehicle Gate existed, on the lower half of the hill adjacent to and west of the main parking lot. The site is not fenced or marked to identify its location. It was used from 1944 until 1946 for disposal of waste. Beta/gamma-contaminated solid waste was put in black drums and buried in trenches. Liquid waste contaminated with plutonium was put in stainless-steel drums and either buried in trenches or stored above ground in a ravine. Following closure of SWSA 2, the drums were removed and reburied in SWSA 3. Following drum removal between 1946 and 1949, the SWSA 2 hillside was bulldozed, backfilled, contoured, and seeded. Analyses of core samples indicated no contamination from uranium, plutonium, or Cs-137. Ground-water samples showed no detectable contamination; analyses included tritium, gross alpha, and gross beta.

- SWSA 3: Approximately 7 acres about 0.5 mi west of SWSA 1 and 0.6 mi west of the west ORNL entrance. SWSA 3 opened in 1946 and received contaminated trash, laboratory equipment, and other materials. The drums from SWSA 2 were placed in this area. Alpha-contaminated waste was put in drums and placed in concrete-lined trenches on the northeast end of the burial ground. Later, as the burial ground extended to the west, the drums were placed directly in unlined trenches and covered with concrete. Beta/gamma-contaminated wastes were buried in separate unlined trenches and backfilled with soil. Some large equipment contaminated with low levels of radioactivity was stored above ground until removal in 1979. Some items were moved to an area between SWSA 4 and the Chemical Waste Pits, while others were moved to SWSA 5 or 6 and buried. SWSA 3 closed in 1951. Ground-water samples indicate small amounts of trivalent rare earths, Sr-90, Sr-89, and H-3 contamination.

- SWSA 4: This location, covering approximately 23 acres, received waste from 1951 until 1959. SWSA 4 is in Melton Valley on the south side of and at the foot of Haw Ridge, immediately west of White Oak Creek. Records about waste disposed of in SWSA 4 before 1957 are incomplete due to a fire. ORNL generated about 50% of the waste buried in SWSA 4 during 1957 and 1958; the remainder came from more than 50 other agencies; Argonne National Laboratory, Knolls Atomic Laboratory, Mound Laboratory, and the General Electric Company (Evendale, Ohio) were principal generators. Surface- and ground-water samples indicate the presence of radioactive contamination. One well sample indicated alpha contamination while another 8 of 16 well samples indicated beta/gamma contamination. Radioactive contaminants include Sr-90, Ru-106, Cs-137, Co-60, Po-210, Pu-239, H-3, Sb-125, and trivalent rare earths.

5.2 Radiological Exposure Sources from ORNL Operations

The following subsections provide an overview of the internal and external exposure sources for the ORNL class under evaluation.

5.2.1 Internal Radiological Exposure Sources from ORNL Operations

The diversity of operations at the ORNL (X-10) site makes it difficult for NIOSH to collect complete details of all ORNL internal exposure sources. Nevertheless, NIOSH has determined that the internal dose potential during the period under evaluation is associated with reactors, machine shops, accelerators, and other research and support activities as well as radioactive waste disposal. Although not all specific areas where waste materials were generated and buried are readily identifiable from the documents available to NIOSH, a potential for internal intakes from these activities is assumed to exist.

Radionuclides with the widest application throughout ORNL facilities during the period under evaluation are:

- Plutonium (Pu-238, Pu-239, Pu-240, Pu-241)
- Uranium (U-238, U-233, U-234, U-235)
- Fission and activation products (e.g., Sr-90, Cs-137, Zn-65, Co-60)
- Thorium (Th-232)
- Exotic radionuclides (e.g., C-14, Ca-45, P-32, S-35, Ba-140/La-140, and others produced by reactor neutron irradiation and/or accelerator processes).

5.2.1.1 Plutonium

Plutonium exposure potential has existed at ORNL from the site's inception to the present because of the numerous reactors, separations facilities, and accelerator facilities. Activities with the potential for plutonium intakes have occurred since 1944. Many facilities exhibited potential plutonium exposure during the period under evaluation, as shown in Table 5-2. Surveys, air samples, and bioassay samples for plutonium (via gross alpha analysis) were routinely performed, as indicated by the air sample database and confirmed by many available documents. Positive results have been noted for many samples within the documents (Monitoring, 1945-1990; Monitoring, Jan-Jul1949) and the air sample database (Monitoring, Jun1944-Dec1947).

There is no definitive historical information on the isotopic ratios of ORNL plutonium sources except for some documents from the period 1954-1956 related to using electromagnetic equipment. Other than the electromagnetic equipment areas, there is also no information available to NIOSH about how typical isotopic ratios varied with time and location. The dominant isotope (by activity) in most of the plutonium to which ORNL workers might have been internally exposed is Pu-239. Lab-scale separation activities (i.e., gram quantities) conducted in 1954 using electromagnetic equipment (calutrons) at the Y-12 location assigned to the stable isotopes program were noted in two reports (Bell, 1954; Martin, 1956). Various isotopic abundances were achieved for Pu-239, Pu-240, Pu-241, and Pu-242. In December 1955, a seventh separation of the heavier plutonium isotopes from irradiated plutonium was completed with an estimated production of 1.0 gram of 85% Pu-240 and 160 mg of Pu-241 (Progress Report, Dec1955). No other reports documented plutonium separation activities involving larger than gram-scale quantities.

5.2.1.2 Uranium (U-238, U-233, U-234, U-235)

Uranium exposure potential has existed at ORNL since the site's inception to the present because of the numerous reactors, separations facilities, and accelerator facilities. Activities with the potential for uranium intakes have occurred since 1943. Many facilities have exhibited potential uranium exposure during the period under evaluation, as shown in Table 5-2. Surveys, air samples, and bioassay samples for uranium (via gross alpha analysis) were routinely performed, as indicated by many documents and the air sample database. Positive results have been noted for many samples within the documents available to NIOSH (Monitoring, 1945-1990; Monitoring, Jan-Jul1949) and the air sample database (Monitoring, Jun1944-Dec1947).

ORNL uranium processes included (Brooksbank, 1994):

- Bismuth phosphate
- REDOX
- Hexone-25
- TBP-25
- PUREX
- THOREX

5.2.1.3 Fission and Activation Products (e.g., Sr-90, Cs-137, Zn-65, Co-60)

Fission and activation product exposure potential has existed at ORNL since the site's inception to the present because of the numerous reactors, separations facilities, and accelerator facilities. Many facilities have exhibited fission and activation product exposure potential during the period under evaluation, as shown in Table 5-2. Surveys, air samples, and bioassay samples for fission and activation products (via gross alpha and gross beta/gamma analysis) were routinely performed, as indicated by many available documents and database (Monitoring, 1945-1990).

Many of the electromagnetically-produced radionuclides generated at ORNL (i.e., at Y-12) were also fission and/or activation products. Table 5-4 identifies the produced radionuclides identified from 1943 through 1955 in the various monthly reports, annual reports, and other relevant data capture documents. This listing of fission products does not include radioisotopes generated by reactor operations and fuel separations activities not specifically listed in the available documents but which would be expected to be present as early as 1943 when the Graphite Reactor became operational.

Table 5-4: Isotopes Identified in ORNL Documents from 1943 through 1955
(This tables spans four pages)

Isotope	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955
americium-241										X		X	
antimony-122													
antimony-124						Z			X	X	X	X	R
antimony-Be						X	X					R	R
antimony-125									R			X	R
argon-37									G	G	G	G	G
argon-41								G					
arsenic-73								X	X	X		X	
arsenic-74									X	X		X	
arsenic-76											X		
arsenic-77												R	
barium-131													
barium-133												R	R
barium-140					X		X		X	X	X		R
beryllium-7							X	X	X	X	X	X	R
beryllium-9											X		
bismuth-207											X		
bismuth-210						Z							R
boron-10					X							X	
bromine-82													
cadmium-115						Z		X	X	X	X	R	R
cadmium-115m												R	R
calcium-45					X	X	X	X	X	X	X	X	R
carbon-14				X*	X	X	X	X	X	X	X	X	R
cerium-141							X		X	X	X	X	R
cerium-144						X	X	X	X	X	X	X	R
cesium-134											X	X	R
cesium-137					X	X	X	X	X	X	X	X	R
chlorine-35							X						
chlorine-36					X	X	X	X	X	X	X	X	R
chlorine-38					X								
chromium-51									X	X	X	X	R
cobalt-56									X	X	X		
cobalt-57							X	X	X	X		X	R

Table 5-4: Isotopes Identified in ORNL Documents from 1943 through 1955 (This tables spans four pages)													
Isotope	**1943**	**1944**	**1945**	**1946**	**1947**	**1948**	**1949**	**1950**	**1951**	**1952**	**1953**	**1954**	**1955**
cobalt-58												X	R
cobalt-60						X	X	X	X	X	X	X	R
copper-64													
europium-152-154										X	X		
europium-152						Z				X			
europium-154								X		X		X	
europium-155						X		X		X		X	R
fission products						X		X	X	X	X	X	R
Au198							X				X		
hydrogen-3 gas							X	X	X	X	X	X	R
hydrogen-3 zirconium											X	X	R
indium-111												R	
indium-114						X			X		X	R	R
iodine-125								X		X	X	R	
iodine-129													R
iodine-131				X	X	X	X	X	X	X	X	X	R
iridium-192										X	X	X	R
iron-55-59						X	X	X	X	X		R	R
iron-55					X	X	X	X	X	X	X	X	R
iron-59					X	X	X	X	X	X	X	X	R
krypton-85												G	G
lanthanum-140		X	X	X	X	X	X	X	X	X	X	X	
manganese-52									X	X	X		
manganese-54								X	X	X	X	X	R
mercury-203						X			X	X	X	X	R
neodymium-147							X		X	X	X	R	R
nickel-59						X							
nickel-63						X			X	X	X	R	R
nickel-65													
niobium-95					X		X	X	X	X	X	X	R
osmium-185						Z							
osmium-191						Z							
osmium-193						Z							
phophorus-32				X	X	X	X	X	X	X	X	X	R
polonium-208								X	X				

Table 5-4: Isotopes Identified in ORNL Documents from 1943 through 1955
(This tables spans four pages)

Isotope	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955
polonium-210		Z				Z							
potassium-40						X	X						
potassium-42						Z				X	X	R	R
praesodymium-142													
praesodymium-143							X		X	X	X	R	R
promethium-147							X	X		X	X	X	R
protactinium-233								X					
rubidium-86													R
rhodium-102					X								
rhodium-105					X								
ruthenium-103					X				X	X	X	R	R
ruthenium-106					X	X	X	X	X	X	X		R
samarium-151								X		X			
samarium-153													
scandium-46						Z		X		X		X	R
selenium-75						Z	X		X		X	X	R
silver-110						Z				R	X	R	R
silver-111													
sodium-22							X	X	X	X	X	X	R
sodium-24										X	X	X	R
strontium-85					X					X	X	X	R
strontium-89					X	X	X	X	X	X	X	X	R
strontium-90						X	X	X	X	X	X	X	R
sulfur-35					X	X	X	X	X	X	X	X	R
tantalum-182						Z			X			R	R
technicium-99					X							R	R
terbium-160								X					
thallium-204						Z	X		X	X	X	R	R
Tungsten-51						Z	X						
thorium-234					X	X							
tin-113								X	X		X	X	R
tungsten-185						Z			X	X	X		
tungsten-187						Z					X	R	R
yttrium-88												X	
yttrium-90				X									

Table 5-4: Isotopes Identified in ORNL Documents from 1943 through 1955
(This tables spans four pages)

Isotope	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955
yttrium-91					X	X	X	X	X	X	X	X	R
zinc-65					X	X		X	X	X	X	R	R
zirconium-95					X	X	X	X	X	X	X	R	R
Ra:Be (radium-226)					X								
Rare Earth (gross)							X	X	X	X			

Sources: See reference list below.
* = carbon-14: First shipment of 1 mCi of C-14 in August 1946.
R = Notes listed in Annual Summary Report though not in Monthly reports.
X = Notes listed in Monthly reports. (December 1946-December 1954)
Z = Notes listed in 1948 Radioisotopes Catalog though not in Monthly Reports or identified on other reports.
G = Notes inert gas, not an internal hazard

Data sources for Table 5-4 above include the following references:

1947:
Progress Report, Jan1947
Progress Report, Feb1947
Progress Report, Mar1947a
Progress Report, Mar1947b
Progress Report, May1947
Progress Report, Jun1947
Progress Report, Jul1947
Progress Report, Aug1947
Progress Report, Nov1947

1948:
Progress Report, Feb1948
Progress Report, Jul1948
Progress Report, Aug1948
Progress Report, Oct1948
Progress Report, Nov1948

1949:
Progress Report, Feb1949
Progress Report, Apr1949
Progress Report, May1949
Progress Report, Jun1949
Progress Report, Sep1949
Progress Report, Dec1949

1950:
Progress Report, Jan1950
Progress Report, Mar1950
Progress Report, Apr1950

1951:
Progress Report, Feb1951
Progress Report, Apr1951
Progress Report, May1951
Progress Report, Jun1951
Progress Report, Jul1951
Progress Report, Aug1951
Progress Report, Sep1951
Progress Report, Oct1951b
Progress Report, Dec1951

1952:
Progress Report, Jan1952
Progress Report, Feb1952
Progress Report, Mar1952
Progress Report, Apr1952
Progress Report, May1952
Progress Report, Jun1952
Progress Report, Jul1952
Progress Report, Aug1952
Progress Report, Sep1952
Progress Report, Oct1952
Progress Report, Dec1952

1953:
Progress Report, Jan1953
Progress Report, Mar1953
Progress Report, Apr1953
Progress Report, May1953
Progress Report, Jun1953
Progress Report, Jul1953
Progress Report, Aug1953
Progress Report, Oct1953
Progress Report, Nov1953
Progress Report, Dec1953

1954:
Progress Report, Feb1954
Progress Report, Mar1954b
Progress Report, Jul1954
Progress Report, Aug1954
Progress Report, Sep1954
Progress Report, Oct1954
Progress Report, Nov1954
Progress Report, Dec1954

1957:
Seagren,1957

5.2.1.4 Thorium (Th-232)

Thorium exposure potential has existed at ORNL since 1944 because of the numerous laboratory facilities as well as fuel development and testing facilities. Some facilities have exhibited thorium exposure potential during the period under evaluation, as shown in Table 5-5. Initial thorium processing was performed in Building 3019 (Pilot Plant). Potential intakes may have resulted from basic thorium research, operations with nuclear fuel development operations, nuclear fuel separations activities, and laboratory activities. Surveys, air samples, and bioassay samples for thorium (via gross alpha analysis) were routinely performed, as indicated by the air sample database and many available documents. Positive results have been noted for many samples within the documents (Monitoring, 1945-1990) and air sample database (Monitoring, Jun1944-Dec1947). Many documents were obtained related to the thorium processes and activities at the site. Limited documentation has been obtained regarding thorium bioassay prior to 1955. However, concerns associated with thorium alpha emissions and exposures cannot be limited by operational location during the period under evaluation.

Thorium operations began in 1944 with lab-scale preparation and testing of thorium carbonate (the likely locations were 706A and 205). In 1946, test runs for the development of 23 (U-233) extraction from irradiated slugs occurred in 706A (the code word for U-233 at the time was 23). From 1947 through around 1950, thorium extraction runs were performed in 706A and 706C. In 1948-1949, a pilot plant (the 23 Pilot Plant) was constructed in 706HB with thorium extraction runs occurring from 1949-1950 through around 1955. In 1954, the Thorex Pilot Plant was installed in Building 205; it processed thorium from 1954 through the end of the period under evaluation.

Table 5-5: Principal Facilities with Internal Exposure Potential for Thorium during Evaluation Period

Current Building Number	Former Building Number	Facility Name or Description	Dates of Operation	Likely Potential Periods of Thorium Exposure During Evaluation Period
3001	105	Graphite Reactor	Nov. 1943–Nov. 1963	1944-1955
3019	205	Pilot Plant	Dec. 1943–present (partly inactive and pending D&D)	1946-1955
3026-C`	706-C	Radiochemistry Laboratory	1944–circa 1997	1944-1955
3026-D	706-D	Radiochemistry Laboratory (RaLa building from May 1945 until 1958); Segmentation Facility	1945–(pending D&D)	1945-1955
3028	901	North Tanks Farm	1943-1986	1944-1955
3503	706-HB	(23 Pilot Plant)		1949-1955
3550	706-A	Research materials Preparations Facility	1943-no end date known	1944-1955
Misc	---	Various other laboratory testing facilities	1943- no end date known	1944-1955
Misc	---	Various storage facilities	1943-1978	1944-1955

Source: ORAUT-TKBS-0012-2

Table 5-6 presents a timeline of thorium and thorium-related activities from 1943-1955 derived from documents available to NIOSH.

Table 5-6: Operational Timeline of Thorium and Related Processes, 1943-1955

Years	Thorium and Related Processes
1943 - mid-1944	No evidence of thorium work or processes.
1944	Lab scale work on thorium carbonate. Preparation and irradiation of thorium carbonate for U-233 Program.
1946	Lab scale separation and purification of U-233 from solutions containing thorium nitrate.
mid-1946	Thorium slug removal from pile and processing.
1947 - 1950	Hexone-23 slug extraction process.
1948 - 1949	Constructed the 23 Pilot Plant.
1950	Approximately 1 Kg shipped to ORNL.
1951 - 1953	>2000 Kg annually shipped to ORNL.
1952	Approximately 2.76 Kg U-233 isolated from runs of 3689 Kg of Hanford irradiated thorium.
1952 - 1953	Interim 23 process work in Pilot Plant (mostly runs of Hanford irradiated thorium).
1953	>4000 Kg shipped to ORNL.
1953 - 1954	Thorex fuel blanket material processing. Thorex Pilot Plant installed in Building 3019 .
1954	Thorium purification studies initiated. Also began work on refining technology, separations from decay products, and fluoride reduction. Conducted thorium oxide blanket studies and pile irradiation of sample slurry. First Thorex cycle completed.
1955	Second Thorex cycle completed. Approximately 5000 lbs of ThO2 prepared and made ready for blanket studies.
1955	13073 Kg non-irradiated thorium processed and 6466 Kg irradiated thorium processed.
1955	Metallex lab scale studies. Larger scale runs conducted the following year.
1955-1960	Thorex processing of irradiated thorium metal (Hanford, SRS metal)

Sources: Booth, 1946; Brooksbank, 1994; Division Monthly reports 1951-1954 [see reference list preceding Table 5-4]; McCarley, 1956; Progress Report, Jan-Jul1946, pdf p. 188; Progress Report, Feb1947; Progress Report, May1954; Thompson, 1963; Thorium, 1944

5.2.1.5 Exotic Radionuclides Produced by Reactor Neutron Irradiation and/or Accelerator Processes

ORNL built and operated cyclotrons and accelerators on the Y-12 site. These operations generated radionuclides (e.g., C-14, Ca-45, P-32, Ba-140/La-140, and others). NIOSH has access to data for these operations. However, this topic is reserved for this evaluation report because cyclotron and accelerator operations at both ORNL (X-10) and Y-12 will be addressed in a future combined evaluation effort.

5.2.2 External Radiological Exposure Sources from ORNL Operations

A great variety of radioactive nuclides were created, separated, processed, and used at ORNL. These can be broadly categorized into the groups of mixed fission products, activation products, and the uranium and thorium isotopes.

5.2.2.1 Photon

Photon exposure resulted from the mixed fission and activation products from the reactors and from isotopes produced at Y-12 (See Table 5-4). Exposure rates varied by building and by dates, but generally, exposure potential increased with time due to increased production and an increasing number of reactors on site. Examples of survey data have been located but are not complete for all locations for all time periods (Clark, 1944; Perry, 1947; Progress Report, Jan-Dec1947; Simons, 1945). However, such surveys indicate the contemporary controls and enforcement of restricted areas.

Direct photon exposure also resulted from workers in the proximity of the test and the research nuclear reactors. Exposure at the Graphite Reactor was monitored by routine surveys. Examples of these surveys have been located (Progress Report, Jan-Jul1946, pdf p. 6; Clifford, 1951). Survey data for other reactors have been located but are not complete for all reactors for all time periods (Exposure, 1951). Reactor operations began in 1943 with the Graphite Reactor and increased in 1951 with the addition of the Low Intensity Test Reactor and the Bulk Shielding Reactor. Three additional reactors became operational in 1954: the Homogeneous Reactor Experiment, the Aircraft Reactor Experiment and the Tower Shielding Reactor. In addition, the three critical assemblies that comprised the Critical Reactor Experiments ran from 1945 through 1948. Although these were brought to critical levels and therefore would have created some level of exposure, they were operated from behind a 2-foot thick shield due to risk of a criticality accident (ORNL, 1967). Table 5-7 includes the names, locations, and operational lifetimes for all reactors existing from 1943 through 1955 (Campbell, 1956; Holland, 1970; ORNL, 1967; Progress Report, Dec1951; Progress Report, Mar1954a; Progress Report, Jun1954; Progress Report, Mar1955; Rosenthal, 2009).

Table 5-7: Reactors at ORNL from 1943 through 1955	
Reactor	**Dates**
Pile (Graphite Reactor) Building 3001	1943 - 1963
Low Intensity Test Reactor (LITR) Building 3005	1951 - 1968
Bulk Shielding Reactor (BSR) Building 3010	1951 - 1987
Homogeneous Reactor Experiment (HRE-1) Building 7500	1952 - 1954
Aircraft Reactor Experiment (ARE) Building 3019	1954
Tower Shielding Reactor (TSR-I)	1954 - 1958
Critical Reactor Experiments A series of three small reactors for testing enrichments, moderators, and reflector configurations	1946 - 1948

Source: Campbell, 1956, pdf p. 38; Mann, 1947;-Martin, 1948; ORAUT-TKBS-0012-02; ORNL, 1948; ORNL, 1958; ORNL, 1992; Progress Report, Jan1951; Progress Report, Dec1951; Progress Report, Mar1954a, pdf p. 15; Progress Report, Jun1954, pdf p. 150; Progress Report, Mar1955, pdf p. 13; Rosenthal, 2009; ORNL, 1952, pdf p. 7; AEC, 1960, pdf p. 552

5.2.2.2 Beta

Beta exposure resulted from the mixed fission and activation products from the reactors, and from isotopes produced at Y-12 (see Table 5-1). Exposure rates varied by building and by dates, but generally, exposure potential increased with time due to increased production and an increasing number of reactors on site. Examples of survey data have been located but are not complete for all locations for all time periods (Clark, 1944; Perry, 1947; Progress Report, Jan-Dec1947; Simons, 1945). However, such surveys indicate the application of contemporary controls and the enforcement of restricted areas.

5.2.2.3 Neutron

ORNL workers may have been exposed to neutrons from neutron sources and from the existing nuclear reactors. An undated memo, which can be reasonably dated to circa 1951 from the operational statuses of the reactors mentioned, listed all sources of neutron exposure (Neutron Problems, unspecified). It stated that there were “12 PoBe” and “8 RaBe” neutron sources, ranging in strength from 0.4 to 12 curies.

Reactors operating during the period under evaluation included those created as experimental facilities for measuring reactor kinetics, neutron irradiation, and shielding factors (e.g., the Graphite Reactor and the Bulk Shielding Reactor).

In addition, in the Critical Reactor Experiments facility, three bench-scale critical assemblies were created to study design parameters for neutron reflectivity and criticality measurements. These assemblies were brought to critical levels for short periods and later disassembled. Although these assemblies were brought to critical levels and produced neutrons, they were operated behind a 2-ft. shield due to concern of a criticality accident (ORNL, 1967). Table 5-7 lists all ORNL reactors in existence from 1943 through 1955.

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

The following subsections provide an overview of the state of the available internal and external monitoring data for the ORNL class under evaluation.

6.1 Available ORNL Internal Monitoring Data

Data Description

A large amount of raw bioassay data exists at the ORNL complex. These data were transcribed into an electronic database hosted on ORNL equipment and maintained by ORNL personnel. This database (Monitoring, 1945-1990) was queried for historical urinalysis records on October 30, 2003 and was used by NIOSH for the ORNL Internal Technical Basis Document (ORAUT-TKBS-0012-5). A supplemental query was performed on December 12, 2003. These database queries were compiled into a single database (Monitoring, 1945-1990).

These queries requested information on the samples and the instrumentation used in the analysis. No personal information or individual dose results were requested or received. These database queries generated 66,204 records for the period 1945-1988. These records were compiled into a single database and data validation and comment fields were added to each record. Then the records were examined and classified according to usability for the ORNL Internal Technical Basis document MDA calculations (ORAUT-TKBS-0012-5). For consistency, and because they were previously examined, these data were used for this evaluation report. Duplicate records and unusable records (e.g., gross errors) were not included in this assessment. The database recovered 23913 records from 1945 through 1959 (which includes most years of the period under evaluation). Of these, 22497 are clearly for urinalysis and 1416 are for fecal samples. These data were also cross-verified with a 1949 Logbook containing plutonium urine sample data obtained through data capture (Monitoring, Jan-Jul1949). The first samples identified are plutonium samples from 1945 through 1948. No bioassay samples in the database were prior to 1945.

Although not included in the database or individual files, there are indications of ORNL urine sample results from as early as 1943 (Davis, 1954). This is discussed later in this report. The presentation of available internal monitoring data in this report (Section 6.1) also reflects data obtained from ORNL during multiple data capture trips conducted by NIOSH.

A second set of data obtained by ORISE in 2011 was also evaluated (Monitoring, 1943-1959). This second data set of 23328 samples provided similar sample results as the 2003 data (Monitoring, 1945-1990) but did not provide as comprehensive information on specific radionuclides, and thus, was not used in this evaluation. The 2011 set of bioassay results was obtained from the Oak Ridge Institute for Science and Education (ORISE) Center for Epidemiologic Research (CER) Dosimetry Database, which contains urinalysis records from the ORNL site for the period 1943 to 1959. ORISE obtained this database from ORNL for an epidemiological study of site workers. Because the varied operations at ORNL involved exposure potential to many radionuclides, the database contains urinalysis data for numerous radionuclides.

There are fairly extensive air monitoring records from 1944 through 1947 that are suitable for assigning estimates of exposure and dose. This is discussed later in this report.

Overview

The start-up of the Graphite Reactor and plutonium separation activities in late 1943 introduced the potential for personnel exposures from intakes of radioactive material. Laboratory operations involving radioactive materials increased over subsequent years as ORNL expanded its roles in radionuclide production and the development of chemical separations processes. Development of methods and techniques for internal monitoring (bioassay) was one of the many ORNL priorities in its early years of operation because such methods simply did not exist.

Although ORNL used air sampling and radiological contamination monitoring programs as qualitative indicators of internal exposure, urinalyses for various internal contaminants did not begin at the site until about 1945, though possibly as early as 1943. A limited number of *in vivo* measurements appear to have begun at ORNL in 1959. ORNL maintained early tolerance levels for airborne contamination based on "product" (i.e., Pu-239) concentrations in the air (Wirth, 1946). These early tolerance levels for alpha and beta-gamma contaminants were 3E-11 and 1E-07 $\mu Ci/cm^3$ respectively during the mid-1940s.

Isotope-specific analyses for *in vitro* samples did not become routine until 1989. Prior to that time, chemical methods were used to separate radioelements as well as practicable, and the materials were assayed in terms of total activity. The activity measured would later be assigned to a predominant nuclide. Thus, a result from the early years might indicate Sr-90, when in reality it includes Sr-89. The same is true for early plutonium results and results for transuranic materials. Thus, "associated" radionuclides are inherently included in such results. Process knowledge of radionuclides present in various work areas was used to assign nuclides to sample results. Division codes and building locations sometimes provide information on individual locations and specific radionuclides that were monitored.

ORNL Bioassay Programs

In Vitro Sampling and Analysis

For much of ORNL's operational history, health physics representatives, using professional judgment, designated personnel for participation in internal dosimetry monitoring (primarily urinalysis during the period under evaluation).

ORNL has collected urine and fecal samples from individuals suspected of potential intakes from 1945 (and possibly as early as 1943) to the present. Urine samples have been, and still are, the preferred method. The volume of sampling during the period under evaluation was relatively low and assays were for uranium and plutonium. The processing of urine samples at the ORNL Urinalysis Building started in 1947 (Davis, 1954). At that time, analytical procedures were only available for uranium and plutonium and the number of collected samples was not extensive. During the early period when checks were made only for plutonium and uranium, the personnel in the urinalysis building used organizational charts for determining the personnel to be sampled and requests were also made through employees' supervisors. At this time, this was considered a workable method because of the few people involved. During the mid-to-late 1940s, urine and fecal samples were collected in the early years of the bioassay program based on the Area Health Physicist's knowledge of field conditions (e.g., known spills/incidents, air and contamination sample results, etc.). When the assay for fission products was instituted (~1950), the Health Physicist also determined which employees should be sampled.

Although one plutonium bioassay for 1945 and four plutonium bioassays for 1946 were found in the database, and more than 100 plutonium bioassay samples were identified for successive years (Monitoring, 1945-1990), reports obtained by NIOSH during on-site data capture indicate plutonium bioassay monitoring occurring as early as 1943. One particular report noted that when operations started at Clinton Laboratories (now ORNL) in 1943, urine samples were sent to Argonne National Laboratory (ANL) in Chicago for processing (Davis, 1954). Another report indicated that plutonium urine sample analysis carried out at the Met Lab (ANL) started with the first weekly series on January 1945 (Wirth, 1945a). Further data captures identified 164 plutonium urine samples taken from February 1945 through May 28, 1945 (Monitoring, Feb-Jun1945). No earlier samples have been identified. Further discussion is detailed later in this report.

The ORNL database contains values for isotopic activities during times when isotope-specific analyses were not possible or routinely performed. In earlier years, the element of concern was extracted chemically from the biological sample and the total radioactivity of the element in the extract was measured. At some point after the extraction and sample count, the total sample activity was attributed to a specific radionuclide. Many of the isotopic assignments were based on process knowledge.

In order to evaluate the effectiveness of the bioassay program, and as a possible basis for improvement, a study was conducted of all urinalysis samples submitted from July 2, 1953 to August 23, 1954 (Davis, 1954b). The total number of samples was 1265. It was concluded that the method for the period seemed adequate and the recommendation was that the major emphasis be placed on obtaining samples for employees regularly working with radioactive materials and the schedule for sampling to be left at the discretion of the Health Physics area surveyor. It was further recommended that the surveyor, each year, select at random a number of employees who do not work regularly with radioactive materials and suggest that they submit a sample.

In Vivo Sampling and Analysis

Few *in vivo* measurements have been obtained by NIOSH for the period under evaluation. Reports noted thyroid counting results as early as 1946, 1948, and 1951 (Incident, Jan1951; Monitoring, Oct1948b; Progress Report, Jun1946). One report indicate that the whole-body counting (WBC) facility began operation in July 1959 (Progress Report, Jul1966), and other reports indicate a May-June 1960 date (Mani, 1983; Watts, 1995). Thus, it is likely that the WBC facility began limited operations in 1959.

The initial *in vivo* counter at ORNL used a 4-inch by 4-inch NaI (Tl) crystal and a tilted chair counting arrangement (Progress Report, Jul1961). Prior to February 27, 1961, *in vivo* counting had been restricted to checking individuals involved in known contamination incidents (Progress Report, Jul1961). From December 1962 to May 1965, a program to obtain baseline counts on essentially everyone with any significant potential for future exposure was accomplished (Mani, 1983).

ORNL has collected whole-body, lung, and wound counting data for employees since 1959. For the most part, *in vivo* counting was used until the late 1980s to confirm potential intakes from known incidents or intakes identified by the *in vitro* monitoring program. Although the Health Physics Division Annual Report for the period ending July 31, 1965 indicated that routine *in vivo* monitoring for all site radiological workers began in 1965, it appears that a formal program did not begin until the mid-to-late 1980s (Progress Report, Jul1965, pdf p. 251).

Air Sample Data

ORNL maintained early tolerance levels for airborne contamination based on "product" (i.e., Pu-239) concentrations in the air (Parker, 1944). These early tolerance levels for alpha and beta-gamma contaminants were 3E-11 and 1E-07 $\mu Ci/cm^3$, respectively, as early as 1944 and maybe 1943 (Monitoring, Jun1944-Dec1947). The 3E-11 uCi/cm^3 value for alpha was for prevention of deposition of 1 microgram of plutonium in the body (Wirth, 1946). For general safety and convenience, other alpha emitters were considered at the same activity level (Wirth, 1946). In addition, the laboratory later established tolerance levels for materials such as I-131 and noble gases. In practice, controls were established to attempt to maintain exposures at ten percent or less of tolerance levels. Controls were established requiring an approved respirator, combat mask, or air-line hood in any location where the concentration of airborne alpha emitters may be greater than 3E-11 uCi/cm^3. Similar precautions were taken for airborne beta/gamma emitters (Wirth, 1946).

There are fairly extensive air-monitoring records identified in the 1944 through 1947 timeframe that are suitable for assigning estimates of exposure level and/or dose (Monitoring, Jun1944-Dec1947). Tolerance levels are well documented and there is strong evidence (i.e., memoranda and monthly reports) that exposure was controlled based on samples results (Progress Report, Jan-Dec1946, pdf pp. 205, 330; Wirth, 1946). These memoranda include weekly reports on the airborne activity levels in various areas, as well as precautions taken or to be taken in the future (Monitoring, Jun-Nov1944; Monitoring, Aug1944). While exposure to greater concentrations was likely over short periods for some occupations, the overriding control goal was to limit the average exposure over longer timeframes.

Based on interviews with former ORNL employees and the sample location descriptions, these air samples are believed to be representative of the breathing zone. Air samples were normally taken at head height with the intent of sampling a worker's breathing zone to compare to tolerance levels. About one-half of these air samples had sample location descriptions that were noted as six inches from the hood or hood samples. Other samples were noted as being taken during assault mask use (possible breathing zone), were in unspecified locations in rooms or during activities, or were indeterminate. One report in 1944 indicated that, during an air contamination event, air samples were noted as being taken in front of a hood; however, on the following page, the sample locations were noted only as hood samples (Koval, 1945). In the electronic database, these samples were also identified only as hood samples. NIOSH considers this an indication that samples designated as hood samples in the air sample database could be considered “breathing zone” air samples. Further discussion on air sample data is detailed later in this report.

6.1.1 Personnel Monitoring for Plutonium (Pu-238, Pu-239, Pu-240, Pu-241)

As discussed above, ORNL maintained early tolerance levels for airborne contamination based on “product” (i.e., Pu-239) concentrations in the air (Parker, 1944). The early tolerance levels for alpha contaminants were 3E-11 $\mu Ci/cm^3$ as early as 1944 and maybe 1943. The 3E-11 value for alpha was for prevention of deposition of 1 microgram of plutonium in the body (Wirth, 1946). For general safety and convenience, other alpha emitters were considered at the same activity level (Wirth, 1946). In practice, controls were established to attempt to maintain exposures at ten percent or less of tolerance levels. Controls were established to require an approved respirator, combat mask, or air-line hood in any location where the concentration of airborne alpha emitters may be greater than 3E-11 uCi/cm^3.

One report dated June 28, 1945 (Wirth, 1945b) noted that approximately 40 employees of Clinton Laboratories have been working with varying quantities of plutonium. Also, a smaller group of perhaps 10 men who have been working in other fields of isolation of fission products may have had exposure to smaller quantities of plutonium. No other reports were identified that indicate the number of workers exposed to plutonium.

Documented urinalysis results for total plutonium during the period from 1945 through 1959 have been obtained by NIOSH. The number of plutonium bioassay results from the records identified by NIOSH for the period under evaluation (and extended out through 1959) are shown in Table 6-1 and Figure 6.1. Limited or no bioassay data are available for 1943-1944.

Urine samples for plutonium have been, and still are, the preferred bioassay monitoring method. As stated previously, NIOSH finds indication that some early Clinton Laboratories urine samples were sent to ANL in 1943 for processing (Davis, 1954). In the early years, the volume of sampling during this period was relatively low and assays were for uranium and plutonium. The processing of urine samples at ORNL at their Urinalysis Building started in 1947. At that time, analytical procedures were only available for uranium and plutonium and the number of samples collected was not extensive. During the early period when checks were made only for plutonium and uranium, the personnel in the urinalysis building used organizational charts for determining the personnel to be sampled and requests were also made through employees’ supervisors. At that time, this was considered a workable method because of the few people involved. In the mid-to-late 1940s, the sampling program made the Health Physicist in the field responsible for determining which employees should be sampled, scheduling the sampling, and handing out the request forms. Another report indicated that plutonium urine sample analysis carried out at the Met Lab (ANL) started with the first weekly series in February 1945, with the first 47 plutonium urine samples analyzed for Clinton Laboratory personnel in the period February 6, 1945 through March 14, 1945; plutonium analysis continued at the Met Lab for at least six months thereafter (Wirth, 1945a).

One plutonium bioassay in 1945, and four plutonium bioassays for 1946, were found in the electronic database. Greater than 100 plutonium bioassay samples were identified in the years thereafter, reports from data capture indicate plutonium bioassay monitoring as early as 1943. Further NIOSH data capture identified the first 164 plutonium urine samples taken from February 1945 through May 28, 1945 and include some control samples (Monitoring, Feb-Jun1945). These 1945 plutonium samples were not identified within the electronic database records or in the NOCTS-DOE records. Other reports (Monitoring, Feb-Mar1945; Whitaker, 1945) indicate potential sample cross-contamination issues with the initial 164 plutonium samples and some interference with the LaF_3 carrier. Indications were that at least some of the samples were collected in the 706-A locker room (in the Chemistry Building which housed many extraction processes). Steps were taken around April 30, 1945 to minimize contamination issues, including Monday collections, required bathing, and a new location for sampling (i.e., in the 703-A Administration Building) (Monitoring, Feb-Jun1945). It is postulated that these 1943 to 1945 plutonium urine samples are not in the database because they precede the routine sampling program at the site; they were collected as part of a study to determine "the amount of plutonium, if any, that may be fixed in the bodies of any chemists at Clinton Laboratories" (Wirth, 1945a). In a report dated January 31, 1947 (Progress Report, 1946-1956, pdf p. 7), a method for removing the lanthanum reagent in-growth was noted. (There was a naturally-occurring contaminant [possibly radium] in the reagent that could be interpreted as plutonium). The lab removed the alpha contaminant activity by a resin column extraction so that only 0.1 counts per minute per milligram remained and there was no appreciable alpha in-growth over a period of two weeks. Prior to this, precipitation methods largely removed the alpha contaminant in-growth in the reagent for only a few days.

NIOSH data capture attempts have not identified other plutonium sample results after May 28, 1945 through December 16, 1946, although indications are that several hundred plutonium urine bioassays were taken. More research and data capture is ongoing to obtain these results. One ORNL logbook was found for the period of January 1949 through July 1949 which contained over 150 plutonium urine bioassay sample results (Monitoring, Jan-Jul1949). The samples in the logbook were in sequential order starting with number 446, indicating earlier plutonium sample data exist. More data capture efforts are ongoing to locate the earlier logbooks. These January-July 1949 logbook plutonium samples were cross-verified with the electronic database records and the records located in the NOCTS-DOE records. The logbook plutonium samples were found in the database and NOCTS-DOE records; however, uranium results also in the logbook were not found in the electronic database or NOCTS-DOE records.

About 400 plutonium samples (four in December 1946, 188 in 1947, 191 in 1948, and about 25 in 1949) were indicated in the database from December 16, 1946 through mid-January 1949 (when the logbook entries began). Given that 164 samples were indicated in the Met Lab data (in 1945) and that about 400 samples were indicated in the database (1946 through mid-January 1949), there appears to be more plutonium samples taken than the first sequential number in the 1949 logbook would indicate.

Before 1989, ORNL did not routinely perform isotope-specific analyses for plutonium. Rather, the Laboratory separated plutonium as an element and analyzed it by proportional counting. Therefore, the historic plutonium analysis technique was unable to differentiate among the alpha-emitting isotopes Pu-238, Pu-239, and Pu-240. The default isotope for dose reconstruction using plutonium bioassays is Pu-239. One report on September 1, 1947 noted the use of calcium oxelate for the determination of plutonium (Progress Report, 1946-1956, pdf p. 21).

NIOSH's current assignment of internal dose for potential exposures occurring from 1943 through 1950 is based on a modified ORAUT-OTIB-0018 approach. ORAUT-OTIB-0018*, Internal Dose Overestimates for Facilities with Air Sampling Programs,* applies through 1950 and uses the ORNL plutonium tolerance level limit of 3E-11 μCi/mL (ORAUT-OTIB-0018). The ORNL co-worker study, ORAUT-OTIB-0034, is based on bioassay results and applies starting in 1951 (ORAUT-OTIB-0034). The modified ORAUT-OTIB-0018 approach was developed based on air concentration limits. ORAUT-OTIB-0018 is considered to generally provide an overestimate for a number of reasons. Exposure at the maximum permissible air concentration is assumed for 40 hours per week, 50 weeks per year. While exposure to concentrations greater than the maximum permissible air concentration is likely over short periods for some occupations, the overriding control factor was to limit the average exposure over longer timeframes. In addition, the nuclide that results in the largest dose is assumed to comprise 100% of the intake; the list of possible nuclides includes some that are very unlikely to be present in significant quantities. During the early years of ORNL, several of the nuclides on the list were just being discovered or were yet to be discovered. The NIOSH-assigned nuclide might change from year to year to ensure that the largest possible dose is assigned in each year until the date of diagnosis.

Although not included in the individual files, there are limited urine sample results from ORNL in 1945 (i.e., 164 plutonium urine samples taken from February 1945 through May 28, 1945) (Monitoring, Feb-Jun1945). An analysis of the data indicates that the geometric mean of this distribution is somewhat large (1.7 pCi/1400 mL) and the fit to the results indicates that there are possibly two distributions. If this value is assumed to be due to a constant, chronic intake of Type M Pu-239 beginning in early 1944, an airborne concentration of 8.1 × 10-11 μCi/mL is indicated. This is almost three times larger than the tolerance level of 3 × 10-11 μCi /mL in effect at the time. If Type S is assumed, the airborne concentration is expected to be two orders of magnitude larger than the tolerance level. In a memorandum dated May 11, 1945, it was reported that the findings appeared to be above control levels, which resulted in a more rigid collection technique and system of collecting samples being implemented on April 25 (Monitoring, Feb-Apr1945). Results in the first two weeks of this more-rigid collection system were not substantially different from previous results, but samples in the subsequent, final four weeks of the study showed little detectable activity and include some control samples (Monitoring, Feb-Jun1945). The geometric mean before April 25, 1945 is 3.1 pCi/day, while after this date it drops to 0.54 pCi/day. The arithmetic average of the results from April 25 through the end of the study is about 25% of the average during the previous weeks, and the average from the final four weeks is about 3% of the earlier weeks. These comparisons indicate that the ORNL concerns about the collection system before April 25 may have been justified.

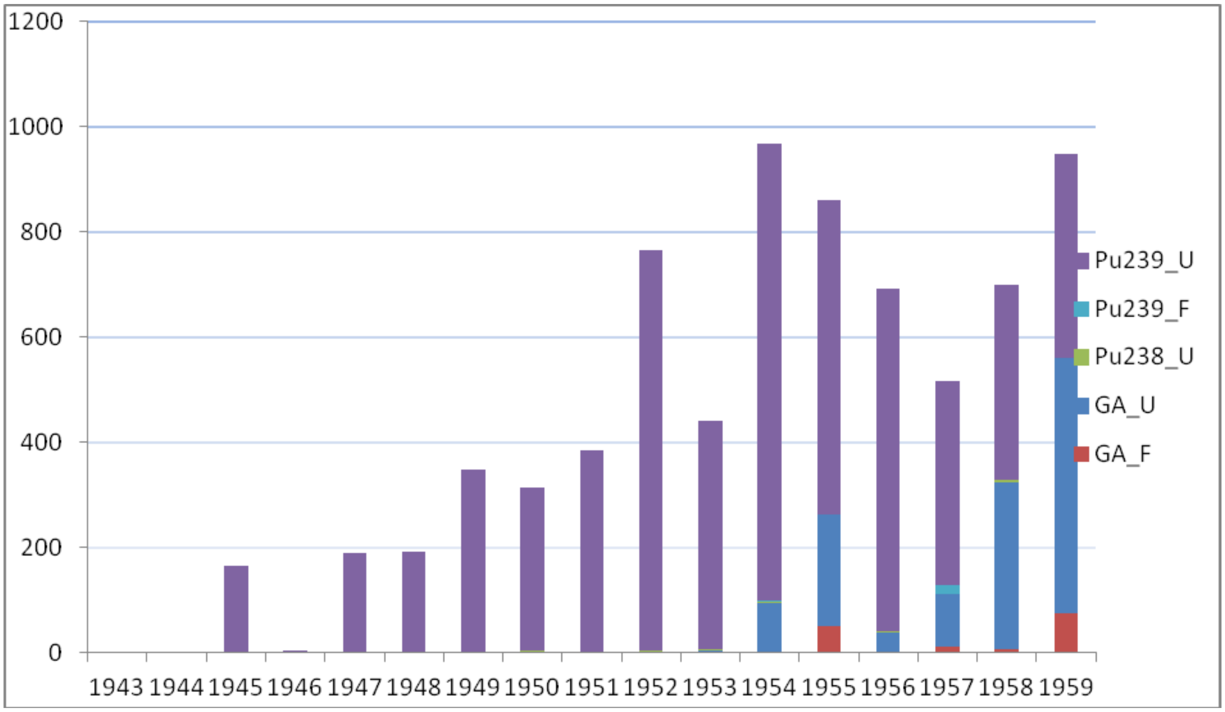
In addition to the urine samples, 1483 alpha air-monitoring results were available for 1944 through 1947 at ORNL (Monitoring, Jun1944-Dec1947). The two largest values, both many orders of magnitude larger than the tolerance level in use at the time, were excluded from the analysis because one appeared to be a miscalculation (based on the recorded alpha activity) and the other was collected inside a hot cell. Results were fit to a lognormal distribution. The geometric mean is 5% of the tolerance level applied in ORAUT-OTIB-0018, and the 95th percentile is equal to the tolerance level. Notes indicating that assault masks had been worn were present for just under 10% of the samples; many of the samples were collected inside of hoods. Given this information, ORAUT-OTIB-0018 appears to be a reasonable upper bound because the 95th percentile of the air-monitoring results coincides with the value applied in that document. Assault masks were used in many situations and many of the results exceed the activity to which the individual would have been exposed because samples were collected inside of hoods. Conservativeness is built into ORAUT-OTIB-0018 by the inclusion of alpha emitters with large dose coefficients that were likely not present or present only in very small quantities.

The number of identified plutonium bioassay results is presented in Table 6.1 and Figure 6-1.

Table 6-1: Available Bioassay Measurements for Plutonium Performed at ORNL, 1943-1959

Year	Pu-239 Urine	Pu-239 Fecal	Pu-238 Urine	Gross Alpha Urine	GA Fecal	Total Pu and Gross Alpha
1943	0	0	0	0	0	0
1944	0	0	0	0	0	0
1945	165[a]	0	0	0	0	165
1946	4	0	0	0	0	4
1947	188	0	0	0	0	188
1948	191	0	0	0	0	191
1949	348	0	0	0	0	348
1950	311	0	3	0	0	314
1951	385	0	0	0	0	385
1952	760	0	4	0	0	764
1953	436	0	1	4	0	441
1954	868	2	4	93	0	967
1955	596	0	2	211	50	859
1956	651	1	2	38	0	692
1957	389	15	0	102	10	516
1958	370	0	5	318	6	699
1959	386	0	2	484	75	947

Source: Monitoring, 1945-1990; Monitoring, Jan-Jul1949
[a] Includes 164 plutonium samples identified from data capture in 1945 not in database.



Source: Monitoring, 1945-1990; Monitoring, Jan-Jul1949
Includes 164 plutonium samples identified from data capture in 1945 but not in database.

Figure 6-1: Bioassay Measurements for Plutonium Performed at ORNL, 1943-1959

6.1.2 Personnel Monitoring for Uranium (U-238, U-233, U-234, U-235),

As discussed above, ORNL maintained early tolerance levels for airborne contamination based on "product" (i.e., Pu-239) concentrations in the air (Parker, 1944). The early tolerance levels for alpha were 3E-11 $\mu Ci/cm^3$ as early as 1944 and maybe 1943 (Monitoring, Jun1944-Dec1947). For general safety and convenience, other alpha emitters were considered at the same activity level (Wirth, 1946). In practice, controls were established to attempt to maintain exposures at ten percent or less of tolerance levels. Controls were established to require an approved respirator, combat mask, or air-line hood in any location where the concentration of airborne alpha emitters may be greater than 3E-11 uCi/cm^3 (Wirth, 1946).

Documented urinalysis results for total uranium during the period from 1949 through 1959 have been obtained by NIOSH. The number of uranium bioassay results recorded during the period under evaluation (and extended out through 1959) is shown in Table 6-2 and Figure 6-2. Limited or no bioassay data are available for 1943-1948. Urine samples for uranium have been, and still are, the preferred method.

One report indicated that as of September 1, 1947, work continued on the development of a practical procedure for the routine determination of uranium in urine (Progress Report, 1946-1956, pdf p. 22). Another report dated February 28, 1949 (Progress Report, 1946-1956, pdf p. 79) noted a method for analyzing for uranium, developed to meet the need for a method sufficiently sensitive for monitoring significant body content of U-233, had been put into routine operation and during the last six months, 158 uranium analyses had been made on urine specimens. The volume of sampling during this period was relatively low and assays were for uranium and plutonium. As previously discussed, the processing of urine samples at ORNL at their Urinalysis Building started in 1947. At that time, analytical procedures were only available for uranium and plutonium and the number of samples collected was not extensive. During the early period when checks were made only for plutonium and uranium, the personnel in the urinalysis building used organizational charts for determining the personnel to be sampled and requests were also made through employees' supervisors. At that time, this was considered a workable method because of the few people involved. In the mid-to-late 1940s, the sampling program in use made the Health Physicist in the field responsible for determining which employees should be sampled, scheduling the sampling, and handing out the request forms.

As previously noted, although 79 bioassays were found in the database for 1949 (starting August 5, 1949) and more than 100 uranium bioassay samples were identified for years thereafter, reports obtained during data captures indicate uranium bioassay monitoring occurring as early as 1947 (Davis, 1954b). Other weekly reports indicate uranium urine bioassay monitoring results beginning in August 1948 (Weekly Report, Aug 28, 1948; Weekly Report, Sep 12, 1948; Weekly Report, Oct 17, 1948; Weekly Report, Nov 14, 1948; Weekly Report, Nov 28, 1948; Weekly Report, Dec 12, 1948; Weekly Report, Jan 16, 1949; Weekly Report, Feb 6, 1949; Weekly Report, Mar 27, 1949). One report (Progress Report, 1946-1956, pdf p. 79) ending in February 1949 indicated that in the last six months 158 uranium analyses had been made on urine specimens. These 1948-1949 samples were not found in the database or in the NOCTS-DOE records.

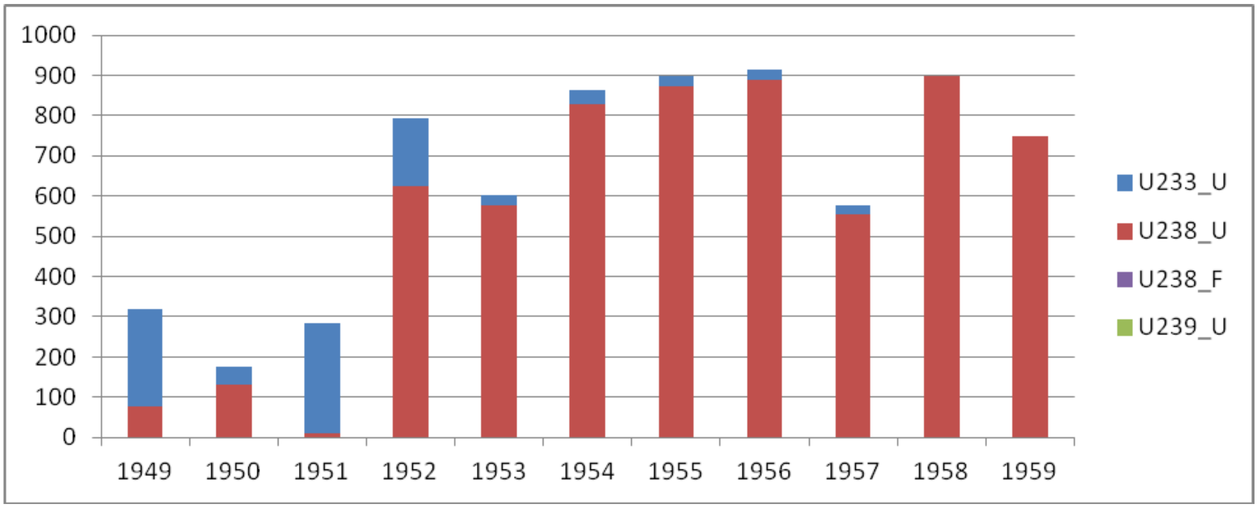
More research and data capture is ongoing to obtain these sample analysis results. One ORNL logbook was found for the period January through July 1949; it contains 151 uranium (U-233) urine bioassay sample results (i.e., prior to the data found in the electronic database) (Monitoring, Jan-Jul1949). Another logbook for the period May through August 1949 contains 88 uranium (U-233) urine bioassay sample results. The samples in the January-July logbook are in sequential order starting with number 446 and ending with sample 604, indicating earlier sample data may also exist. The May-August samples are in sequential order starting with number 605. More data capture efforts are ongoing in an attempt to locate the earlier logbooks. These logbook uranium samples were cross-verified with the electronic database records and the records located in the NOCTS-DOE records. The plutonium samples were found in the database and NOCTS-DOE records; however, uranium results in the logbook were not found in the electronic database or NOCTS-DOE records. Also, the logbook uranium results were for U-233 and most uranium samples found in the database were identified as U-238 (with one U-233 sample).

Before 1989, ORNL did not routinely perform isotope-specific analyses for uranium. Rather, the laboratory separated uranium as an element and analyzed it by proportional counting. Therefore, the historic uranium analysis technique was unable to differentiate among the alpha-emitting isotopes U-233, U-234, U-235, and U-238. The default isotope for dose reconstruction using uranium bioassays is U-234.

Table 6-2: Available Bioassay Measurements for Uranium Performed at ORNL, 1949-1959

Year	U-233 urine	U238 urine	U238 fecal	U239 urine	Total U
1949	240[a]	77	0	1	318
1950	44	131	0	0	175
1951	274	11	0	0	285
1952	170	625	0	0	795
1953	25	576	0	0	601
1954	33	830	0	0	863
1955	27	872	0	1	900
1956	27	887	1	1	916
1957	22	554	1	1	578
1958	0	896	1	1	898
1959	0	747	0	1	748

[a] Includes 239 uranium samples identified from data capture in 1949 not in database.
Source: Monitoring, 1945-1990; Monitoring, Jan-Jul1949; Monitoring May-Aug 1949



Source: Monitoring, 1945-1990; Monitoring, Jan-Jul1949; Monitoring May-Aug 1949
[a] Includes 239 uranium samples identified from data capture in 1949 not in database.

Figure 6-2: Bioassay Measurements for Uranium Performed at ORNL, 1949-1959

6.1.3 Personnel Monitoring for Fission and Activation Products

As discussed above, tolerance levels for alpha and beta-gamma contaminants were 3E-11 and 1E-07 $\mu Ci/cm^3$, respectively, as early as 1944 and maybe 1943 (Monitoring, Jun1944-Dec1947). For general safety and convenience, other alpha-emitters were considered at the same activity level (Wirth, 1946). In addition, the laboratory later established tolerance levels for materials such as I-131 and noble gases. In practice, controls were established to attempt to maintain exposures at ten percent or less of tolerance levels. Controls were established to require an approved respirator, combat mask, or air-line hood in any location where the concentration of airborne alpha emitters may be greater than 3E-11 uCi/cm^3 and similar precautions were taken for airborne beta/gamma emitters based on 1E-7 uC/cm^3 (Wirth, 1946).

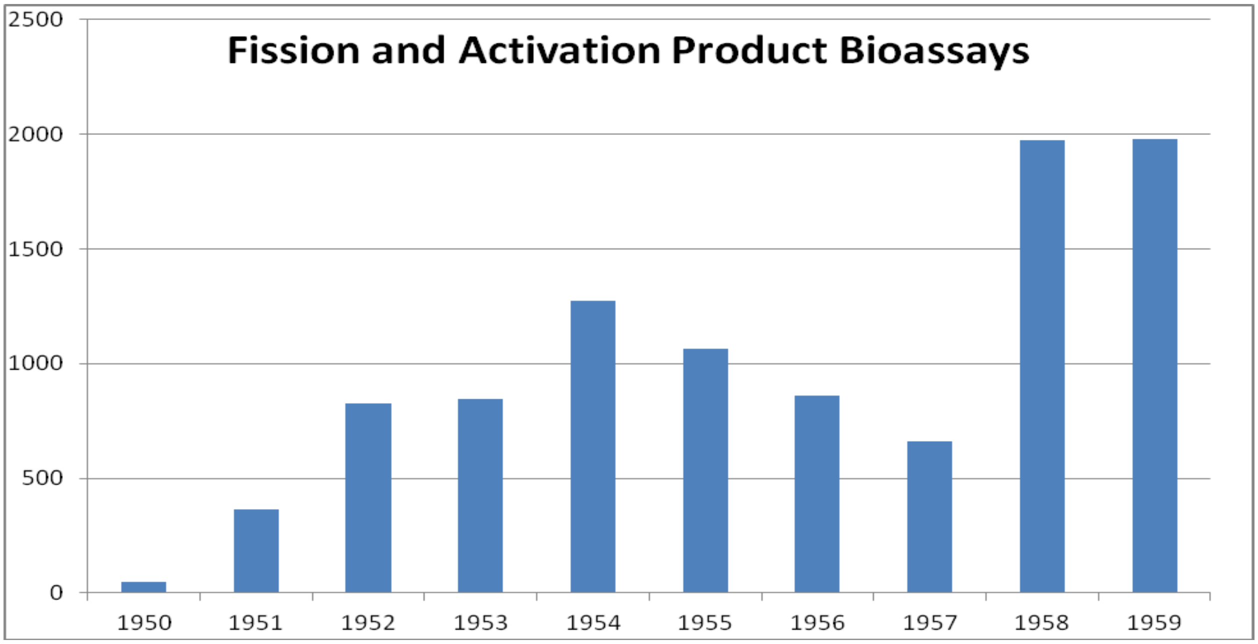
Documented urinalysis results for fission products during the period from 1943 through 1959 have been obtained by NIOSH. The number of fission product bioassay results recorded during the period under evaluation (and extended out through 1959) is shown in Table 6-3 and Figure 6-3. Limited or no bioassay data are available prior to 1950.

Forty-eight (48) fission product bioassays were found in the database for 1950 and more than 300 fission product bioassay samples (primarily cesium and strontium) were identified in successive years. Urine samples and *in vivo* counting for fission and activation products have been, and still are, generally the preferred method. One report indicated gross beta urine bioassay monitoring results as early as October 1948. (Weekly Report, Oct 17, 1948). One report dated January 15, 1950 indicates that an exploratory survey (urinalysis) for alkaline earth and rare earth beta-gamma emitting elements was made on 38 individuals (Progress Report, 1946-1956, pdf p. 127). Another report noted this exploratory survey, but noted that the rare earth analysis was to supplement the fission-product-in-urine procedure already in place (Progress Report, Oct1950). Another report dated April 15, 1950 indicates that an analysis procedure for strontium was in use (Progress Report, 1946-1956, pdf p. 149). A survey of urinalyses for fission products conducted at ORNL during the last two years determined that where measurable amounts were found, it was due, in most cases, to radioisotopes of strontium (Progress Report, 1946-1956, pdf p. 257).

Table 6-3: Bioassay Measurements for Fission and Activation Products Performed at ORNL, 1950-1959

Year	Bioassays
1950	48
1951	364
1952	828
1953	844
1954	1271
1955	1063
1956	861
1957	659
1958	1975
1959	1980

Source: Monitoring, 1945-1990



Source: Monitoring, 1945-1990
NOTE: Does not include plutonium, uranium, and thorium bioassays.

Figure 6-3: Bioassay Measurements for Fission and Activation Products Performed at ORNL, 1950-1959

6.1.4 Personnel Monitoring for Thorium

As previously noted, there are fairly extensive air-monitoring records in the 1944 through 1947 timeframe that are suitable for assigning estimates of exposure and/or dose.

Approximately 1500 air sample results were identified in an electronic database (Monitoring, Jun1944-Dec1947). Based on interviews with former ORNL employees and the sample location descriptions, these air samples are believed to be representative of the breathing zone. Air samples were normally taken at head height with the intent of sampling a worker's breathing zone to compare to tolerance levels. About one-half of these air samples had sample location descriptions which were noted as six inches from the hood or hood samples. Other samples were noted as during assault mask use (possible breathing zone), were in unspecified locations in rooms or during activities, or were indeterminate. There were 1141 alpha air samples noted in Building locations 706-A and 706-C from 1944-1947 where much of the thorium-related processes occurred. More data capture efforts are ongoing to locate additional air sample information. It is postulated that this large number of air samples from the primary thorium-processing facilities would bound thorium exposure for the period 1944-1946. This period coincides with the period in which primarily only lab-scale thorium processes occurred.

Documented urinalysis results for thorium during the period from 1943 through 1959 have been obtained by NIOSH. One Th-232 urine sample was identified in 1950 and 1954, and others were identified from 1956 through 1959. Gross alpha fecal samples were identified starting in 1955. Th-232 fecal sampling started in 1955 (two samples) and more than 100 were identified in successive years. The number of thorium bioassay samples recorded during the period under evaluation (and extended out through 1959) is shown in Table 6-4 and Figure 6-4. As indicated, limited or no thorium bioassay monitoring results were identified from 1943 through 1953.

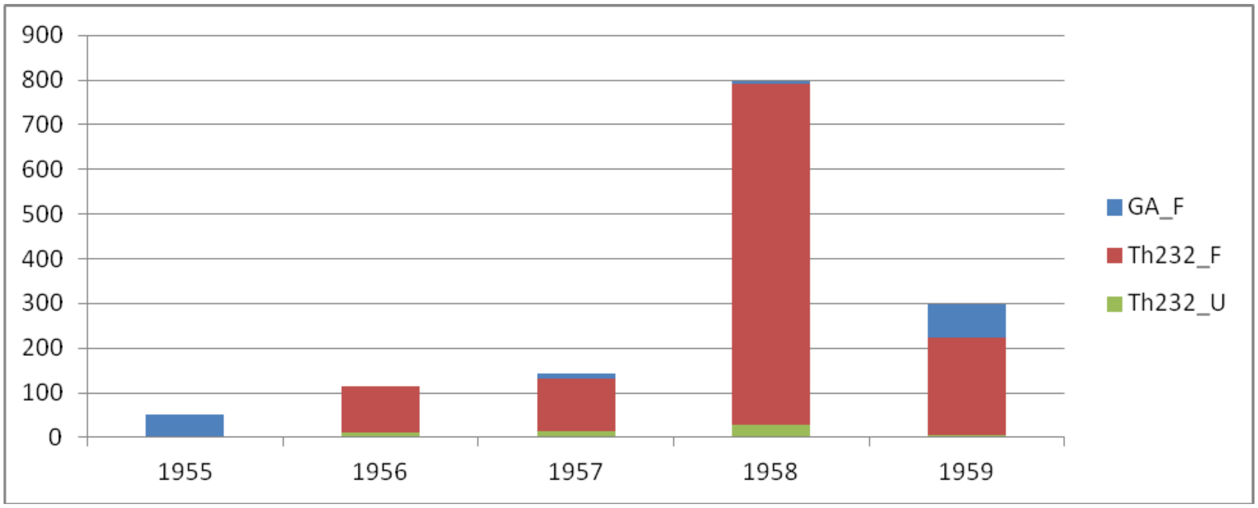
Contemporary ICRP biokinetics models for thorium show that urine bioassay lacks the sensitivity to demonstrate compliance with regulatory limits, and therefore, urine bioassay is not used as part of a routine thorium bioassay program. However, it was determined that thorium bioassay monitoring began in 1955 via the gross alpha fecal samples in 1955 and Th-232 fecal samples from 1956 and thereafter. A NIOSH review of a 1959 procedure for preparing urine samples for gross alpha measurements indicates that thorium would be present in the samples (i.e., not separated out in the sample preparation). Fecal sample preparation would be similar to that of the urine for gross alpha. Given the timeline of thorium processes at ORNL, it is postulated that these 1955 gross alpha fecal samples were for thorium monitoring.

The ORNL database contains values for isotopic activities during times when isotope-specific analyses were not possible or routinely performed. In earlier years, the element of concern was extracted chemically from the biological sample and the total radioactivity of the element in the extract was measured. At some point after the extraction and sample count, the total sample activity was attributed to a specific radionuclide. Many of the isotopic assignments were based on process knowledge. During the period 1955 to 1956, there was a transition from gross alpha fecal to Th-232 fecal.

Table 6-4: Bioassay Measurements for Thorium Performed at ORNL, 1955-1959

Year	Gross Alpha fecal	Th-232 fecal	Th-232 urine	Total
1955	50	2	0	52
1956	0	103	11	114
1957	10	118	14	132
1958	6	764	28	798
1959	75	217	7	299

Source: Monitoring, 1945-1990



Source: Monitoring, 1945-1990

Figure 6-4: Bioassay Measurements for Thorium Performed at ORNL, 1955-1959

In vivo counting was implemented in 1959-1960 and would have been sensitive to thorium daughter products, but was not available during the period under evaluation. Later on, whole-body counting and chest counting were routinely used as part of the ORNL internal dosimetry program.

Representative air sampling data have been requested for locations where un-encapsulated thorium was processed prior to 1960. ICRP 75, *General Principles for the Radiation Protection of Workers*, discusses the uses of area air sampling to establish trends and representative air sampling to quantify the extent of airborne contamination to which workers are likely to be exposed. The air sampling requirement specified in the August 1954 Test Authorization Number 3-138 suggests that the air sampling data will satisfy the "representative sampling" definition in ICRP 75, which states that representative sampling typically involves using fixed samplers at locations intended to be reasonably representative of the breathing zone of the workers. If air sample data are available as expected, then intake rates can be calculated based on an assumption of a default breathing rate and an appropriate occupancy factor in these areas using the air sample data.

6.1.5 Personnel Monitoring for Exotic Radionuclides

ORNL built and operated cyclotrons and accelerators on the Y-12 site. These operations generated radionuclides (e.g., C-14, Ca-45, P-32, Ba-140/La-140, and others). NIOSH has access to data for these operations. However, this topic is reserved for this evaluation report because cyclotron and accelerator operations at both ORNL (X-10) and Y-12 will be addressed in a future combined evaluation effort.

6.2 Available ORNL External Monitoring Data

Copies of original documents containing film badge and pocket dosimeter results with dates between 1944 and 1949 have been found. They can be found in the following references:

1944:
Monitoring, Jan-Dec1944
Monitoring, Jan1944-Feb1950
Monitoring, Aug1944-Oct1945

1945:
Monitoring, May-Aug1945

1947:
Monitoring, Jan1947
Monitoring, Feb1947
Monitoring, Mar1947
Monitoring, Mar-Jun1947
Monitoring, Apr1947
Monitoring, May1947
Monitoring, Jun1947a
Monitoring, Jun1947b
Monitoring, Jul1947a
Monitoring, Jul1947b
Monitoring, Jul-Dec1947
Monitoring, Aug1947a
Monitoring, Aug1947b
Monitoring, Aug1947c
Monitoring, Sep1947a
Monitoring, Sep1947b
Monitoring, Oct1947a
Monitoring, Oct1947b
Monitoring, Nov1947a
Monitoring, Nov1947b
Monitoring, Dec1947a
Monitoring, Dec1947b
Monitoring, 1947-1948

1948:
Monitoring, Jan1948
Monitoring, Feb1948
Monitoring, Mar1948
Monitoring, Apr1948
Monitoring, May1948
Monitoring, Jun1948
Monitoring, Jul1948
Monitoring, Aug1948
Monitoring, Sep1948
Monitoring, Oct1948a
Monitoring, Nov1948
Monitoring, Dec1948

1949:
Monitoring, Jan1949
Monitoring, Jan-Apr1949
Monitoring, Jan-Dec1949
Monitoring, Feb1949
Monitoring, Mar1949
Monitoring, Apr1949
Monitoring, Apr-Jun1949
Monitoring, May1949
Monitoring, May-Dec1949
Monitoring, Jun1949
Monitoring, Jul1949
Monitoring, Jul-Aug1949
Monitoring, Aug1949
Monitoring, Sep1949
Monitoring, Oct1949
Monitoring, Nov1949
Monitoring, Dec1949

1951:
Monitoring, Feb-Apr1951

1989:
Ahmed, 1989

One document containing similar data for 1954 has been found (Monitoring, Jan-Dec1954). The above data include both photon and beta results and are associated with names or payroll numbers.

Copies of original Weekly Neutron Film Reports for 1947, 1948, and 1949 have been found. These reports contain employee names and badge numbers along with the number of tracks observed for "Open Window," "Shield," and "Star Tracks" - with the greatest majority of the results listed as having zero tracks. These reports can be found in the following references:

Progress Report, Aug-Dec1947
Progress Report, Dec1947-Feb1948
Progress Report, Feb-Apr1948
Progress Report, Apr-Jul1948
Progress Report, Jul-Sep1948
Progress Report, Sep-Oct1948
Progress Report, Oct-Dec1948
Progress Report, Dec1948-Apr1949
Progress Report, May-Jun1949
Progress Report, Apr-Jul1949
Progress Report, Jul-Sep1949
Progress Report, Sep1949-Jan1950

In addition, reports on specific incidents within the period of interest have been located that include names of the employees present and film badge results. These reports can be found in the following references:

Incident, Jul1951
Incident, Oct1951
Incident, Nov1951
Monitoring, Jul1951
Incident, Jan1952
Incident, Mar1952
Incident, Apr1952
Incident, Aug1952
Incident, Sep1952
Incident, Apr-May1954
Incident, Dec1960
Incident, Apr1976

In response to a NIOSH request, a spreadsheet report from ORNL's exposure database was provided by the site (Monitoring, 1943-1959b). The dates in the spreadsheet range from 1943 through 1959. It contains 45,447 rows for dates between 1943 and 1955. Each row has the name of the employee, either a five-digit or six-digit badge number, sample date, year, "Gamma_Exposure," and "Beta_Exposure." ORNL indicated that the field labeled "Gamma_Exposure" includes all assigned neutron exposure results (Personal Communication, 2012e). Although an exact count of the individuals included may not be possible due to potential misspellings and name changes, the spreadsheet contains 8074 unique names. In the great majority of the results, a department code is also listed. Table 6-5 is a list of years, the count of distinct results (each with both a gamma and beta result), and the number of distinct names in the spreadsheet for those years. Note that the total of names by year is greater than the number of distinct names in the spreadsheet due to people working at the site for multiple years.

Table 6-5: Number of Records by Year in ORNL Report from Exposure Database

Year	Record Count	No. of Names
1943	1345	857
1944	4117	2106
1945	2946	1747
1946	2674	1799
1947	3215	2266
1948	3793	2584
1949	2516	2039
1950	3442	2599
1951	4174	3086
1952	4355	3271
1953	3953	3158
1954	4536	3336
1955	4536	3471
---	Total = 46,928	---

Source: Monitoring, 1943-1959b

A comparison of the data in this spreadsheet with the data obtained in 2004 that formed the basis for ORAUT-OTIB-0021, *External Coworker Dosimetry Data for the X-10 Site*, shows that they are essentially the same.

Type of dosimeter, frequency, and minimum reported dose are documented for all years. From 1943 through June 1944, pocket ionization chambers were used on a daily basis. After June 1944, film badges were used. After 1951, dosimeters were used by all employees at the site. The pocket ionization chamber was read daily; the film badge was read weekly though 1951 and weekly for radiation workers through 1954. For non-radiation workers between 1951 and 1954, the film badge was read annually (Ahmed, 1989). Calibration data for 1953, 1954, and 1955 are documented (Gordon, 1986).

The types of film badges used at ORNL are well documented (Davis 1954a; Parrish, 1982; Thornton, 1961). During the period under evaluation, advances were made in both the type of filters used in film badges and the film types they contained to compensate for energy dependence, to extend the dose range, to minimize any interference, and to measure multiple radiation types in a single device. Of particular interest was the development of the "ORNL Badge" in 1954, which combined the film badge with the identification badge (Davis 1954a, pdf p. 174). Table 6-6 lists the types of film badges used at ORNL between 1946 and 1955.

Table 6-6: Types of Film Badges Used at ORNL from 1946 through 1955

Year Introduced	Material Used in Construction	Filters	Films Used
1944	Tin	Cd, W	DuPont 552
1949	Stainless Steel	Cd, W	DuPont 552 and fine grained particle
1951	Stainless Steel	Pb, Cd, Cu, Pl, W	DuPont 552, NTA
1953	Plastic	Pb, Cd, Cu, Pl, W	DuPont 552, NTA
1954	Plastic	Pb, Cd, Cu, Pl, W	DuPont 553, NTA

Source: Adapted from Thornton, 1961, pdf p. 7

Between 1944 and 1949, neutron dosimetry was conducted through the use of Eastman "Special Fine-Grain Particle Safety Film," which recorded tracks from recoil protons resulting from incident neutrons. Thermal neutron exposure could be distinguished from fast through the use of a cadmium shield for a portion of the film (Bradley, 1945; Cheka, unspecified).

Neutron tolerance levels for the period (1650 /cm^2-second for thermal and 266/cm^2-second for fast) was measurable by these fine-grain films (Cheka, unspecified, Wirth, 1945c). The calibration data and conversion factors for the observed-tracks-per-field is documented (Cheka, unspecified).

After 1950 and through 1954, NTA film was used for neutron dosimetry.

A letter from 1951 states that a "film loaded finger ring" was in use and had been "for some years" (Hart, 1951). The minimum threshold of sensitivity was "0.3 r...when exposed to Radium gamma." A March 12, 1948 summary of radiation protection requirements states that ring badges are required for certain types of work (Monitoring, Jul-Dec1947, pdf p. 5).

Several documents provide the history of the research and development of the ORNL badges (Ahmed, 1989; Davis 1954a, pdf p. 171; Parrish, 1982; Thornton, 1961). The report ORNL-3126, *The ORNL Badge Dosimeter and Its Personnel Monitoring Applications*, was published in 1961 and is the basis for much of the information in the current technical basis documents used by NIOSH to support dose reconstructions.

These reports on the history of ORNL dosimetry also include information on the creation and use of NTA-type film badges, starting as early as 1949. In addition, many documents containing neutron exposure data have been located.

Some limited photon survey data have been found but they are incomplete for any location or time and only serve to show that such surveys were used to document levels in restricted areas. With the exception of the Graphite Reactor, no neutron survey data have been located for areas related to occupational exposure for the reactors or for the Critical Experiments.

In 1946, gamma and thermal neutron surveys were made around the Graphite Reactor. Survey locations included the north and south faces of the reactor, locations near beam ports, and the "Operator Table" or "Operator Desk." A total of 156 paired measurements have been located (Progress Report, Jan-Jul1946).

The document, *ORNL Historical X-ray Practices and Protocols* (ORNL, post-2002), lists the specific X-ray equipment, procedures, and technique factors used at the site. It also states that prior to October 3, 1947, all pre-employment X-rays, and presumably any routine annual X-rays, were performed at Oak Ridge Hospital. Oak Ridge Hospital is located on what was then the Clinton Engineering Works site and is EEOICPA-covered from 1943 to 1959. After October 3, 1947, X-rays were performed on the ORNL site.

Details regarding the various analyses used and the associated minimum detectable activities are presented in the *Technical Basis Document for the ORNL Site - Occupational External Dose* (ORAU-TKBS-0012-6).

7.0 Feasibility of Dose Reconstruction for the Class Evaluated by NIOSH

The feasibility determination for the class of employees under evaluation in this 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. 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 7.5. This approach is discussed in DCAS'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-00189 as submitted by the petitioner. (Section 7.4)

7.1 Pedigree of ORNL 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.

7.1.1 Internal Monitoring Data Pedigree Review

NIOSH obtained both air sampling and bioassay results for the period under evaluation. Air sample results were received for 1944-47. Bioassay sample results were obtained starting in 1944. The bioassay results are urinalyses starting in 1945 and fecal sample results starting in 1955.

As discussed in Section 5.0, a database containing approximately 1500 air monitoring records from 1944 through 1947 was reviewed and determined to be suitable for assigning internal dose estimates (Monitoring, Jun1944-Dec1947). The air monitoring records were gross alpha activity measurements, approximately 1100 of which were taken in Building 706-A where plutonium and thorium processing took place. The noted sample locations and descriptions indicate to NIOSH that these air samples adequately represent the breathing zone air concentrations. Based on interviews with former ORNL employees, air samples were normally taken at head height and were intended to be representative of what a worker might breathe because the results were compared to their established tolerance levels to determine if respiratory controls were needed. The sample results were commonly given in activity units (uCi/cm^3) and as a percent of the tolerance level (Monitoring, Jun1944-Dec1947). The alpha tolerance level was 3E-11 uCi/cm^3. The alpha tolerance level was put in place to prevent the inhalation and subsequent deposition of 1 microgram of plutonium in the body (Wirth, 1946). For general safety and convenience, other alpha emitters were considered at the same activity level (Wirth, 1946). The air sampling protocol for monitoring alpha activity in air was reviewed by NIOSH and found to be sufficient for personnel monitoring and establishing controls. The volume of breathing zone air samples and the comparison to tolerance levels that was in place to control excessive inhalation of airborne radioactivity is indicative of an established air monitoring program.

Upon further review of the air monitoring records database, a corresponding reference document number was found for each data entry. The reference document numbers corresponded to documents contained within the ORNL Central Files. During data capture visits to ORNL, NIOSH specifically requested and reviewed documents and memos from the Central Files that were referenced in the air monitoring records database (Air Contamination, Nov1944; Air Contamination, Jan1945). All of the air sample data obtained from these documents and memos were found to be included in the database of air monitoring records, confirming that the database was accurately created using primary source documents.

The air sampling database was determined to be sufficient to use as internal monitoring data. The database was created using primary source documents, contains a large volume of breathing zone air samples, and the samples were taken using an adequate air sampling protocol.

A large amount of raw bioassay data exists at the ORNL complex. These data were transcribed into an electronic database hosted on ORNL equipment and maintained by ORNL personnel. This database (Monitoring, 1945-1990) was queried in 2003 for historical urinalysis records and generated 66,204 records for the period 1945-1988 (ORAUT-TKBS-0012-5). These records were compiled into a single database and a data validation and comment field was added to each record. The records were then examined by NIOSH and classified according to usability and later used to develop the minimum detectable activities (MDAs) for various radionuclides detected in urine or fecal samples. These data were also cross-verified with a 1949 Logbook containing approximately 150 plutonium urine sample results obtained through data capture and found to be accurate (Monitoring, Jan-Jul1949). A similar check with the electronic database was conducted against the dosimetry records of 16 former ORNL employees who worked during the 1940s. Bioassay results in their records were verified to be included in the electronic database. No records of urinalysis for uranium or fission products were found before 1949 and 1950, respectively. Duplicate records and unusable records (e.g., gross errors) were not included in this assessment.

7.1.2 External Monitoring Data Pedigree Review

Primary documentation and summary reports are available for both photon and beta exposure for individual workers (see Section 6.2 for references). In addition, NIOSH has almost 46,000 photon results and the same number of beta results for more than 9,000 individuals. Documents with neutron results for both fine-grain film and for NTA film are available for certain years with results listed by employee name, badge number, or both.

Examples of calibration methods for beta on film (Hart, 1947a; Weeks, 1945) photon on film (Gupton, 1981; Monitoring, 1953-1970; Progress Report, Jul1955-Jan1956), neutron on film (Bradley, 1945) and pocket dosimeters (Hart, 1947b) are available.

For the great majority of claimants, their results can be expected to exist in one or more of the documents acquired by NIOSH from ORNL, or they may be obtained from ORNL.

NIOSH has obtained sufficient data on workers for all years of the class under evaluation to estimate likely worker exposures using co-worker data. A co-worker study has been performed against the data and is presented in ORAUT-OTIB-0021, *External Coworker Dosimetry Data for the X-10 Site*.

For those workers who do not have exposure results and those results cannot be obtained from DOE, the results of the co-worker analysis in ORAUT-OTIB-0021 may be applied.

7.2 Evaluation of Bounding Internal Radiation Doses at ORNL (X-10)

The principal sources of internal radiation doses for members of the class under evaluation include plutonium, uranium, thorium, and mixed fission products. The following subsections address the ability to bound internal doses, methods for bounding doses, and the feasibility of internal dose reconstruction.

7.2.1 Evaluation of Bounding Process-Related Internal Doses

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

7.2.1.1 Urinalysis Information and Available Data

As previously discussed in Section 7.1, there is an extensive urine bioassay database that NIOSH believes is sufficient for bounding internal radiation exposure estimates due to plutonium, uranium and mixed fission products. The earliest urine bioassay data contained in the database are for plutonium starting in 1947, uranium in 1949, and fission products in 1950 (Monitoring, 1945-1990). In addition to the bioassay database, approximately 150 plutonium urinalysis results from 1945 were located in documents in the ORNL Central Files (Monitoring, Feb-Jun1945). Although NIOSH believes sufficient data are currently available for bounding internal radiation exposures during specified time periods, NIOSH is continuing to pursue additional data. NIOSH will continue to evaluate as additional urine bioassay data become available and are compiled.

The first urine bioassays for ORNL employees were for plutonium. An internal document describing the bioassay program at ORNL in the 1940s stated that urine bioassay analyses were performed on site at the ORNL facility starting in 1947 (Davis, 1954b). Prior to that, urine samples were collected and sent to the Met Lab in Chicago for analysis (Davis, 1954b). Procedures were developed in 1944 and 1945 for the detection of plutonium in urine. Two such documents include: *Methods of Analysis of Stools and Urine for Product* (1944), and *Procedures for the Detection of Plutonium in Human Urine* (1945) (Russell, 1945; Stone, 1944). NIOSH evaluated radiochemistry and sample preparation in the latter procedure and determined that it was sufficient for detecting plutonium. The earliest urine bioassay sample results obtained by NIOSH were reported in 1945 for plutonium (Monitoring, Feb-Jun1945). Approximately 150 plutonium sample results were reported in 1945. These results were not included in the bioassay database, but were instead located in documents in the ORNL Central Files (Monitoring, Feb-Jun1945). All other plutonium sample results were obtained from the bioassay sample database. The bioassay database lists only four plutonium urine bioassay results in 1946, but no fewer than 188 for each of the following years, with a maximum of 868 in 1954.

Starting in 1948, the monthly Radiation Survey and Monitoring Section reports included results from the Body Fluid Analysis Group (Hart, Apr1949; Hart, May1949). The results included the number of samples taken and the target radionuclides. The Body Fluid Analysis Group appeared to be a newly-formed group and indicated an expanding area of personnel monitoring. The bioassay database continued to show increasing numbers and an expanding list of target radionuclides. The first uranium bioassay results for uranium reviewed by NIOSH are from 1949 (Monitoring, 1945-1990). There were 77 results that year and several hundred in the following years. Urine bioassay results for mixed fission products appear in the bioassay database starting in 1950 with results for cesium and strontium (Monitoring, 1945-1990).

7.2.1.2 Fecal Bioassay Data

Fecal bioassay results first appeared in the bioassay database in 1955 with results for thorium. The sampling frequency appeared to be regular, with over 1300 fecal sample results for thorium reported from 1955-59 (Monitoring, 1945-1990). Fecal analysis procedures were developed in the mid-1940s, but a program with regular results did not appear to emerge until the mid-1950s. The radiochemistry and sample preparation procedures that were previously developed for fecal analysis (Stone, 1944) were reviewed by NIOSH and determined to be sufficient for analyzing for thorium. These data were also previously reviewed by NIOSH in the development of fecal bioassay minimum detectable activity (MDA) values for the ORNL Occupational Internal Dose TBD (ORAUT-TKBS-0012-5).

Based on the quantity of fecal bioassays and the sampling and analysis procedures, NIOSH believes the fecal bioassay data are sufficient for establishing a bounding dose estimate for thorium. Although NIOSH believes sufficient data are currently available for bounding internal radiation exposures during specified time periods, NIOSH is continuing to pursue additional data. NIOSH will continue to evaluate as additional fecal bioassay data become available and are compiled.

7.2.1.3 Airborne Levels

As described in Section 7.1, there is extensive air monitoring data from 1944-47 (Monitoring, Jun1944-Dec1947). Approximately 1500 air sample results were recorded, with approximately 1100 from Building 706-A, which is where thorium and plutonium processing activities took place. As described in Section 7.1.1, the samples were determined to be breathing zone samples which were analyzed for gross alpha, and are sufficient for establishing a bounding dose estimate for potential thorium intakes for the years 1944-47.

NIOSH performed extensive research in an effort to locate air sampling data after 1947 but was unsuccessful. A regularly-generated report titled *Report for the Radiation Survey and Monitoring Section* listed air sample totals over a given time period, usually one week. Reports located in 1948 and 1949 routinely listed air sample totals of approximately 200-250 per month (Hart, Apr1949; Hart, May1949). Individual air sample results from which these totals were generated could not be located.

Tables 7-1 and 7-2 below illustrate the air sample data available in the electronic database as well as the summary data in the report series, *Report for the Radiation Survey and Monitoring Section*. Table 7-1 shows the number of air samples taken in various locations from 1944 through 1947. As stated previously, there were approximately 1500 air sample results recorded during this time period. Table 7-2 tabulates the results from nine weekly reports from August 1948 through April 1949. There were a total of 534 air samples taken, averaging approximately 60 per week. At that rate, there were approximately 3000 air samples taken per year, which is significantly more than the 1500 taken from 1944 through 1947 – evidence of an expanding air-sampling program. It is clear that air sampling continued at an increased rate after 1947; however, only summary totals could be found, not the actual sample results.

Table 7-1: ORNL Air Samples by Location (Electronic Database)				
Building	**1944**	**1945**	**1946**	**1947**
100		96	31	4
101		1		
102			2	
105		41	3	1
115		2	1	2
204	19	7	1	
205	72		22	1
706-A	655	415	21	18
706-C	1	15	1	15
706-D		30	1	6

Source: Electronic database

Table 7-2: No. of Air Samples from Nine Weekly Reports (Aug48 through Apr49)					
	Building				
	105	**205**	**706-A**	**706-C**	**706-D**
No. of Air Samples	41	53	137	54	249

Source: Weekly Report, Aug 28, 1948; Weekly Report, Sep 12, 1948; Weekly Report, Oct 17, 1948; Weekly Report, Nov 14, 1948; Weekly Report, Nov 28, 1948; Weekly Report, Dec 12, 1948; Weekly Report, Jan 16, 1949; Weekly Report, Feb 6, 1949; Weekly Report, Mar 27, 1949

7.2.2 Evaluation of Bounding Ambient Environmental Internal Doses

Because NIOSH has determined that it is not possible to completely reconstruct internal radiation doses for the period from June 17, 1943 through July 31, 1955, it is not necessary to fully evaluate environment internal doses for the period under evaluation. Consistent with the findings presented in this Section 7.0, NIOSH will include environmental internal doses, as appropriate, during assignment of nuclide-specific partial internal dose estimates for periods when dose reconstruction is considered feasible.

7.2.3 Methods for Bounding Internal Dose at ORNL (X-10)

The principal sources for internal radiation doses relative to this evaluation are plutonium, uranium, thorium, and fission products. The evaluation of doses from accelerator- or cyclotron-produced radionuclides is reserved because such operations at both ORNL (X-10) and Y-12 will be addressed in a future combined evaluation effort. Although NIOSH has determined that it does not have sufficient data, including bioassay or air monitoring results, to estimate with sufficient accuracy total internal exposures to all the principal sources of internal radiation during the period, NIOSH believes that internal dose estimates can be made for each of the principal sources of internal radiation exposures for various time periods between June 17, 1943 and July 31, 1955.

Plutonium

The ORNL graphite reactor achieved criticality in December 1943, and plutonium production and processing followed starting in 1944. NIOSH obtained a database of approximately 1500 air samples, as discussed earlier in Section 7 (Monitoring, Jun1944-Dec1947). This database contained air samples from 1944 through 1947. Approximately 1100 of these air samples were taken in Building 706-A, where plutonium and thorium processing took place. These air samples were analyzed for gross alpha activity, and therefore, the results include alpha-emitting radionuclides present in the air for the specified location (e.g., plutonium or thorium). Bounding dose estimates for potential internal plutonium intakes can be made by using the gross alpha air sample results taken in areas where plutonium-processing activities took place. These results sufficiently estimate the plutonium concentrations in the air that could have been inhaled by workers in the area. Dose estimates from potential plutonium intakes based on air samples results can therefore be made from 1944 to 1947.

In addition, plutonium bioassay results are available starting in 1945 (Monitoring, Feb-Jun1945). In that year, approximately 150 samples were analyzed. There were only four plutonium bioassay results for 1946, but 188 samples in 1947, increasing to a maximum of 868 samples in 1954, and leveling to several hundred samples in 1955. Based on the quantity of plutonium bioassay samples, and the protocols that were in place at the time, NIOSH believes these results are sufficient for providing SEC-period dose estimates from potential plutonium intakes from 1945 through 1955.

Therefore, NIOSH believes that, based on the available air sample data and urine bioassay data, internal doses due to plutonium can be estimated with sufficient accuracy for the period from January 1, 1944 through July 31, 1955 (all years of the period under evaluation). NIOSH will continue to evaluate as further air and plutonium bioassay data become available and are compiled.

Uranium

The first bioassay results located for uranium are during 1949. They were analyzed on site and were included in the ORNL bioassay database. There are 77 sample results reported for 1949, and approximately 3000 between 1950 and 1955 (Monitoring, 1945-1990). The large number of uranium bioassay samples is indicative of a developed program and provides sufficient data for making bounding dose estimates from potential uranium intakes from 1949 through 1955.

NIOSH has determined that it does not have sufficient data, including bioassay or air monitoring results, to estimate internal uranium doses with sufficient accuracy during the period June 17, 1943 through December 31, 1948 (the period prior to uranium-specific bioassay data). With the availability of uranium bioassay data starting in 1949, NIOSH believes that it has adequate monitoring data to allow for sufficiently accurate estimation of internal uranium doses for workers during the period from January 1, 1949 through July 31, 1955.

Thorium

NIOSH obtained a database of approximately 1500 air samples, as discussed earlier in Section 7 (Monitoring, Jun1944-Dec1947). This database contained air samples from 1944 through 1947. Approximately 1100 of these air samples were taken in Building 706-A, where plutonium and thorium processing took place. These air samples were analyzed for gross alpha activity, and therefore, the results include alpha-emitting radionuclides present in the air for the specified location (e.g., plutonium or thorium). Bounding dose estimates for potential internal doses from thorium intakes can be made by using the gross alpha air samples results taken in areas where thorium processing activities took place. These results would sufficiently estimate the thorium concentrations in the air that could have been inhaled by workers in the area. Bounding dose estimates from potential thorium intakes based on the air samples results can therefore be made from 1944 to 1947.

The first bioassay results for thorium are 51 fecal bioassay results starting in August 1955 (Monitoring, 1945-1990). The thorium fecal bioassay program continued to expand in the following years with 103 results in 1956, 125 in 1957, and 770 in 1959. The thorium fecal bioassay program coincides with the rapidly developing thorium operations at ORNL (described in Section 5). The large number of thorium bioassay samples is indicative of a developed program and provides enough data for making bounding dose estimates from potential thorium intakes starting in August 1955.

With the availability of air monitoring data through 1947, NIOSH believes that it has adequate monitoring data to allow for sufficiently accurate estimation of internal thorium doses for workers during the period from January 1, 1944 through December 31, 1947. NIOSH will continue to evaluate as further air data become available and are compiled. During the period 1948 through July 1955, NIOSH has no available thorium-related air or bioassay data until thorium-specific fecal sample results become available in August 1955. NIOSH has determined that it does not have sufficient data, including bioassay or air monitoring results, to estimate internal thorium doses with sufficient accuracy during the period from January 1, 1948 through July 31, 1955.

Fission Products

Bioassay results for fission products appeared in the ORNL bioassay database starting in 1950, with results for cesium and strontium (Monitoring, 1945-1990). There were 47 sample results reported in 1950, 360 in 1951, and over 700 for each of the following years through 1955. The large number of fission product bioassay samples is indicative of a developed program and provides enough data for making bounding dose estimates from potential fission product intakes from 1950 through 1955.

NIOSH has determined that it does not have sufficient data, including bioassay or air monitoring results, to estimate internal fission product doses with sufficient accuracy during the period January 1, 1944 through December 31, 1949 (the period prior to cesium and strontium bioassay data). With the availability of cesium and strontium bioassay data starting in 1950, NIOSH finds that it has adequate monitoring data to allow for sufficiently accurate estimation of internal fission product doses for workers during the period from January 1, 1950 through July 31, 1955.

7.2.4 Internal Dose Reconstruction Feasibility Conclusion

The evaluation concludes that it is not feasible for NIOSH to reconstruct with sufficient accuracy the internal doses at ORNL (X-10) from:

- uranium exposures during the period June 17, 1943 through December 31, 1948;
- thorium exposures during the period from January 1, 1948 through July 31, 1955; and
- fission product exposures during the period from January 1, 1944 through December 31, 1949.

Combining the periods above yields a summative time period for dose reconstruction infeasibilities of June 17, 1943 through July 31, 1955. Therefore, the NIOSH-recommended SEC class includes the period from June 17, 1943 through July 31, 1955.

NIOSH believes that internal doses due to plutonium can be estimated with sufficient accuracy for the entire period from January 1, 1944 through July 31, 1955. NIOSH also believes that for some periods of time between June 17, 1943 and July 31, 1955, it is feasible to reconstruct doses for each of the other principal sources for internal radiation doses. However, there are no time periods between June 17, 1943 and July 31, 1955 when total internal doses can be reconstructed for all principal sources of internal radiation dose. NIOSH will continue to evaluate as further data become available and are compiled.

Although NIOSH found that it is not possible to completely reconstruct internal radiation doses for the period from June 17, 1943 through July 31, 1955, NIOSH intends to use any internal monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Dose reconstructions for individuals employed at ORNL (X-10) during the period from June 17, 1943 through July 31, 1955, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

Table 7-3 shows the available internal monitoring data by internal exposure sources and year.

Table 7-3: Available ORNL (X-10) Internal Monitoring Data

<table>
<tr><th rowspan="2">Internal Sources</th><th colspan="13">Year</th></tr>
<tr><th>1943</th><th>1944</th><th>1945</th><th>1946</th><th>1947</th><th>1948</th><th>1949</th><th>1950</th><th>1951</th><th>1952</th><th>1953</th><th>1954</th><th>1955</th></tr>
<tr><td>Plutonium</td><td></td><td>Air</td><td>Bio</td><td>Air</td><td colspan="9">Bioassay</td></tr>
<tr><td>Uranium</td><td colspan="6">No Data (Infeasible)</td><td colspan="7">Bioassay</td></tr>
<tr><td>Thorium</td><td></td><td colspan="4">Air Data</td><td colspan="7">No Data (Infeasible)</td><td>Bio</td></tr>
<tr><td>Fission Products</td><td></td><td colspan="6">No Data (Infeasible)</td><td colspan="6">Bioassay</td></tr>
<tr><td>Reactor/Cyclo-tron/Accelerator</td><td colspan="13">Reserved for a joint ORNL (X-10) and Y-12 evaluation</td></tr>
</table>

7.3 Evaluation of Bounding External Radiation Doses at ORNL

The principal source of external radiation doses for members of the evaluated class was a combination of direct exposure from reactors and from various fission products and production nuclides. See Section 5.0 for a discussion of the radionuclides that are known to have been present.

The following subsections address the ability to bound external doses, methods for bounding doses, and the feasibility of external dose reconstruction.

7.3.1 Evaluation of Bounding Process-Related External Doses

The section summarizes the extent and limitations of information available for reconstructing the process-related external doses of members of the class under evaluation. Primary documentation and summary reports are available for both photon and beta exposure for individual workers (see Section 6.2 for references). In addition, NIOSH has almost 46,000 photon results and the same number of beta results for more than 9,000 individuals. In addition, NIOSH has previously completed a co-worker study for ORNL, ORAUT-OTIB-0021, *External Coworker Dosimetry Data for the X-10 Site*.

Photon

The external dosimetry data are sufficient to perform SEC-period dose reconstructions for photon exposures from all external gamma and X-ray sources present at ORNL for all workers in the class under evaluation. Specific data are available for many individuals. For any worker whose exposure results are not in NIOSH's possession and cannot be obtained from DOE, the factors from the ORNL co-worker study (ORAUT-OTIB-0021) may be used.

Beta

The external dosimetry data are sufficient to perform SEC-period dose reconstructions for beta exposures from all external beta sources present at ORNL for all workers in the class under evaluation. Specific data are available for many individuals. For any worker whose exposure results are not in NIOSH's possession and cannot be obtained from the DOE, the factors from the ORNL co-worker study (ORAUT-OTIB-0021) may be used.

Neutron

Neutron exposures occurred from a variety of sources in distinct locations. Each circumstance will be described separately with a proposed bounding method. NIOSH believes that the data are sufficient to reconstruct SEC-period estimates of neutron exposures for the all members of the class under evaluation.

For the cases of potential neutron exposure, NIOSH will develop a ratio of neutron-to-photon exposure. It is known that some, if not all, results reported by ORNL may include ORNL-assigned neutron exposure. NIOSH'S N:P ratio method will be claimant-favorable for such ORNL data because it will overestimate neutron exposure in those cases in which an employee was assigned neutron exposure, and also in the case when an employee did not actually receive neutron exposure but only worked in the vicinity of a neutron source.

Graphite Reactor

Neutron and gamma surveys were performed early during the reactor's operation around the locations of likely worker exposure (Progress Report, Jan-Jul1946). These results have been used to develop a neutron-to-photon ratio of 0.1. This ratio may be applied to the photon exposure results for employees. This is a conservative estimate because, during the history of the reactor, it is expected that gamma levels would have increased due to activation effects while, with the reactor aging, the neutron levels would not have increased, thus overestimating neutron exposure for later years. Note that the Graphite Reactor was the only reactor operating at ORNL prior to 1951.

Low Intensity Test Reactor (LITR)

The LITR was created as a full-scale mockup of the Materials Test Reactor (MTR). Although there are differences between the shielding of the two reactors, similarities (e.g., size, overall design, and fuel type) lead NIOSH to believe that an N:P ratio that has been developed for the MTR may be applied to the LITR for dose reconstruction of the neutron component.

In a memo discussing a proposed increase in the operating power level of the LITR, a comparison is made between the LITR and the MTR:

> *A comparison of the LITR with the MTR shows that only minor differences exist as far as safety is concerned. Major differences exist in the materials of construction, water system and shielding, but it is believed that these do not appreciably decrease the safety of the LITR.* (Larson, 1953, pdf p. 4)

Of the factors mentioned, the most significant issue related to the possible use of MTR data for LITR workers is the difference in shielding. The memo goes on to describe the difference between the two shields:

> *The shield of' the LITR is composed mostly of unmortared concrete blocks with only the outer one-foot being mortared. While this is not as efficient as the MTR shield in that more thickness is required (because ordinary concrete instead of high density barytes concrete was used), it is satisfactory and appears to be generally sufficient for 3000 KW operation.* (Larson, 1953, pdf p. 5)

The greatest difference appears to be the thicknesses needed to provide similar worker exposure levels.

In the technical basis document*, Idaho National Laboratory and Argonne National Laboratory-West – Occupational External Dosimetry*, an N:P ratio is developed based on the measured thermal and fast neutron dose equivalent rates and gamma dose rates at the MTR test floor (ORAUT-TKBS-0007-6). The calculated value is 0.58 $\pm$ 0.48. Note that this document indicates that this value will overestimate exposure due to the likelihood of many employees receiving gamma exposure while not in the vicinity of the reactor.

Bulk Shielding Reactor (BSR)

The Bulk Shielding Reactor (BSR) was a swimming pool reactor with a pool that was 20 feet deep with the top of the reactor 16 feet below the surface. Measurements made within the BSR pool showed that the fast neutron flux decreased by six orders of magnitude within a distance of 120 cm of water (about 4 feet) (Eggen, 1960). The potential neutron flux at the surface (16 feet above the reactor) would be unmeasurable or zero. Typically, experiments were lowered into the pool to place them in the vicinity of the reactor. There were no beam holes or other significant pathways in the BSR design, so there would effectively be no neutron exposures to workers as a result of BSR operations.

However, it is important to note that one experiment has been located during which the water level was lowered to a minimum of 30 centimeters over the reactor (Hungerford, 1954). There is nothing in the documentation of this experiment indicating that any personnel were in the vicinity of the water's surface. However, many paired photon and neutron data were collected as part of the experiment. These data can be used should the need arise to develop an N:P ratio for such exposure. For all other cases, a value of zero is appropriate for neutron exposure from the Bulk Shielding Reactor.

Homogeneous Reactor Experiment (HRE)

Although information exists on the power levels and shielding used, no survey data or neutron spectra have been located for the HRE or its successor, the Homogeneous Reactor Test (HRT). Due to the unique design of a homogenous reactor, it is not appropriate to use information gathered from other reactors to estimate neutron exposure data directly. For example, shielding was required for the fuel loop to account for the production of delayed neutrons after the fuel had left the central core.

However, NIOSH has found that claimant data reported by ORNL for persons known to have worked at the HRE includes original NTA badge track results with data labels "OW" and "S".

The film badge in use during the operation of the HRE had an open window, an area shielded by cadmium, and several other shielding components. For personnel with a potential for neutron exposure, these badges contained both a film for photon and beta exposure, and a separate NTA film behind that (Thornton, 1961). The open window area allowed the full spectrum of neutrons (fast plus thermal) to impact the NTA film. Fast neutrons produced a visible track due to the scattering of a recoil proton resulting from the neutron impacting a hydrogen nucleus.

Thermal neutrons captured by nitrogen in the film created a track from the 584 KeV proton produced by the N^{14} (n,p) C^{14} reaction (Cheka, unspecified). This track is equivalent to one created by a recoil proton from a collision with a neutron with energy of greater than 1 MeV. The cadmium filter absorbed thermal neutrons and allowed the fast neutrons to pass through to the film. The net difference between the number of tracks under the shielded area and the number of tracks in the open window area provide the number of tracks created by thermal neutrons. Note that although NTA film has a well-established threshold for the measurement of proton recoil tracks from neutrons with energies below 0.5 MeV, this technique bypasses that limitation.

NTA films were developed for potentially-exposed personnel, and the number of tracks per field of view for each area (shielded and open window) were recorded. These track data are available to NIOSH from the individual claimant requests that have been made to date. It is expected that further employee NTA results may be obtained from ORNL following identification of individuals who worked at the HRE.

NIOSH believes that these data, combined with claimant gamma exposure data, may be used to develop an N:P ratio for worker neutron exposure at the HRE.

Aircraft Reactor Experiment (ARE)

The ARE was operational for a very short time in 1954. During November 3-8, during the "Low Power Run," the ARE was brought to a maximum of 20 kilowatts; during November 8-12, during the "High Power Run," it was brought to 2.5 megawatts. Operations were terminated after November 12 (Cottrell, 1955). The reactor was shielded laterally by six feet of concrete. During the High Power Run, three layers of 2.5 feet thick concrete blocks were added over the reactor.

During the Low Power Run, measurements were made in the reactor pit of the gamma, fast neutron, and thermal neutron levels when the reactor was at 2.7 watts. Readings were taken at the top center of the reactor and at the side at the mid-plane. These data may be used to develop a neutron-to-photon ratio that takes into account the concrete shielding between the reactor and the control room.

Tower Shielding Reactor (TSR)

No neutron data have been located for the TSR. However, paired neutron and photon data along with a neutron spectrum were measured for the second Tower Shielding Reactor, TSR-II. The TSR-II may be considered as an analog for the TSR because it used the same type of fuel plates and was a redesign of the TSR-I in a spherical shape (Rosenthal, 2009, pdf p. 64). The TSR-II was used in, and operated from, the same locations as the TSR-I and was operated under the same procedures (Hart, 1959).
It was confirmed during an employee interview that no personnel were allowed within the fence or outside of the underground control facility during any reactor operations (Personal Communication, 2012c).

In *A Study of the Radiation Shielding Characteristics of Basic Concrete Structures at the Tower Shielding Facility*, measurements of gamma, fast neutron, and thermal neutron levels were made for various thicknesses of concrete ranging from none to 20 inches thick. These measurements were made in two bunkers located approximately 700 feet from the reactor (Cain, 1964). Spectral information for the TSR-II may be found in *Absolute Neutron Spectrum for the TSR-II* (Maerker, 1972) and in *Low Energy Neutron Spectrum for TSR-II* (Freestone, 1970). These data may be used to estimate an N:P ratio for employee exposure for personnel present in the underground control facility during TSR-I operation.

Although the design for the TSR-II eventually allowed operation at 1 MW, it operated at 100 kW through 1970. The above measurements were made prior to 1964. The TSR-I operated initially at 100 kW but was soon increased to 500kW (Rosenthal, 2009, pdf pp. 63, 64). Due to the proportionality of the production of neutrons and photons, the similar spectra expected from the use of the same fuel, and the use of the same facility (including the worker shielding), it is expected that the differences in power levels would not cause a significant difference in the neutron-to-photon ratios expected from the two reactors.

Critical Reactor Experiments

These experiments were operated at very low power levels, from zero to tenths of watts. They were performed for very short time periods at or near criticality for a maximum of 20 minutes. They were operated from behind a two-foot thick concrete wall with a water window of the same thickness. The shielding was designed as a precaution against criticality events. There were no criticality accidents. Neutron levels within and near the assemblies were monitored closely during each step of the experiments.

The neutron exposure levels to employees would have been zero or unmeasurable. A value of zero neutron exposure is appropriate for work with the Critical Experiments.

Neutron (α-n) Sources

From 1989 through 1991, Pacific Northwest Laboratory performed measurements to characterize the response of the CEDS neutron TLDs to various workplace neutron spectra at ORNL and Y-12. The measurements consisted of characterization of workplace neutron fields using tissue-equivalent proportional counters, Bonner spheres, He^3 detectors, and other instruments (Battelle, Vol. 1; Battelle, Vol. 2; Battelle, Vol. 3; Battelle, Vol. 4).

These data, along with 2,694 dosimetry records with reported neutron exposures, have been analyzed for a variety of source locations and types. In ORAUT-TKBS-0012-6, there are N:P ratios based on both worker location and source type, including manufactured alpha-neutron sources.

As the spectrum of these sources should be constant regardless of time period, it is appropriate to use these ratios for earlier workers.

7.3.2 Evaluation of Bounding Ambient Environmental External Doses

For workers who were monitored with film badges and pocket dosimeters, any ambient environmental exposures would have been accumulated along with the occupational exposures.

The Occupational Environmental Dose TBD applies to workers who were not monitored for external or internal radiation exposure (ORAUT-TKBS-0012-4). Environmental dose is that which workers could have received while being outdoors on the ORNL site from inhalation of radioactive materials in the air, direct radiation from airborne releases, or direct radiation in the vicinity of process buildings and waste-handling areas. ORAUT-TKBS-0012-4 provides a table of annual average airborne concentration and intake data for I-131, tritium, and particulate mixed fission products. The concentration data are derived from a combination of conservative assumptions of airborne releases and dispersion and onsite air-monitoring data. NIOSH considers this information sufficient to allow bounding of ambient environmental external dose for all members of the class who were not monitored with external radiation dosimetry.

7.3.3 ORNL Occupational X-Ray Examinations

Prior to October 3, 1947, occupational medical X-rays were performed at Oak Ridge Hospital (an EEOICPA-covered site located on what was then the Clinton Engineering Works site) (ORNL, post-2002). Starting October 3, 1947, occupational X-rays were performed on the ORNL site. Therefore, NIOSH has determined that it is applicable and feasible to reconstruct occupational medical X-ray exposures for ORNL (X-10) workers during period from June 17, 1943 through July 31, 1955.

7.3.4 Methods for Bounding External Dose at ORNL

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

- Photon Dose
- Beta Dose
- Neutron Dose
- Medical X-ray Dose (as applicable per Section 7.3.3)

7.3.4.1 Methods for Bounding Operational Period External Dose

Photon Dose

NIOSH has determined that external photon dose may be reconstructed.

The primary method is the use of individual records. Film badge frequencies and thresholds are known and documented. Missed dose may be applied using this information. Standard methods may be applied for missing data, and for employees with no exposure results, the ORNL co-worker study (ORAUT-OTIB-0021) may be used. For unmonitored radiation workers routinely exposed (i.e., those who were expected to have been monitored), a conservative estimate of their probable exposure may be based on the 95th percentile of all photon exposure results for that year. For unmonitored radiation workers likely exposed to intermittent low levels of external radiation, the 50th percentile of all photon exposure results for that year provides a conservative estimate of their probable exposure. For unmonitored employees who were unlikely to have been exposed, the ambient environmental exposure may be assigned.

Beta Dose

NIOSH has determined that external beta dose may be reconstructed.

The primary method is the use of individual records. Film badge frequencies and thresholds are known and documented. Missed dose may be applied using this information. Standard methods may be applied for missing data, and for employees with no exposure results, the ORNL co-worker study (ORAUT-OTIB-0021) may be used. For unmonitored radiation workers routinely exposed (i.e., those who were expected to have been monitored), a conservative estimate of their probable exposure may be based on the 95th percentile of all beta exposure results for that year. For unmonitored radiation workers likely exposed to intermittent low levels of external radiation, the 50th percentile of all beta exposure results for that year provides a conservative estimate of their probable exposure. For unmonitored employees who were unlikely to have been exposed, the ambient environmental exposure may be assigned.

Neutron Dose

NIOSH has determined that for each of the areas of neutron exposure, an N:P ratio exists or may be created.

Using the appropriate N:P ratio against the gamma exposure data will allow for a conservative bounding estimate of an employee's likely neutron exposure. This method will be claimant-favorable because in the absence of individually applicable data, it will assign neutron exposures to employees who may have simply worked in those areas without actually being exposed to neutrons. The method will also be claimant-favorable in those cases in which neutron exposures were calculated by the ORNL site and added to the gamma results; for such employees, their neutron exposure will be overestimated. Note that the great majority of neutron exposure results reviewed in the original documents, although not complete for the time period, have values of zero. The levels of neutron exposures for most locations are expected to have been low due to the nature of the experimental activities. The risk of vastly overestimating neutron exposure using the N:P ratio is believed to be small.

Medical X-ray Dose

The Occupational Medical Dose TBD (ORAUT-TKBS-0012-3) provides information on doses workers received from X-rays that were required as a condition of employment. These X-rays were included in pre-employment screenings, annual physical exams, and termination exams. These X-ray exams were initially performed at the hospital in Oak Ridge, where photofluorographic techniques appear to have been used. ORNL took over with its own X-ray equipment on October 3, 1947 and those examinations were conventional exposures. In 1959, Oak Ridge Hospital became what is now known as Methodist Medical Center of Oak Ridge. Oak Ridge Hospital is EEOICPA-covered from 1943 to 1959. The current ORNL Medical Department provided a description of radiographic procedures that have been used to conduct X-ray examinations for workers at the ORNL site (ORNL, post-2002, Table 3-2). This information indicates that from October 3, 1947 to the present, all medical X-rays for screening conducted onsite in the ORNL Medical area used conventional, radiographic (non-PFG) equipment.

7.3.4.2 Methods for Bounding Ambient Environmental External Doses

Workers who were monitored for external exposure would have been assigned results from methods that incidentally included any ambient environmental exposure. That is, radiation workers wore dosimetry while on site regardless of location. This is confirmed in reviewed documentation and through employee interviews.

The methods proposed in the ORNL Occupational Environmental Dose TBD are adequate to bound ambient environmental external doses for those who may have not been monitored for external exposure (ORAUT-TKBS-0012-4). The TBD addresses the primary contributions to environmental exposures, the release points, the stack emissions, and their contribution to the average annual concentrations. The TBD makes conservative assumptions to assign exposures based on immersion at those concentrations.

7.3.5 External Dose Reconstruction Feasibility Conclusion

External dose for photon and beta exposure may be reconstructed for all members of the class under evaluation. External dose for neutron exposure may be reconstructed for all members of the class under evaluation.

7.4 Evaluation of Petition Basis for SEC-00189

The following subsections evaluate the assertions made on behalf of petition SEC-00189 for the Oak Ridge National Laboratory.

7.4.1 ORAUT-TKBS-012-5

SEC-00189: *The X-10 technical basis document ORAUT-TKBS-0012-5, Oak Ridge National Laboratory Occupational Internal Dose, conducted by NIOSH/ORAU, states that internal monitoring records are limited or do not exist for most radionuclides during this timeframe because internal monitoring as a form of personnel monitoring was just starting to be developed in the mid to late 1940's. As such, the applicability for use of this TBD starts in 1947.*

In the course of this evaluation, NIOSH determined that internal monitoring was limited until the late 1940s. Therefore, limited monitoring data exist for some of the primary sources of internal radiation exposure. The bioassay data used to develop the ORNL Occupational Internal Dose TBD included urinalysis results starting in 1947 (only four results were from 1946) (ORAUT-TKBS-0012-5). The TBD provides a methodology for estimating internal doses only for radionuclides where bioassay data are available. As described in this evaluation, NIOSH is recommending the period from June 17, 1943 through July 31, 1955 for inclusion in the SEC.

7.4.2 ORAUT-OTIB-0034

SEC-00189: *The technical information bulletin, ORAUT-OTIB-0034, Internal Dosimetry Coworker Data for X-10, conducted by NIOSH/ORAU, is only applicable starting in 1951. It cites a lack of internal dosimetry data prior to 1951.*

Prior to 1951, there are bioassay data for plutonium, uranium, cesium, and strontium. However, starting in 1951, the ORNL bioassay program expanded to cover many other radionuclides. The applicability starting in 1951 is based on this more comprehensive bioassay program. As described in this evaluation, NIOSH is recommending the period from June 17, 1943 through July 31, 1955 for inclusion in the SEC.

7.4.3 ORAUT-OTIB-0018

SEC-00189: *The technical information bulletin, ORAUT-OTIB-0018, Internal Dose Overestimates for Facilities with Air Monitoring Programs, conducted by NIOSH/ORAU, is only applicable starting in 1953.*

The assertion that *ORAUT-OTIB-0018, Internal Dose Overestimates for Facilities with Air Monitoring Programs,* is only applicable in 1953 reflects the difficulties with estimating internal doses before 1953. As described in this evaluation, NIOSH is recommending the period from June 17, 1943 through July 31, 1955 for inclusion in the SEC.

7.5 Summary of Feasibility Findings for Petition SEC-00189

This report evaluates the feasibility for completing dose reconstructions for employees at the Oak Ridge National Laboratory (X-10) from January 1943 through July 1955. NIOSH found that the available monitoring records, process descriptions and source term data available are not sufficient to complete sufficiently accurate dose reconstructions for the evaluated class of employees.

NOTE: The start date for the NIOSH-proposed class to be added to the SEC was changed from January 1, 1943 to June 17, 1943 because NIOSH obtained documentation showing that construction at the site did not start (i.e., ground-breaking) until February 1943, and the first uranium slug shipment left Aluminum Company of America for the site on June 17, 1943 (Alcoa, 1944). Thus, ORNL first had radioactive materials on site sometime after June 17, 1943.

Table 7-4 summarizes the results of the feasibility findings at ORNL (X-10) for each exposure source during the time period January 1943 through July 1955.

Table 7-4: Summary of Feasibility Findings for SEC-00189
January 1, 1943 through July 31, 1955

Source of Exposure	Reconstruction Feasible	Reconstruction Not Feasible
Internal		**X**
- Pu	X (Jan 1, 1944 through Jul 31, 1955)	
- U	X (Jan 1, 1949 through Jul 31, 1955)	X (Jun 17, 1943 through Dec 31, 1948)
- Th	X (Jan 1, 1944 through Dec 31, 1947)	X (Jan 1, 1948 through July 31, 1955)
- Fission Products	X (Jan 1, 1950 through Jul 31, 1955)	X (Jan 1, 1944 through Dec 31, 1949)
- Reactor-, Cyclotron-, or Accelerator-produced Radionuclides	*Reserved for a joint ORNL (X-10) and Y-12 evaluation*	*Reserved for a joint ORNL (X-10) and Y-12 evaluation*
External	**X** (Jun 17, 1943 through Jul 31, 1955)	
- Gamma	X	
- Beta	X	
- Neutron	X	
- Occupational Medical X-ray	X	

As of July 10, 2012, a total of 1302 claims have been submitted to NIOSH for individuals who worked at ORNL during the period under evaluation in this report. Dose reconstructions have been completed for 1074 individuals (~82%).

Although NIOSH found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any internal and external monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at ORNL during the period from June 17, 1943 through July 31, 1955, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

8.0 Evaluation of Health Endangerment for Petition SEC-00189

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.

This evaluation concluded that for some periods of time between June 17, 1943 and July 31, 1955, it is feasible to reconstruct doses for each of the principal sources for internal radiation doses. However, there are no time periods between June 17, 1943 and July 31, 1955 when doses can be reconstructed for all principal sources of internal radiation dose. NIOSH's evaluation determined that it is not feasible to estimate radiation dose for members of the NIOSH-evaluated class with sufficient accuracy based on the sum of information available from available resources. Therefore, the resulting NIOSH-proposed SEC class must include a minimum required employment period as a basis for specifying that health was endangered.

9.0 Class Conclusion for Petition SEC-00189

Based on its full research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class to be added to the SEC includes all employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area at the Oak Ridge National Laboratory (X-10) in Oak Ridge, Tennessee, from June 17, 1943 through July 31, 1955, for a number of work days aggregating at least 250 work days, occurring either solely under this employment, or in combination with work days within the parameters established for one or more other classes of employees in the Special Exposure Cohort.

NIOSH has carefully reviewed all material sent in by the petitioner, including the specific assertions stated in the petition, and has responded herein (see Section 7.4). NIOSH has also reviewed available technical resources and many other references, including the Site Research Database (SRDB), for information relevant to SEC-00189. In addition, NIOSH reviewed its NOCTS dose reconstruction database to identify EEOICPA-related dose reconstructions that might provide information relevant to the petition evaluation.

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

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Progress Report, Sep1951, *Operations Division Monthly Report for Month Ending September 30, 1951*; M. E. Ramsey; issued January 18, 1952; SRDB Ref ID: 110019

Progress Report, Oct1951a, *Health Physics Division Quarterly Progress Report for Period Ending October 20, 195*1; K. Z. Morgan; DSA Ref ID: 114348

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Progress Report, Dec1951, *Operations Division Monthly Report for Month Ending December 31, 1951*; M. E. Ramsey; issued March 6, 1952; SRDB Ref ID: 110026

Progress Report, Jan1952, *Operations Division Monthly Report for Month Ending January 31, 1952*; M. E. Ramsey; issued March 31, 1952; SRDB Ref ID: 110029

Progress Report, Feb1952, *Operations Division Monthly Report for Month Ending February 29, 1952*; M. E. Ramsey; issued April 28, 1952; SRDB Ref ID: 110030

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Progress Report, Apr1952, *Operations Division Monthly Report for Month Ending April 30, 1952*; M. E. Ramsey; issued June 30, 1952; SRDB Ref ID: 110032

Progress Report, May1952, *Operations Division Monthly Report for Month Ending May 31, 1952*; M. E. Ramsey; issued July 23, 1952; SRDB Ref ID: 110033

Progress Report, Jun1952, *Operations Division Monthly Report for Month Ending June 30, 1952*; M. E. Ramsey; issued August 13, 1952; SRDB Ref ID: 110055

Progress Report, Jul1952, *Operations Division Monthly Report for Month Ending July 31, 1952*; M. E. Ramsey; issued September 8, 1952; SRDB Ref ID: 110034

Progress Report, Aug1952, *Operations Division Monthly Report for Month Ending August 31, 1952*; M. E. Ramsey; issued October 1952; SRDB Ref ID: 110056

Progress Report, Sep1952, *Operations Division Monthly Report for Month Ending September 30, 1952*; M. E. Ramsey; issued November 20, 1952; SRDB Ref ID: 110038

Progress Report, Oct1952, *Operations Division Monthly Report for Month Ending October 31, 1952*; M. E. Ramsey; issued December 19, 1952; SRDB Ref ID: 110044

Progress Report, Dec1952, *Operations Division Monthly Report for Month Ending December 31, 1952*; M. E. Ramsey; issued February 21, 1953; SRDB Ref ID: 110045

Progress Report, Jan1953, *Operations Division Monthly Report for Month Ending January 31, 1953*; M. E. Ramsey; issued March 4, 1953; SRDB Ref ID: 110046

Progress Report, Mar1953, *Operations Division Monthly Report for Month Ending March 31, 1953*; M. E. Ramsey; issued May 11, 1953; SRDB Ref ID: 110048

Progress Report, Apr1953, *Operations Division Monthly Report for Month Ending April 30, 1953*; M. E. Ramsey; issued June 28, 1953; SRDB Ref ID: 110049

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Progress Report, Jul1953, *Operations Division Monthly Report for Month Ending July 31, 1953*; M. E. Ramsey; issued September 15, 1953; SRDB Ref ID: 110052

Progress Report, Aug1953, *Operations Division Monthly Report for Month Ending August 31, 1953*; M. E. Ramsey; issued October 12, 1953; SRDB Ref ID: 110066

Progress Report, Oct1953, *Operations Division Monthly Report for Month Ending October 31, 1953*; A. F. Rupp; issued sometime in 1953; SRDB Ref ID: 110084

Progress Report, Nov1953, *Operations Division Monthly Report for Month Ending November 30, 1953*; A. F. Rupp; issued January 15, 1954; SRDB Ref ID: 110088

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Progress Report, Feb1954, *Operations Division Monthly Report for Month Ending February 28, 1954*; A. F. Rupp; issued April 19, 1954; SRDB Ref ID: 110092

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Progress Report, Sep1954, *Operations Division Monthly Report for Month Ending September 30, 1954*; A. F. Rupp; issued November 16, 1954; SRDB Ref ID: 109938

Progress Report, Oct1954, *Operations Division Monthly Report for Month Ending October 31, 1954*; A. F. Rupp; issued December 22, 1954; SRDB Ref ID: 109970

Progress Report, Nov1954, *Operations Division Monthly Report for Month Ending November 30, 1954*; A. F. Rupp; issued January 18, 1955; SRDB Ref ID: 110095

Progress Report, Dec1954, *Operations Division Monthly Report for Month Ending December 31, 1954*; A. F. Rupp; issued February 4, 1955; SRDB Ref ID: 110096

Progress Report, Mar1955, *Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending March 10, 1955;* W. H. Jordan, S. J. Cromer, R. I. Strough, A. J. Miller, and A. W. Savolainen; issued April 21, 1955; SRDB Ref ID: 103364

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Weekly Report, Feb 6, 1949, *Report for Radiation Survey-Monitoring Section, Week Ending February 6, 1949*, Oak Ridge National Laboratory; February 8, 1949; SRDB Ref ID: 116255

Weekly Report, Mar 27, 1949, *Report for Radiation Survey-Monitoring Section, Week Ending March 27, 1949*, Oak Ridge National Laboratory; March 29, 1949; SRDB Ref ID: 116262

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Attachment 1: Data Capture Synopsis

Table A1-1: Data Capture Synopsis for ORNL (X-10)

Data Capture Information	General Description of Documents Captured	Date Completed	Uploaded To SRDB
Primary Site/Company Name: Oak Ridge National Laboratory (ORNL); DOE 1943-Present Alternate Site Names: Clinton Laboratories Holifield National Laboratory Operating Contractor Names: E.I. DuPont for the University of Chicago Monsanto Chemical Company Carbide & Carbon Chemicals Company Union Carbide Corporation Martin Marietta Lockheed Martin UT-Battelle Physical Size of the Site: 4470 Acres, 150 Buildings in 1943. By 1951 there were approximately 270 numbered facilities, including buildings and ancillary structures, such as stacks. Site Population: World War II Era: 1513 Employees Currently: Approximately 4600 Employees	Medical records, nuclear accident dosimetry, health physics periodic reports, film badge data, personnel monitoring for fast neutrons, building lists, hot run reports, health and safety reports, dust studies, radiation surveys including neutron surveys, urinalysis results, remediation reports, site and division histories, incident investigations, operational reports, exposure reports, division reports, isotope production in the 86 inch cyclotron, isotope inventories, Aircraft Nuclear Propulsion reports, site vicinity environmental reports, waste disposal reports, activity hazard reports, personnel contamination reports, bioassay reports, reactor reports, airborne radioactivity and air monitoring reports, Health Department reports, bioassay methods reports, and neutron dosimetry reports. NOTE: NIOSH and the ORAU Team are awaiting the release of additional Central Files (CF) reports which are being scanned at ORNL, Monsanto (MON) reports being scanned at ORNL, an index of radiological survey reports, and title lists for reports by selected ORNL authors.	OPEN	1,448
State Contacted: NA	NOTE: Contacting the state was not considered necessary since ORNL is an active DOE site and cooperated with relevant data collection.	12/08/2011	0
Ames Laboratory	Reference to shipments of uranium from the Ames Laboratory to ORNL.	10/18/2005	1
Argonne National Laboratory - East	Material transfers to ORNL, ORNL's use of vacuums in Pu decontamination, reactor planning meeting minutes, promethium incident reports, radiation hazard meetings, clearance procedures, investigation reports, and urinalysis records.	07/06/2012	11
Auxier and Associates	Health physics manuals.	05/14/2004	3

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
Battelle Memorial Institute, King Avenue	Battelle's procurement of thorium for ORNL and ORNL's performance evaluation of Battelle's bioassay program.	09/30/2011	2
Brookhaven National Laboratory	Environmental monitoring, ORNL's providing radioisotopes for cancer research, the 1992 DOE annual exposure report, waste disposal reports, 1947 AEC rules concerning radiation hazards, progress in implementing the DOE Radcon Manual, ambient air monitoring facilities at DOE facilities, a comparison of exposures at DOE accelerators, and BNL's intention to perform dosimetry intercomparisons with ORNL.	11/18/2008	12
Cincinnati Public Library	Manhattan Engineer District (MED) and Atomic Energy Commission (AEC) histories, an internal dosimetry article, an automatic beta spectrometer, and 1955 ORNL radiation control action levels.	12/06/2011	9
Claimant Provided	A waste pond incident dose reconstruction, a waste solution contamination incident dose reconstruction, a FOIA request, and documents provided by a Linde Ceramics Plant claimant.	01/31/2011	6
Colorado Mesa University Tomlinson Library	The decontamination of the ORNL Thorex Pilot Plant and uranium extraction from Dakota lignites.	04/19/2011	2
Curtiss-Wright, Cheswick, PA	An ORNL individual exposure history report.	04/29/2009	1
Department of Labor / Paragon	ORNL remedial action documents and surveys from New York sites, a thorium slug report, a complex-wide low-level mixed waste report, and the Li(B) ingot preparation report.	01/23/2012	33
DOE	The definition of weapons-usable U-233.	06/18/2008	1
DOE Albuquerque Operations Office	The hazard level classifications of nonreactor nuclear facilities.	04/15/2010	1
DOE Environmental Measurements Laboratory	Development of urinalysis to estimate uranium body burden, occupational exposures to airborne uranium at feed materials facilities, and a discussion of criticality alarms.	01/21/2011	4
DOE Germantown	Excerpts from the Manhattan District history, a thoria report, U-233 recovery and supply reports, uranium recovery from phosphoric acid, a beryllium history, and meeting reports.	03/07/2011	17
DOE Legacy Management - Grand Junction Office	ORNL remedial action reports and surveys from various sites, electromagnetic separation of isotopes, analysis and handling of radioactive scrap, Oak Ridge area environmental surveys, disposition of Aircraft Nuclear Propulsion Project equipment, Elza Gate surveys and remedial action documents, division reports, material transfers, bioassay records, tritium work for the Savannah River Site, jacketing of slugs, uranium handling rules, a U-233 status report, thorium reports, an ORNL subcontractor list, and budget reviews.	08/30/2011	167

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
DOE Legacy Management - Morgantown	Environmental reports, Fernald material transfers and thorium work, recycled uranium processing, thorium processing, a 1950 study of uranium in urine of ORNL personnel, appraisals of ORNL's occupational medicine program, and Pu-242 tracer data.	12/01/2011	71
DOE Legacy Management - MoundView (Fernald Holdings, includes Fernald Legal Database)	Mound reports from Monsanto's tenure as the ORNL operating contractor, epidemiology studies, ORNL summaries of occurrence reports, trip reports, conference reports, material transfers, thorium research, permissible polonium concentrations, criticality dosimetry, material control documents, and a 1947 neutron film badge report.	05/13/2010	71
DOE Legacy Management - Westminster Office	The 1987 preliminary environmental survey report which identifies ORNL as performing sampling and analysis in support of the survey.	03/15/2012	1
DOE Oak Ridge Operations Office	1952 Building 3019 radiation reports, 1955 Thorex Pilot Plant radiation exposure report, Tiger Team reports, industrial hygiene reports, dosimetry reports, uranium and plutonium urine controls, environmental reports, and dosimetry records of 16 former ORNL workers.	07/13/2012	47
DOE Oak Ridge Operations Office Public Reading Room	Material accountability reports and thorium processing.	04/08/2011	10
DOE Oak Ridge Operations Records Holding Task Group	Organizational charts, building lists, film badge reports, researchers notes, progress reports, material requirements and transfers, Np-237 processing, thorium processing reports, 1945 urine analyses, and ORNL's transuranic capabilities.	04/05/2011	53
DOE Office of Scientific and Technical Information (OSTI)	Progress reports, trip reports, histories, film badge studies, thyroid counts, maps with building numbers, personnel monitoring records, neutron film calibration, air sample analyses, health physics reports, health physics instruments, environmental reports, source term data, urinalysis results, health physics facility appraisals, meeting minutes, diagnostic x-ray equipment, incident reports, procedures, film badge calibrations, reactor studies, pocket dosimeter logs, and ambient air sample results.	03/19/2012	600
[Name redacted]	Report from the 1985 workshop on radiobiological effectiveness of neutrons.	08/13/2003	1
Federal Records Center (FRC) - Atlanta	1949 film badge data, film badge issue record, fallout monitoring, hood effluent contamination, treatment and disposal of waste liquors, tritium information, and 1951 revision of building names and numbers.	02/26/2007	14
Federal Records Center (FRC) - Chicago	Aircraft Nuclear Propulsion Project personnel exposures and ORNL inspections of ANP work areas.	09/30/2008	4

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
Federal Records Center (FRC) - Dayton	Health Physics Division reports, radiological characterizations, site map, spent fuel surveys, waste disposal report, and personnel exposure data.	03/20/2006	14
Federal Records Center (FRC) - Denver	Photodosimetry Evaluation Book Volume IV, Pu-244 recovery at Savannah River Site, and ORNL's revision to downblending monitoring equipment installation issues.	02/01/2012	3
Federal Records Center (FRC) - Kansas City	Personnel exposure reports.	03/06/2009	3
Federal Records Center (FRC) - San Bruno	1946 radioactive materials rules and procedures, accelerator hazards, air sampling equipment and procedures, fuels and materials development programs, and corrective action plan for tritium facilities.	01/31/2006	5
Feed Materials Production Center (FMPC)	Th-230 content of thorium inventories, ORNL summaries of occurrence reports, and trip reports.	03/14/2007	6
Feed Materials Production Center (FMPC) / SC&A	Description of the 1968 Oak Ridge mobile in vivo laboratory.	06/26/2003	1
General Electric, Evendale, OH	An affidavit documenting material transfers from General Electric, Evendale to ORNL.	09/24/2010	1
General Electric, Vallecitos, CA	A summary of neutron dosimetry intercomparison studies.	05/18/2007	1
Hagley Museum and Library	Trip reports, criticality incident report, history of Clinton Engineer Works, loading of L Reactor with enriched slugs, and Hanford histories with ORNL references.	10/01/2010	38
Hanford	Hanford reports mentioning material transfers to and from ORNL and ORNL trips and visitors, Y-12 health physics reports, an ORNL contamination scoping survey, evaluations of internal exposures, historical radionuclide release from Oak Ridge Operations Office facilities, material transfers and accountability, Np-237 recovery studies, and thorium fuel processing studies.	01/25/2012	88
Idaho National Laboratory (INL)	ORNL's supplying U3O8 for the BORAX IV Reactor, ORNL's development of INL's ICPP processes, and report of an ORNL tritium release.	04/04/2012	3
Indiana Department of Homeland Security	Report of an ORNL survey of the Joslyn Manufacturing and Supply site.	07/05/2012	1
Interlibrary Loan	Environmental levels of radioactivity reports, a retrospective exposure assessment, the production of transuranium elements, thorium production, a nuclear criticality safety course, TLD studies, problems with using sphere ratios to determine albedo correction factors, and proceedings of the 1993 incineration conference.	05/29/2012	29
Internet	ORNL's design of Operation Henre at the Nevada Test Site.	12/17/2007	1

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
Internet - Defense Technical Information Center (DTIC)	Neutron counting and dosimetry, radiation hazards, plutonium stabilization plans, fallout studies, Defense Nuclear Facilities Safety Board reports, reactor core physics, waste classification, and a shielding study of the Tower Shielding Facility.	07/20/2012	38
Internet - DOE	DOE handbook for airborne releases and environmental assessment of the Building 3019 shutdown.	12/04/2008	2
Internet - DOE Comprehensive Epidemiologic Data Resource (CEDR)	No relevant documents identified.	12/05/2011	0
Internet - DOE Environmental Management	Chapter 3 of Linking Legacies, radioactive wastes.	10/28/2007	1
Internet - DOE Legacy Management Considered Sites	Elza Gate survey and report, a fuel materials report, irradiation of Bismuth-209 for the production of Polonium-210 at the Dayton Project, the ORNL survey of Bethlehem Steel, and Tonawanda area progress reports.	05/05/2012	8
Internet - DOE National Nuclear Security Administration (NNSA) - Nevada Site Office	No relevant documents identified.	02/17/2010	0
Internet - DOE OpenNet	Human radiation studies and interviews, United States Transuranium Registry reports, AEC semiannual reports to Congress, progress reports, Advisory Committee for Biology and Medicine meeting minutes, environmental release reports, summary histories, Mound purchase order status reports, and a Mound site release package.	05/05/2012	49
Internet - DOE Office of Scientific and Technical Information (OSTI)	Thorium metallurgy report, remedial action reports, U-233 research, fuels research, and a dosimeter intercomparison at the Health Physics Research Reactor.	12/18/2009	22
Internet - DOE OSTI Energy Citations	Environmental reports, thorium processing, decontamination proposals and reports, carbide fuel development, Cm-244 bioassay, and radioactive waste shipments.	04/24/2012	27
Internet - DOE OSTI Information Bridge	Reports to Congress, waste inventory databases, fuels and materials reports, environmental reports, histories, lists of AEC isotope customers, radiation protection for the isochronous cyclotron, operational reports, research reports, thorium reports, division reports, fuel cycle conference proceedings, Pu-238 fuel reports, characterization of Cassini power source welds, and reactor reports.	06/28/2012	238
Internet - Environmental Protection Agency	ORNL's 2006 user's guide to the dose and risk calculation software.	05/19/2008	1

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
Internet - Google	Decommissioning reports, operational reports, division reports, environmental reports, reports to Congress, trip reports, histories, lists of DOE radioisotope customers, epidemiological reports and public health assessments, waste stream reports, neutron dosimetry, accident investigation reports, descriptions of animal studies, and environmental remediation plans.	06/09/2012	512
Internet - Hanford Declassified Document Retrieval System (DDRS)	Hanford reports mentioning material transfers to and from ORNL and ORNL trips and visitors.	09/01/2010	26
Internet - Health Physics Journal	Design and dosimetry for an Sr-90-Y-90 irradiation facility, a radioiodine environmental model, report on an ORNL fast neutron survey meter, a review of emission sources, missing dose from the ORNL mortality study, and fast neutron spectra and dose rate calculations.	06/20/2012	6
Internet - Journal of Occupational and Environmental Hygiene	See Cincinnati Public Library and Interlibrary Loan.	12/05/2011	0
Internet - Massachusetts Department of Environmental Protection	A reference to ORNL's inspections and surveys at the Ventron site.	04/19/2012	1
Internet - National Academies Press (NAP)	The 2005 National Research Council report on accelerating the treatment of radioactive wastes at DOE sites and an analysis of cancer risks in populations near nuclear facilities.	03/27/2012	2
Internet - NIOSH	A report on beryllium contamination at covered facilities under EEOICPA and the Evaluation Report for Special Exposure Cohort petition SEC-00152.	01/09/2012	2
Internet - NRC Agencywide Document Access and Management (ADAMS)	ORNL QA program, licensing correspondence, transuranic waste issues, spent fuel and radioactive waste inventories, weapons-usable waste storage reports, environmental impact statements, material transfer records, methods for estimating fugitive emissions, and NRC oversight of the DOE.	03/27/2012	52
Internet - ORNL Library	Operations reports, division reports, histories, hazard evaluations and reports, electromagnetically enriched isotopes inventory reports, Aircraft Nuclear Propulsion Project reports, research reports, shielding reports, reactor handbooks and manuals, slug preparation, radiation surveys, reactor reports, instrument development, solvent extraction reports, neutron studies, Thorex Pilot Plant exposure analysis, and remedial action reports.	07/06/2012	636

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
Internet - University of Hawaii, Manoa, Technical Report Archive and Image Library	An areal survey of ORNL and surrounding areas, and an evaluation of radiation protection afforded by typical Oak Ridge dwellings.	11/08/2007	2
Internet - US Army Corps of Engineers / FUSRAP	A report referencing material transfers between ORNL and the Dayton Project.	05/08/2012	1
Internet - US Transuranium and Uranium Registries	No relevant documents identified.	02/17/2010	0
Lawrence Berkeley National Laboratory (LBNL)	LBNL bioassay cards, post 1983.	05/23/2007	1
Lawrence Berkeley National Laboratory (LBNL) / SC&A	LBNL's forecast for transuranium elements and epidemiological studies of Oak Ridge radiation workers.	07/22/2009	2
Lawrence Livermore National Laboratory (LLNL)	Plutonium-beryllium source safety testing, a hazards control progress report, an Np-237 incident sample sent to ORNL, ORNL's intercomparison study including LLNL, and a DOE accelerator report.	06/12/2009	5
Los Alamos National Laboratory (LANL)	Excursions at the Critical Experiments Laboratory, waste disposal issues, disposal of weapons-usable material, material transfers to ORNL, special work permits, and americium oxide production.	03/09/2012	18
Los Alamos National Laboratory (LANL) / ORNL	Human studies project compiled correspondence.	12/08/2007	1
Massachusetts Department of Public Health	ORNL measurements of states' background radiation levels, ORNL responses to questions regarding Ventron, and ORNL's environmental assessment for Nuclear Metals' license renewal.	04/11/2012	4
Metals & Controls Corporation	Confirmation that Metals & Controls supplied fuel elements to ORNL.	08/24/2004	1
Missouri Department of Natural Resources	A plutonium storage working group report, interviews regarding material transfers, and St. Louis area environmental impact statements.	10/03/2008	4
Mound Museum	Mound technical reports and newsletters referring to ORNL and the index to Mound Laboratory notebooks.	02/01/2012	23
National Archives and Records Administration (NARA) - Atlanta	Dosimetry studies, dosimetry results and calibrations, incident investigations, radiation/contamination surveys, air sample results, thorium and U-233 reports, reactor operating safety limits, employee medical information, proposals for new labs, newspaper articles, progress reports, Aircraft Nuclear Propulsion Project reports, and Aircraft Reactor Experiment reports.	08/18/2011	191
National Archives and Records Administration (NARA) - Atlanta / SC&A	Correspondence from 1955 on decontamination of gloves and a report of 14 cans of high-level scrap shipped from Pinellas to ORNL.	04/16/2004	2
National Archives and Records Administration (NARA) - College Park	Tolerance levels, researchers notes, material balance report, sample analyses, Monsanto monthly reports, betatron records, and thorium research planning.	08/19/2010	33

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
National Archives and Records Administration (NARA) - Kansas City	Facility decontamination history, decommissioned facility survey program, 1977 listing of contaminated facilities, and TLD issue sheets and exposure reports.	07/16/2008	6
National Institute for Occupational Safety and Health (NIOSH)	Human radiation studies interviews, histories, organization charts, Worker Outreach meeting minutes and sign-in sheets, a listing for Oak Ridge in Sandia National Laboratories WebDose tables, research reactor reports, and health physics problems from thorium.	07/06/2012	43
National Institute for Occupational Safety and Health (NIOSH) / SC&A	Highly enriched uranium and plutonium working group reports.	02/16/2006	6
National Technical Information Service (NTIS)	Progress reports on the feasibility study of correlating morbidity and mortality to occupational radiation exposure.	08/21/2006	2
Nevada Test Site	The Nevada Test Site (NTS) Environmental Impact Statement which identifies ORNL as a generator of waste stored at NTS.	10/01/2003	3
New Jersey Department of Environmental Radiation	ORNL remedial action documents and surveys from the Middlesex site.	01/30/2008	3
New York State Archives	AEC Process Development minutes and reports from 1952-1954.	03/21/2012	2
Nuclear Regulatory Commission Public Document Room	Transportation reports, waste disposal reports, stable cesium iodide chemistry, a trip report, ORNL reports for the NRC, and an evaluation of radionuclide geochemical information.	05/21/2012	14
Oak Ridge Gaseous Diffusion Plant (K-25)	1958 radiation protection training programs.	06/09/2005	1
Oak Ridge Institute for Science and Education	Data validation for the Oak Ridge mortality study and chelation DTPA data for DOE employees.	08/06/2009	13
Oak Ridge Library for Dose Reconstruction	Environmental reports, incident reports, radioactive material releases, waste disposal analyses and periodic reports, internal dosimetry methods and procedures, operations reports, reactor reports and descriptions, Health Physics Division reports, radioactive effluent reports, RALA reports, hazards evaluations, radiation dosimetry computer codes, assays of dissolver solutions, researcher notebooks, and 1946 air monitoring procedures.	08/15/2011	870
Oak Ridge Public Library	Histories, photographs, public affairs articles, and procedures.	11/18/2010	10
ORAU Team	Technical basis documents, annual DOE radiation exposure reports, incident reports, ORAU Team Technical Information Bulletins, documented communications, ORNL dosimetry procedures, instrument evaluation summaries, and an evaluation of electret ionization chambers for alpha surface contamination screening.	07/10/2012	121

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
Paducah Gaseous Diffusion Plant	Radionuclide releases and reduction program, Np-237 contamination of magnesium fluoride, environmental reports, film badge calibrations, and the study of plutonium and fission products.	10/06/2006	12
R. S. Landauer	No relevant documents identified.	04/26/2012	0
Reactive Metals, Inc.	A compilation of radionuclide releases from DOE facilities as of 1987.	08/17/2006	1
Rocky Flats Plant	The 2003 Dose Reconstruction Project external dosimetry technical basis document.	09/24/2003	1
S. Cohen & Associates (SC&A)	Progress reports, documents from BWXT Y-12, recycle uranium report, trip reports, and an interview.	08/14/2009	43
SC&A / Idaho National Laboratory (INL)	Material transfer and accountability reports.	06/24/2010	109
SC&A / Los Alamos National Laboratory (LANL)	A 1948 LANL progress report detailing RALA discussions with ORNL.	06/24/2010	1
SC&A / Santa Susana Field Laboratory	A trip report from a 1967 tritium symposium.	06/24/2010	1
Sandia National Laboratories, New Mexico	Bioassay and whole body count data, health physics reports, Ross Aviation shipments, and shielding analysis for the Sandia Engineering Reactor Facility.	01/26/2012	47
Santa Susana Field Laboratory	A 1992 report questioning the adequacy of HEPA testing procedures at the High Flux Isotope Reactor.	12/19/2007	1
Savannah River Site	Dosimetry visitor cards with ORNL personnel, irradiations performed for ORNL, classified reports receiving logs, thorium processing, SRS progress reports, decontamination of the ORNL Separations Pilot Plant, material disposal, and thorium and U-233 accountability data.	03/19/2012	103
Science Applications International Corp (SAIC)	Radiation exposure summaries.	09/02/2004	9
Southern Illinois University, Edwardsville, IL	A history of ORNL classified activities, the 1969 isotope user's guide, thorium operations, St. Louis area radiological activities, Oak Ridge site description, transcript of Day Two, and the fifty-sixth meeting of the ABRWH.	10/29/2008	14
United States Enrichment Corporation	Radioactive waste threshold limit report review, an individual exposure history, and a U.S. Navy radioactive waste report.	10/06/2006	3
University of Colorado Norlin Library	AEC/ERDA workshops on neutron dosimetry and a cost/benefit study of a formal safety program.	04/10/2006	3
University of Iowa	ORNL's 2000 radiological survey of the Iowa Ordnance Plant.	07/01/2003	1
University of Rochester Radiation Safety Unit	Material transfers and neutron shielding for cyclotron targets.	09/26/2008	6
University of Tennessee Hodges Library	Health Physics and Health Department reports, internal dosimetry studies, training program and reports, histories, K.Z. Morgan lectures and presentations, procedures, incident reports, notices to employees, bioassay analyses, and area and personnel monitoring reports.	10/11/2011	386

Table A1-1: Data Capture Synopsis for ORNL (X-10)			
Data Capture Information	**General Description of Documents Captured**	**Date Completed**	**Uploaded To SRDB**
Unknown	Environmental program reports, site histories, procedures, health physics manual, radiation accident assessments, finding aids, a mortality study, environmental monitoring reports, contaminant releases, personnel monitoring procedures and reports, ORNL involvement with and surveys of other facilities, Health Physics Division reports, operational progress reports, personnel neutron dosimetry characterization, site surveys, site aerial survey, I-131 releases, summary of radioactive releases, and the 1973 Mancuso report.	02/10/2011	209
Westinghouse Site (United Nuclear Corporation), Hematite, MO	Material transfers, an ORNL citation regarding in vivo counting, and the ORNL Thorium Ceramics Data Manual.	04/09/2009	3
Wyeth Insurance	An American Cyanamid article citing the development of the INL chemical recovery process at ORNL.	02/29/2008	1
Y-12	Neutron spectra and dosimetry, enriched uranium urinalysis procedures, Y-12 radiation protection standards, 86 inch cyclotron run sheets, and efficiency calibrations in the Mobile Body Counter.	03/30/2011	23
Y-12 / ORNL	Plutonium, uranium, polonium, and tritium urinalysis reports, health physics reports, and high bioassay investigations.	05/14/2012	222
Y-12 / SC&A	Medical examination reports, environmental data, radiation exposure data, and Y-12 specifications for recycle material transfers.	07/28/2010	4
TOTAL			**6,992**

Table A1-2: Databases Searched for ORNL (X-10)			
Database/Source	**Keywords / Phrases**	**Hits**	**Selected**
NOTE: Database search terms employed for each of the databases listed below are available in the Excel file called "Oak Ridge National Laboratory, Rev 01 (83.13) 07-30-12"			
Defense Technical Information Center (DTIC) https://www.dtic.mil/ COMPLETED 09/06/2011	See Note above	6,989	28
DOE CEDR https://www.orau.gov/cedr COMPLETED 12/05/2011	See Note above	57	1
DOE Hanford DDRS http://www2.hanford.gov/declass/ COMPLETED 02/17/2010	See Note above	0	0
DOE NNSA - Nevada Site Office www.nv.doe.gov/main/search.htm COMPLETED 02/17/2010	See Note above	12,568	1
DOE OpenNet http://www.osti.gov/opennet/advancedsearch.jsp COMPLETED 08/20/2010	See Note above	5,676	5
DOE OSTI Energy Citations http://www.osti.gov/energycitations/ COMPLETED 08/20/2010	See Note above	92	0
DOE OSTI Information Bridge http://www.osti.gov/bridge/advancedsearch.jsp COMPLETED 08/20/2010	See Note above	79,762	30
Google http://www.google.com COMPLETED 02/17/2010	See Note above	129,329,043	234
HP Journal http://journals.lww.com/health-physics/pages/default.aspx COMPLETED 12/05/2011	See Note above	613	6
Journal of Occupational and Environmental Health http://www.ijoeh.com/index.php/ijoeh COMPLETED 12/05/2011	See Note above	7	2

Table A1-2: Databases Searched for ORNL (X-10)			
Database/Source	**Keywords / Phrases**	**Hits**	**Selected**
National Academies Press http://www.nap.edu/ COMPLETED 02/17/2010	See Note above	513	0
NRC ADAMS Reading Room http://www.nrc.gov/reading-rm/adams/web-based.html COMPLETED 08/26/2010	See Note above	11,183	21
U.S. Transuranium & Uranium Registries http://www.ustur.wsu.edu/ COMPLETED 02/17/2010	See Note above	22	0

Table A1-3: DTIC Documents Requested for ORNL (X-10)			
Document Number	**Document Title**	**Requested Date**	**Received Date**
ORNL-1277? Ref ID: 13233	Nuclear Health Physics Dated 6/12/1952	12/02/2011	01/19/2012
ORNL-989	Biological Effects of Radiation Dated 8/10/1951	12/02/2011	NA - Could not locate
ORNL-66	Power Pile Division Quarterly Report For March, April, May 1948 Dated 6/8/1948	12/02/2011	NA - Cannot obtain; document is confidential

Table A1-4: Interlibrary Loan Documents Requested for ORNL (X-10)			
Document Number	**Document Title**	**Requested Date**	**Received Date**
NA Ref ID: 109315	Alpha-Gamma-Neutron Facilities papers presented at Hot Laboratory Symposium of the American Nuclear Society National Meeting, November 26-28, 1962	02/06/2012	02/06/2012
NA Ref ID: 109320	Transuranium Elements papers presented at the American Nuclear Society National Meeting, June 18-21, 1962	02/06/2012	02/06/2012
NA Ref ID: 109318	Performance of Mechanical Equipment for Dejacketing Spent SRE Core 1 Fuel presented at the American Nuclear Society National Meeting, November 26-28, 1962	02/06/2012	02/06/2012
NA Ref ID: 106142	Task- and Time-Dependent Weighting Factors in a Retrospective Exposure Assessment of Chemical Laboratory Workers; Journal of Occupational and Environmental Hygiene, 2007, Volume 4(2):71-79	12/05/2011	12/28/2011
NA Ref ID: 104937	Action Levels for Radiation Control at Oak Ridge National Laboratory; American Industrial Hygiene Association Journal, 1965, Volume 26(2):165-171	12/05/2011	12/06/2011
NA Ref ID: 101466	The Application of External and Internal Radiation Exposure Limits from American Industrial Hygiene Association Quarterly Vol. 16:307-323 Dated December 1955	08/29/2011	09/06/2011
NA Ref ID: 100982	High Resolution Automatic Beta Spectrometer from Review of Scientific Instruments Vol. 26:959-962 Dated October 1955	08/29/2011	08/30/2011
NA Ref ID: 100981	Developments in Internal Dose Determinations from Nucleonics Vol. 12(6):32-39 Dated June 1954	08/29/2011	08/30/2011
ORNL-547 Ref ID: 92980	Neutron Monitoring by Means of Nuclear Track Film (NTA)	02/25/2011	02/25/2011

Table A1-5: OSTI Documents Requested for ORNL (X-10)			
Document Number	**Document Title**	**Requested Date**	**Received Date**
ORNL-3225	Preparation and Fabrication of ThO2 Fuels Dated June 5, 1962 by D. E. Ferguson, et al.	02/16/2012	
ORNL-3385	Status and Progress Report for Thorium Fuel Cycle Development for Period Ending December 1962 dated June 1963 by D. E. Ferguson, et al.	02/16/2012	
ORNL-390 Ref ID: 105444	Activation Analysis of the Rare Earths Dated 11/30/1949	12/02/2011	12/12/2011
ORNL-1155 Ref ID: 105442	Monitoring of Liquids for Radioactivity Dated 3/11/1952	12/02/2011	12/12/2011
AECD-2996, ORNL-732 Ref ID: 105443	Decontamination And Corrosion Resistance Properties Of Selected Laboratory Surfaces Dated January 1951	12/02/2011	12/12/2011
CF-51-3-78(Del) Ref ID: 110829	A Survey of Homogeneous Reactor Chemical Processing	11/22/2011	06/01/2012
ORNL/TM-6429 Ref ID: 109997	Alternate Fuel Cycle Technologies/Thorium Fuel Cycle Technology Programs. Quarterly Report for Period 1 April--30 June 1978	11/22/2011	03/09/2012
DOE/HTGR-86-062; ORNL/TM-10056 Ref ID: 110827	Application of ENDF Data to the AVR Reactor with Highly Enriched Uranium Fuel and Thorium Feed	11/22/2011	03/26/2012
ORNL/TM-7089 Ref ID: 110001	Consolidated Fuel Reprocessing Program. Progress Report, July 1-September 30, 1979	11/22/2011	03/09/2012
ORNL/TM-7536 Ref ID: 110813	Evaluation of Alternate Extractants to Tributyl Phosphate. Phase I	11/22/2011	03/26/2012
ORNL/TM-6953 Ref ID: 110825	Summary of the Radiological Assessment of the Fuel Cycle for a Thorium-Uranium Carbide-Fueled Fast Breeder Reactor	11/22/2011	03/26/2012
ORNL/TM-7108 Ref ID: 110002	Thorex Solvent Extraction Studies with Irradiated HTGR Fuel: Series I	11/22/2011	03/09/2012
ORNL/TM-6719 Ref ID: 110000	Consolidated Fuel Reprocessing Program. Progress Report, October 1--December 31, 1978	11/22/2011	03/09/2012
ORNL-4278 Ref ID: 94817	Safety Analysis for the Thorium-Uranium Recycle Facility	11/22/2011	11/29/2011
ORNL/TM-12720 Ref ID: 22706	Historical and Programmatic Overview of Building 3019	11/22/2011	11/29/2011

Table A1-5: OSTI Documents Requested for ORNL (X-10)			
Document Number	**Document Title**	**Requested Date**	**Received Date**
AECU-817 Ref ID: 77415	Lecture Notes Health Physics Training Lectures, 1948-1949	11/30/2009	12/18/2009
ORNL-TM-2334 Ref ID: 77086	Radiation Survey and Dosimeter Intercomparison Study at the Health Physics Research Reactor, 1968	8/18/2009	10/06/2009