SEC Petition Evaluation Report
Petition SEC-00084

Report Rev #: 0

Report Submittal Date: September 25, 2007

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Site Expert(s):	NA

Petition Administrative Summary			
Petition Under Evaluation			
Petition #	Petition Type	Petition B Qualification Date	DOE/AWE Facility Name
SEC-00084	83.13	April 4, 2007	Nevada Test Site (NTS)

Petitioner Class Definition
All employees of the Department of Energy or any DOE contractor or subcontractor who worked in any areas of the Nevada Test Site from January 1, 1963 through September 30, 1992.

Proposed Class Definition
All employees of the Department of Energy (DOE) or any DOE contractor or subcontractor who worked in any areas of the Nevada Test Site from January 1, 1963 through September 30, 1992.

Related Petition Summary Information			
SEC Petition Tracking #(s)	Petition Type	DOE/AWE Facility Name	Petition Status
NONE	N/A	N/A	N/A

Related Evaluation Report Information	
Report Title	DOE/AWE Facility Name
N/A	N/A

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Peer Review Completed By:	[Signature on file] *Mark R. Rolfes*	09/25/2007 *Date*
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Evaluation Report Summary: SEC-00084, Nevada Test Site (NTS)

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-00084, qualified on April 4, 2007, requested that NIOSH consider the following class: *All employees of the Department of Energy or any DOE contractor or subcontractor who worked in any areas of the Nevada Test Site from January 1, 1963 through September 30, 1992.*

NIOSH-Proposed Class Definition

Based on its research, NIOSH accepted the petitioner-requested class to define a single class of employees for which NIOSH can estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all employees of the Department of Energy (DOE) or any DOE contractor or subcontractor who worked in any areas of the Nevada Test Site from January 1, 1963 through September 30, 1992. The class was accepted for evaluation (see Section 3.0 below) because 1) documentation adequately supported the petition basis that radiation monitoring records for members of the proposed class may have been compromised by the efforts of workers to protect dosimetry badges from damage, and 2) multiple scientific or technical reports are believed to identify dosimetry and related information that are unavailable for estimating the radiation doses of employees covered by this petition. These bases warranted the evaluation of the proposed class for inclusion in the SEC.

The petitioners also indicated the petition was based on unmonitored, unrecorded, or inadequately monitored and recorded exposure incidents. The petition identifies eight of the ten “unexpected releases of radioactivity” as listed in the NTS Site Profile document as incidents. These eight incidents were specifically identified as having occurred during the period addressed by this petition. While these events have been studied historically and are well-documented sources of exposure, they are specifically excluded from the scope of the NTS Site Profile (ORAUT-TKBS-0008-6). While these events do not clearly qualify as incidents as defined by the program, the issue was deemed worthy of further examination during the evaluation of this petition.

Feasibility of Dose Reconstruction

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

Health Endangerment Determination

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

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SEC Petition Evaluation Report for SEC-00084

1.0 Purpose and Scope

This report evaluates the feasibility of reconstructing doses for all employees of the Department of Energy (DOE) or any DOE contractor or subcontractor who worked in any areas of the Nevada Test Site from January 1, 1963 through September 30, 1992. 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 Office of Compensation Analysis and Support's (OCAS) *Internal Procedures for the Evaluation of Special Exposure Cohort Petitions*, OCAS-PR-004.

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.[1]

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.*

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

[1] NIOSH dose reconstructions under EEOICPA are performed using the methods promulgated under 42 C.F.R. pt. 82 and the detailed implementation guidelines available at http://www.cdc.gov/niosh/ocas.

class or in combination with work days within the parameters established for other SEC classes (excluding aggregate work day requirements).

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 to 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.[2]

3.0 Petitioner-Requested Class/Basis & NIOSH-Proposed Class/Basis

Petition SEC-00084, qualified on April 4, 2007, requested that NIOSH consider the following class for addition to the SEC: *A Class member is any employee of the Department of Energy (DOE) or any DOE contractor or subcontractor during the period from January 1, 1963 through September 30, 1992, who was:*

(1) present during an underground nuclear test and/or performed a drillback, tunnel reentry, or cleanup work following such test at the Nevada Test Site (NTS)(without regard to the duration of employment);

(2) present at an event involving the venting of an underground test or during a planned or unplanned radiation release at NTS;

(3) present for tests or post-test activities related to the Nuclear Rocket Testing Program;

(4) assigned to work at Area 51 (or other classified program areas);

(5) employed at NTS in a job activity that was monitored for exposure to ionizing radiation or worked in a job activity that is or was comparable to a job that is, was, or should have been monitored for exposure to ionizing radiation at NTS, or in combination with work days with the parameters established for one or more other classes of employees in the Special Exposure Cohort (SEC).

Based on NIOSH's consultation call with one petitioner, the petitioners revised the original class definition to include: *all employees of the Department of Energy or any DOE contractor or subcontractor who worked in any areas of the Nevada Test Site from January 1, 1963 through September 30, 1992*.

The petitioners provided information and affidavit statements in support of their belief that accurate dose reconstruction is impossible for the Nevada Test Site (NTS) workers in question. NIOSH deemed the following information and affidavit statements sufficient to qualify SEC-00084 for evaluation:

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[2] 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 petition, submitted by two former workers and one survivor, proposes that it is impossible to adequately reconstruct the dose for members of the proposed class because exposures were unmonitored, unrecorded, or inadequately monitored (involving both incidents and routine practices). The petition contends that information necessary for adequate dose reconstruction is unavailable for the following reasons: 1) the strict confidentiality in which that information was held by the workers, 2) inadequate monitoring, 3) NIOSH lacks a method to estimate internal dose through 1967, 4) NIOSH does not account for hot particle doses, 5) exposure to radon is improperly estimated, 6) the presence of high-fired oxides resulting from atmospheric weapons testing has not been investigated, 7) DOE records used by NIOSH have not been subject to verification and validation, 8) possible lost or destroyed NTS monitoring records, and 9) workers often (for various reasons) did not wear dosimetry badges.
>
> The petition included several affidavits asserting that the external monitoring program was circumvented by personnel deliberately removing their badges in radiological control areas in efforts to comply with supervisory instructions. Additionally, affidavits were provided stating that monitoring records that should exist, do not exist.

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.

Based on its research, NIOSH accepted the petitioner-requested class as defining a single class of employees for which NIOSH can estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all employees of the Department of Energy or any DOE contractor or subcontractor who worked in any areas of the Nevada Test Site from January 1, 1963 through September 30, 1992.

4.0 Data Sources Reviewed by NIOSH

NIOSH identified and reviewed numerous data sources to determine information relevant to determining the feasibility of dose reconstruction for the class of employees proposed for this petition. 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 and 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 NTS operations or related topics/operations at other sites:

- *Technical Basis Document for the Nevada Test Site – Introduction*, ORAUT-TKBS-0008-1; Rev. 00 PC-1; July 20, 2006; SRDB Ref ID: 29994

- *Technical Basis Document for the Nevada Test Site – Site Description*, ORAUT-TKBS-0008-2; Rev. 00; February 02, 2004; SRDB Ref ID: 19793

- *Technical Basis Document for the Nevada Test Site – Occupational Medical Dose*, ORAUT-TKBS-0008-3; Rev. 01; June 22, 2007; SRDB Ref ID: 19794

- *Technical Basis Document for the Nevada Test Site – Occupational Environmental Dose*, ORAUT-TKBS-0008-4; Rev. 00 PC-1; December 08, 2006; SRDB Ref ID: 29995

- *Technical Basis Document for the Nevada Test Site – Occupational Internal Dose*, ORAUT-TKBS-0008-5; Rev. 00 PC-1; July 20, 2006; SRDB Ref ID: 29996

- *Technical Basis Document for the Nevada Test Site – Occupational External Dose*, ORAUT-TKBS-0008-6; Rev. 01; July 30, 2007; SRDB Ref ID: 34013

- *Lawrence Livermore National Laboratory – Occupational Internal Dose,* ORAUT-TKBS-0035-5; Rev. 01 C; July 09, 2007; SRDB Ref ID: 19558

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 and procedures as part of its evaluation:

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

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

- OTIB: *Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace*, ORAUT-OTIB-0014, Rev. 00; June 22, 2004; SRDB Ref ID: 19432

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

- OTIB: *Internal Dose Overestimates for Facilities with Air Sampling Programs*, ORAUT-OTIB-0018, Rev. 01; August 09, 2005; SRDB Ref ID: 19436

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

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

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

4.3 Facility Employees, Survivors, and Experts

To obtain additional information, NIOSH interviewed former NTS employees and survivors of former employees. Interviewee selection was based on the availability to be interviewed, as well as information regarding job description and potential knowledge of hazard conditions at NTS. Whereas considerable information regarding the radiation protection program has previously been collected from Radiation Protection and Safety personnel, the emphasis on selection of interviewees was on trades personnel, security staff, and administrative personnel. The interviews ultimately included employees and survivors representing a wide range of NTS experiences. Information obtained during the interviews contributed to the general knowledge of NTS conditions and monitoring practices and included information regarding records from Area 12 for the period 1970-1995 that were collected and buried in a site landfill. These records included: time records, mine rescue records, sign in/sign out records, logbooks, incident/accident reports – Form 1250, injury reports, personnel rosters, and safety meeting records.

- Personal Communication, 2005, *Personal Communication with [Names Redacted]*; July 22, 2005; SRDB Ref ID: Not currently assigned

- Personal Communication, 2007a, *Personal Communication with a Security Officer*; Telephone Interview by B. Murray and C. Miles; 1100 EDT July 16, 2007; SRDB Ref ID: 34046

- Personal Communication, 2007b, *Personal Communication with a Tunnel Miner/Core Driller*; Telephone Interview by B. Murray and C. Miles; 1430 EDT July 16, 2007; SRDB Ref ID: 34051

- Personal Communication, 2007c, *Personal Communication with a former records manager/administrative/clerical supervisor for underground tests*; Telephone Interview by B. Murray and C. Miles; 1300 EDT July 18, 2007; SRDB Ref ID: 34049

- Personal Communication, 2007d, *Personal Communication with the survivor of a Nuclear Rocket Development Station employee*; Telephone Interview by B. Murray and C. Miles; 1200 EDT July 18, 2007; SRDB Ref ID: 34052

- Personal Communication, 2007e, *Personal Communication with a construction support employee*; Telephone Interview by B. Murray and C. Miles; 1400 EDT July 18, 2007; SRDB Ref ID: 34074

- Personal Communication, 2007f, *Personal Communication with two survivors of a test engineer*; Telephone Interview by B. Murray and C. Miles; 1600 EDT July 18, 2007; SRDB Ref ID: 34035
- Personal Communication, 2007g, *Personal Communication with a custodial employee/shaft miner*; Telephone Interview by B. Murray and C. Miles; 1130 EDT July 19, 2007; SRDB Ref ID: 34038
- Personal Communication, 2007h, *Personal Communication with a plumber/pipefitter*; Telephone Interview by B. Murray and C. Miles; 1200 EDT July 23, 2007; SRDB Ref ID: 34034
- Personal Communication, 2007i, *Personal Communication with a Security Officer*; Telephone Interview by B. Murray and C. Miles; 1330 EDT July 23, 2007; SRDB Ref ID: 34037
- Personal Communication, 2007j, *Personal Communication with an AEC Health Physicist*; email correspondence to B. Murray and C. Miles; July 25, 2007; SRDB Ref ID: 34036
- Personal Communication, 2007k, *Personal Communication with a Health Physicist*; Telephone Interview by B. Murray and C. Miles; 1100 EDT July 25, 2007; SRDB Ref ID: 34039
- Personal Communication, 2007l, *Personal Communication with a Health Physicist*; Telephone Interview by B. Murray and C. Miles; 1230 EDT July 25, 2007; SRDB Ref ID: 34044
- Personal Communication, 2007m, *Personal Communication with a Radiological Control Technician*; Telephone Interview by B. Murray and C. Miles; 1400 EDT August 06, 2007; SRDB Ref ID: 34064
- Personal Communication, 2007n, *Personal Communication with an Operating Engineer*; Telephone Interview by B. Murray and C. Miles; 0900 EDT August 10, 2007; SRDB Ref ID: 34065

4.4 Previous Dose Reconstructions

NIOSH reviewed its NIOSH OCAS Claims Tracking System (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 for the period of January 1, 1963 through September 30, 1992. (NOCTS data available as of August 14, 2007)

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

(January 1, 1963 through September 30, 1992)

Description	Totals
Total number of claims submitted for energy employees of NTS	1494
Number of dose reconstructions submitted for energy employees who were employed during the years identified in the proposed class definition	1352
Number of claims for which internal dosimetry records were obtained for the identified years in the proposed class definition	443
Number of claims for which external dosimetry records were obtained for the identified years in the proposed class definition	1339

NIOSH reviewed each claim to determine whether internal and/or external personal monitoring records could be obtained for the employee. Of the total number of claims submitted for energy employees who were employed during the years identified in the proposed class definition (1352), approximately one third (32.8%) have internal monitoring data available and 99% have external monitoring data available. As of August 14, 2007, eighteen (18) claims had not received a response from DOE for exposure records.

4.5 NIOSH Site Research Database

NIOSH also examined its Site Research Database (SRDB) to locate documents supporting the evaluation of the proposed class. Eight hundred and fifty (850) documents in this database were identified as pertaining to NTS. These documents were evaluated for their relevance to this petition. The documents include historical background on dosimetry monitoring and procedures, air sampling, soil sampling, the radiation safety program, radiation studies, access control/re-entry requirements, and operational requirements for various areas/operations. Also included are logs, radiation safety reports, general safety reports, environmental reports and studies, operations manuals, and survey documentation.

4.6 Documentation and/or Affidavits Provided by Petitioners

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

Ten affidavits, seven from workers and three from survivors:

- *Affidavit from Former Laborer/Labor Foreman*, Attachment 4; January 10, 2007; OSA Ref ID: 102555

- *Affidavit from Former Driller/Drill Supervisor/Project Manager of Drilling*, Attachment 5; January 17, 2007; OSA Ref ID: 102556

- *Affidavit from Former Foreman/Pipe-fitter/Welder*, Attachment 6; January 10, 2006; OSA Ref ID: 102557

- *Affidavit from Former Union President*, Attachment 7; January 29, 2007; OSA Ref ID: 102558

- *Affidavit from Survivor*, Attachment 10; January 18, 2007; OSA Ref ID: 102541

- *Affidavit from Former Carpenter's Apprentice/Carpenter/Welder*, Attachment 11; January 31, 2007; OSA Ref ID: 102542

- *Affidavit from Former Driller*, Attachment 12; January 31, 2007; OSA Ref ID: 102543

- *Affidavit from Survivor*, Attachment 13; January 26, 2007; OSA Ref ID: 102544

- *Affidavit from Survivor*, Attachment 14; January 30, 2007; OSA Ref ID: 102561

- *Affidavit from Former Welder*, Attachment 15; January 31, 2007; OSA Ref ID: 102792

Thirteen miscellaneous documents provided as attachments, including scientific reports, journal articles, email correspondence, and one newspaper article:

- *Nevada Test Site—Review of Medical Surveillance, Summary of Radiation Exposure Date Analyses, Summary of Worker Demographics and Work History Information on Radiation Hazards,* Attachment 1, various documents; Uploaded on February 6, 2007; OSA Ref ID: 102540

- *NIOSH Responses to SC&A Comments: Draft Review of the NIOSH Site Profile for the Nevada Test Site,* SCA-TR-TASK1-0006, Attachment 2; December 31, 2005; OSA Ref ID:102554

- *Email Correspondence Regarding SC&A Findings on the NTS Site Profile,* Attachment 8; February 23, 2006; OSA Ref ID: 102559

- *The Resuspension Pathway for Nevada Test Site Workers*, Rev. 03, Attachment 9, Lynn Anspaugh, SC&A; October 8, 2006; OSA Ref ID: 102560

- *Test Site Workers' Records Dumped*, Attachment 16; Keith Rogers, Las Vegas Review-Journal (Nevada); September 25, 2006; OSA Ref ID: 102545

- *Movement of Radionuclides in Terrestrial Ecosystems by Physical Processes,* Attachment 17; Lynn Anspaugh, Steven Simon, Gordeev Konstantin, Ilya Likhtarey, Reed Maxwell, and Sergei Shinkarev, Health Physics Vol. 82, No. 5; May 2002; OSA Ref ID: 102546

- *Technical Basis for Dose Reconstruction,* Attachment 18, Lynn Anspaugh; January 31, 1996; OSA Ref ID: 102547

- *Introduction to Section II and Overview of Dose Reconstruction; Lessons Learned from Studies in the U.S.*, Attachment 19, Lynn R. Anspaugh; January 1997; OSA Ref ID: 102548

- *A Comprehensive Dose Reconstruction Methodology for Former Rocketdyne/Atomics International Radiation Workers,* Attachment 20, John Boice, Richard Leggett, Elizabeth Ellis, Phillip Wallace, Michael Mumma, Sarah Cohen, Bertrand Brill, Bandana Chadda, Bruce Boecker, Craig Yoder, and Keith Eckerman, Health Physics Vol. 90, No. 5; May 2006; OSA Ref ID: 102549

- *Risk Assessment of Soil-Based Exposures to Plutonium at Experimental Sites Located on the Nevada Test Site and Adjoining Areas,* Attachment 21; David Layton, Lynn Anspaugh, Kenneth Bogen, and Tore Straume; June 1993; OSA Ref ID: 102550

- *Iodine-131 Fallout from Underground Tests,* Attachment 22, E. A. Martell, Science Vol. 143, No. 3602; January 10, 1964; OSA Ref ID: 102551

- *Radionuclides in Surface Soil at the Nevada Test Site,* Attachment 23; Richard McArthur; August 1991; OSA Ref ID: 102552

- *Performance Evaluation of LANL Environmental Radiological Air Monitoring Inlets at High Wind Velocities Associated with Resuspension*, Attachment 24, John Rodgers, Piotr Wasiolek, Jeff Whicker, Craig Eberhart, Keith Saxton, and David Chandler; no date; OSA Ref ID: 102553

5.0 Radiological Operations Relevant to the Proposed Class

The following subsections summarize both radiological operations at NTS from January 1951 (start of operations) through the end of testing in 1992 and the information available to NIOSH to characterize particular processes and radioactive source materials. From available sources NIOSH has gathered process and source descriptions, information regarding the identity and quantities of each radionuclide of concern, and information describing both 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 NTS Plant and Process Descriptions

The Nevada Test Site is located in Nye County in southern Nevada, about 65 miles northwest of Las Vegas and currently encompasses approximately 3,500 km^2 (1375 mi^2). The site was established in 1951 and was the primary location for testing nuclear explosives in the continental United States between 1951 and 1992. The primary missions of NTS included atmospheric and underground nuclear testing, underground nuclear testing, safety testing, research into nuclear reactor and nuclear rocket development, Project Plowshare operations to explore peaceful uses of nuclear detonations, and waste management operations (ORAUT-TKBS-0008-1). The NTS activities were unique and distinct from other DOE facilities in that they were experimental trials conducted in unique environments. The testing was strictly overseen, controlled, and monitored by a highly qualified staff of professional scientists, health and safety personnel, and support staff. The planning and preparation for each test was extensive.

Aboveground nuclear weapons tests began on January 27, 1951. In addition to air drops, atmospheric testing included detonations from towers, detonations on the surface of the ground, and the use of helium-filled balloons to loft weapons above the ground. More than 100 atmospheric tests were conducted before the signing of the Limited Test Ban Treaty in August 1963. The Atmospheric Weapons Testing era at NTS has previously been evaluated and a class of workers at NTS during the January 27, 1951 through December 31, 1962 timeframe has previously been included in the Special Exposure Cohort (ORAUT-TKBS-0008-1).

Since 1963, the United States has conducted all of its nuclear weapons tests underground in accordance with the terms of the Limited Test Ban Treaty. The final atmospheric tests at NTS were in July 1962. Complete containment of all nuclear weapons tests was a primary goal and a dominant consideration in nuclear test operations (ORAUT-TKBS-0008-1).

Post-test drilling of the cavity formed after a detonation in a vertical drill hole was performed to retrieve debris samples, often within a day or two of the detonation. Reentry and mine-back operations related to tests in mined tunnels usually took place within days or weeks of a test. These operations took place in a confined underground environment where personnel entered the test tunnel and excavated up to the experiment chambers (ORAUT-TKBS-0008-1).

Safety tests evaluated the safety of nuclear weapons in accident scenarios. The safety tests used plutonium, uranium, or mixtures of the two, dispersed by conventional explosives. Concurrent with and after these detonations, extensive studies were conducted to understand the dispersal and transport of these radionuclides in the environment, including uptake by plants and animals (ORAUT-TKBS-0008-1).

From 1959 to 1973, the Nuclear Rocket Development Station in Area 25 was used for a series of open-air nuclear reactor, nuclear engine, and nuclear furnace tests and for the High Energy Neutron Reactions Experiment. The goal of the Nuclear Rocket Engine Test program was to develop an operational nuclear rocket for space travel. Engine exhaust dispersed radioactive material from the core and cladding degraded during operation of the engine (ORAUT-TKBS-0008-1).

Shallow borehole tests occurred between 1960 and 1968. Some of theses tests were related to safety studies and others were part of Project PLOWSHARE—to determine if nuclear detonations could be used as a method for excavation. The shallow tests resulted in some large ejection craters (ORAUT-TKBS-0008-1).

NTS has radioactive waste management activities in Areas 3 and 5. DOE disposes of bulk low-level waste in seven selected Area 3 subsidence craters that collectively comprise the Area 3 Radioactive Waste Management Site. This disposal began in the mid-1960s when DOE began removing scrap tower steel, vehicles, and other large objects that had been subjected to atmospheric testing. From 1979 to 1990, large amounts of contaminated soil and other NTS debris were added to the craters. The Area 5 waste management site uses pits and trenches for shallow land burial of low-level waste in standardized packaging (ORAUT-TKBS-0008-1).

DOE adopted greater confinement burial (21 to 40 meters [70 to 120 feet] deep) for wastes that are not appropriate for near-surface disposal due to their radioactive exposure levels. Material was disposed from 1984 to 1989. The specific waste types included certain high-specific-activity, low-level waste (for example, fuel rod claddings and sealed sources, transuranic waste, and some classified material) (ORAUT-TKBS-0008-1).

Table 5-1 summarizes the site activities.

Table 5-1: NTS Development/Activities

Years	Areas	Comments
1951 - 1962	1, 2, 3, 4, 5, 7, 8, 9, 11, 13, 18, Tonopah Test Range	Approximately 106 atmospheric tests were conducted, several of which resulted in radioactive fallout detected in other areas, including outside NTS boundaries
1951 - 1992	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 16, 18, 19, 20, 30, Tonopah Test Range	Approximately 835 underground tests were conducted, including cratering experiments, borehole tests, and tunnel tests; several underground tests resulted in unplanned atmospheric radioactive releases
1951 - Present	Various	Numerous tests and research projects have been conducted across NTS, including: conventional explosives testing, nuclear reactor development tests, radioactive waste disposal, radioactivity dispersal experiments, emergency response training exercises, and nuclear rocket propulsion experiments

5.2 NTS Functions

Nevada Test Site operations included the following discrete functions:

- Atmospheric weapons testing

- Safety testing

- Big explosives experiments

- Underground testing
  - Tests in vertical drill holes
  - Tests in mined tunnels
  - Routine tunnel operations

- Nuclear reactor development testing

- Shallow borehole testing

- Waste disposal
  - Crater disposal—Area 3 Radioactive Waste Management Site
  - Shallow land burial—Area 5 Low-Level Radioactive Waste Management Site
  - Greater confinement disposal—Area 5 Radioactive Waste Management Site

- U1a Underground Complex

- Analytical laboratory, research, and support activities

Additional information regarding the areas and activities of NTS can also be found in ORAUT-TKBS-0008-2.

5.2.1 Atmospheric Weapons Testing

U.S. aboveground nuclear weapons tests began on January 27, 1951, with the detonation of a 1-kiloton (kt) air-dropped weapon over Frenchman Flat. More than 100 atmospheric tests occurred before the signing of the Limited Test Ban Treaty in August 1963.

Radioactivity from atmospheric tests was dispersed by three primary mechanisms: throwout, base surge, and fallout. Typical radionuclides formed during atmospheric testing included isotopes of strontium, cesium, barium, tritium, and iodine. Of these, strontium-90 and cesium-137 are of the most concern because of their longer half-lives of 28 and 29 years, respectively (ORAUT-TKBS-0008-2).

5.2.2 Safety Testing

Safety tests evaluated the safety of nuclear weapons in accident scenarios. The safety tests involved plutonium, uranium, or mixtures of the two, dispersed by conventional explosives. Extensive studies were conducted, concurrent with and after these detonations, to understand the dispersal and transport of these radionuclides in the environment. These studies were documented in a benchmark series of papers by the Nevada Applied Ecology Group, a panel of scientists chartered to investigate the effects of testing at NTS. As a result of the safety tests, the primary radionuclide contaminants at NTS are plutonium, uranium, and americium, with lesser amounts of cesium, strontium, and europium (ORAUT-TKBS-0008-2). Extensive research into the mobility of radionuclides has found that wind can transport such contaminants and concentrate them in mounds around desert shrubs and that water can cause plutonium to migrate deeper into the soil over time. At present, the radionuclides are relatively immobile unless the soil is disturbed. Evidence of "wind-driven" contamination is low. Heat of initial blast, soil bonding and weathering, and rockiness of native soil prevent deep migration (Allen, 1995).

5.2.3 Big Explosive Experiments

The Big Explosives Experimental Facility is in north-central Area 4 of NTS. The area contains seven underground structures previously associated with atmospheric testing; one set of unidentified stanchions that might have been associated with atmospheric testing; the BREN Tower foundations and stanchions; and the Japanese Village complex. The area also has the U-4ad drill hole and drill sump, the U-4af exclusion zone, and a white silicified volcanic core reduction flake. Most of these structures were abandoned as atmospheric testing ended. Two of the buried structures, Bunkers 4-300 and 4-480, have been modified to accommodate modern hydrodiagnostic equipment to serve as a hydrodynamic test facility for detonations of very large conventional high explosive charges and devices. Some detonations at the Big Explosives Experimental Facility involved depleted uranium (ORAUT-TKBS-0008-2).

5.2.4 Underground Testing

Since 1963, the United States has conducted all of its nuclear weapons tests underground in accordance with the terms of the Limited Test Ban Treaty. Complete containment of all nuclear weapons tests was a dominant criterion in the test design for nuclear test operations. Various methods were used for emplacing nuclear test devices to contain the explosion. The most common method was to place a test device at the bottom of a vertical drill hole. Another method was to place a test device in a tunnel mined horizontally to a location sufficiently deep to provide containment. There were two types of tests in vertical drill holes: lower-yield devices in relatively shallow holes in the Yucca Flats area (Areas 1 through 10) and higher-yield devices in deeper holes on Pahute Mesa (Areas 18 through 20) (ORAUT-TKBS-0008-2).

The following paragraphs describe processes associated with nuclear weapons tests in vertical drill holes and mined tunnels.

5.2.4.1 Tests in Vertical Drill Holes

There were two types of tests in vertical drill holes: lower-yield devices in relatively shallow holes in the Yucca Flat area (Areas 1 through 10) and higher-yield devices in deeper holes on Pahute Mesa (Areas 18, 19, and 20). Tests at the Yucca Flat and Pahute Mesa sites had the same general requirements, but differed in the magnitude of the operations. Post-test drilling of the cavity formed after a detonation in a vertical drill hole was performed to retrieve debris samples. The post-test hole was as small in diameter as possible and was drilled at an angle to allow the drill rig to be positioned safely away from the surface at ground zero. It was possible to encounter high gas pressures in the cavity because the drillback was often performed within a day or two of the detonation (ORAUT-TKBS-0008-2). A procedure known as gas blocking was applied to control this type of pressure release.

5.2.4.2 Tests in Mined Tunnels

Tunnel tests evaluated the effects of nuclear weapons explosions, thermal radiation, blast, shock, X-rays, and gamma rays on military hardware, such as communication equipment, rocket nosecones, and satellites. A number of tunnels have been mined into Rainier Mesa, in which most Department of Defense horizontal-line-of sight exposure experiments occurred. In particular, the N-, P-, and T-Tunnel complexes were extensively developed during the past several decades. The Department of Defense currently operates a high explosives research and development tunnel in Area 12.

Of the 61 underground nuclear tests in Area 12 between late 1957 and 1992, only two were in drilled holes, the 59 other tests were in mined tunnels. By the early 1990s there was only one active tunnel in use (ORAUT-TKBS-0008-2).

5.2.4.3 Routine Tunnel Operations

Routine tunnel operations included the potential for personnel exposure to fission or activation products from previously conducted tests in the tunnel complex. These radioactive materials could also be carried by water, seeping through faults and fissures to reenter the working areas (Allen, 1995). Personal communication on September 12, 2007 with the former Health and Safety Manager of NTS indicated that Radiation Monitors conducted radiation surveys and air monitoring to evaluate the radiation conditions in the tunnel before allowing workers to enter for routine operations. The protocols required tunnels to be vented and air monitoring be conducted during routine tunnel operations.

Reentry and Mineback Operations—Reentry and mineback operations related to tests in mined tunnels usually took place within days or weeks of an underground test, but could be conducted at any time after a test. There were two exposure scenarios during reentry and minebacks. The first scenario was based on a loss of containment in the drilling or coring operation; this could occur during the routine drilling operations or be caused by a failure of containment equipment. The radionuclides of concern for this pathway were manganese-54, strontium-90, yttrium-90, ruthenium-103, rhodium-106, iodine-131, iodine-133, cesium-127, and tantalum-182 (Allen, 1995).

The second exposure scenario involved the possibility of fission or activation products entering the working areas of the tunnels by migrating through fissures in the rock, by escaping through line-of-sight pipes when they were opened to remove experiment equipment and samples. The radionuclides of exposure concern for this pathway were cobalt-60, antimony-124, iodine-131, iodine-133, and cesium-137 (Allen, 1995).

Radioactive Releases Resulting from Nuclear Weapons Testing—Containment of underground nuclear explosions was a process that continually evolved through learning, experimentation, and experience. Radioactive releases resulting from nuclear weapons testing included operational releases, late-time seeps, and controlled tunnel purging.

Operational releases were small releases of radioactivity resulting from the operational aspects of vertical drill-hole tests. Activities that often resulted in operational releases included drilling back down to the location of the explosion to collect core samples, collecting gas samples from the explosion, and sealing the drillback holes (OTA, 1989).

Late-time seeps were small releases that occurred days or weeks after a test, when gases diffused through pore spaces of the overlying rock and were drawn to the surface by decreases in atmospheric pressure.

Controlled tunnel purging was an intentional release of radioactive material for the purpose of recovering experimental equipment and ventilating test tunnels. During a controlled tunnel purging, gases from the tunnel were filtered, mixed with air to reduce the concentration, and released over time when weather conditions were favorable for dispersion into sparsely populated areas (OTA, 1989).

Successful containment was defined as no radioactivity detectable offsite and no unanticipated release of radioactivity onsite. By definition, there have been containment failures on four occasions since 1970 (OTA, 1989). Table 2-6 of ORAUT-TKBS-0008-2 includes every instance (for both announced and unannounced tests) where radioactive material reached the atmosphere under any circumstances whatsoever from 1971 through 1988. The bottom portion of Table 2-6 summarizes underground tests prior to 1971 and provides a comparison with other releases of radioactive material.

Operational Releases and Tunnel Purging—Past underground tests formed pockets of radioactive contamination around each underground test site. The source term includes many short- and long-lived radionuclides. For example, for atmospheric testing of a 1-kt nuclear weapon, an initial release of 41 billion Ci decays to about 10 million Ci in just 12 hours. The quantity of radioactivity remaining from a 1-kt underground detonation 180 days after detonation is about 45,000 Ci (including 18,570 Ci of tritium). However, there is considerable uncertainty concerning these estimates. For example, the actual tritium activity after 180 days could range from 5,570 to 55,770 Ci (ORAUT-TKBS-0008-2).

With regard to tunnel tests, purging gases from the tunnel occasionally resulted in releases of radioactivity, and contaminated water drained from the tunnels into containment ponds (Bechtel Nevada, 2002). While the tunnel complex was being secured prior to detonation of the nuclear device, the ventilation line was disconnected at each containment plug and the penetration through the plug was sealed. Thus, it was necessary to reenter the tunnel to reestablish ventilation through the various containment plugs. When radioactive gases were present in a portion of the complex, it became necessary to purge these gases from the tunnel. The major potential for release of radioactive materials to the atmosphere existed during these purging operations. The purging resulted in release of noble gases (krypton-85, krypton-85m, krypton-86, xenon-131m, xenon-133, xenon-133m, and xenon-135) and small quantities of iodine-131 and iodine-133. A release during this phase of the operation was typically of the order of 100 Ci or less of noble gases, with microcurie or millicurie quantities of radionuclides. Reentry drilling produced dust that was removed from the reentry heading by the tunnel ventilation system. This dust contained fission and activation products produced by neutron activation of the horizontal line-of-sight pipe. These releases were in the millicurie range (Black, 1995).

Unexpected Releases of Radioactivity—Although over 90% of all nuclear weapons tests occurred as predicted, sometimes the unexpected occurred. In some cases, the failure resulted in the loss of experimental equipment or required the controlled ventilation of a tunnel system to recover equipment. In even fewer cases (3%), the failure resulted in the unintentional release of radioactive material into the atmosphere. NTS testing was conducted as part of the scientific process of observing and determining the results of radioactive detonations bounded by particular conditions. NTS tests were thoroughly planned and monitored to achieve the necessary information that the test was designed to derive. Ten of these tests resulted in unexpected outcomes. Four of the ten tests resulted in the release of detectable levels of radioactivity off the NTS grounds: DES MOINES, June 13, 1962; BANEBERRY, December 18, 1970; DIAGONAL LINE, November 24, 1971; and RIOLA, September 25, 1980 (ORAUT-TKBS-0008-1).

5.2.5 Nuclear Reactor Development Testing

A number of activities occurred at the Nuclear Rocket Development Station in Area 25. From 1959 through 1973, Area 25 was used for a series of open-air nuclear reactor, nuclear engine, and nuclear furnace tests and for the High Energy Neutron Reactions Experiment. Equipment and facilities still remain from some of these activities, and there are some limited areas of contaminated soil. The total estimated inventory of radionuclides remaining in the soil in this area is about 1 Ci (ORAUT-TKBS-0008-2). The primary soil contaminants are enriched uranium, strontium, cesium, cobalt, and europium. Because of aging and weathering, these materials have become fairly fixed.

Total releases by all tests amounted to about 834,000 Ci (ORAUT-TKBS-0008-2). As noted previously, the radionuclides cobalt-60, strontium-90/yttrium-90, cesium-137, and europium-152 are primarily of concern for dose in this area. When entering into the rocket test areas, personnel wore whole-body thermoluminescent dosimeters (Allen, 1995).

5.2.6 Shallow Borehole Testing

Shallow borehole tests occurred between 1960 and 1968. Some of these tests were safety-related while others were conducted as part of Project PLOWSHARE to determine if nuclear detonations could be used as a method of excavation. The shallow tests resulted in the development of some large ejection craters, most notably the SEDAN crater in the northern end of the Yucca Flat testing area. SEDAN, a 104-kt nuclear device detonated 194 m (635 feet) underground, displaced about 1.2×10^7 tons of earth, and created a crater 390 m (1,280 feet) in diameter and 98 m (320 feet) deep. The estimated remaining inventory of surface radioactivity at the SEDAN crater is 344 Ci. The total estimate for all releases from shallow borehole tests to the surface soil horizon at NTS is 2,000 Ci. The radionuclides of concern resulting from shallow borehole tests include isotopes of americium, cesium, cobalt, europium, plutonium, and strontium (ORAUT-TKBS-0008-2).

5.2.7 Waste Disposal

The following paragraphs describe processes associated with crater disposal, shallow land burial, and greater confinement disposal.

5.2.7.1 Crater Disposal – Area 3 Radioactive Waste Management Site

DOE disposes of bulk low-level waste in seven selected Area 3 subsidence craters that, collectively, comprise the Area 3 Radioactive Waste Management Site. This activity began in the mid-1960s when DOE began removing scrap tower steel, vehicles, and other large objects that had been subjected to atmospheric testing. From 1979 to 1990, large amounts of contaminated soil and other NTS debris were added to the craters. As of 1996, approximately 1,250 Ci had been disposed of in the Area 3 subsidence craters (ORAUT-TKBS-0008-2).

Because the low-level Area 3 Radioactive Waste Management Site is located where the surrounding surface soil has been contaminated by past nuclear tests, the resuspension of this soil by wind or vehicular activity results in the detection of above-background levels of plutonium in air samples collected inside and outside the perimeter fence (Bechtel Nevada, 2002).

5.2.7.2 Shallow-Land Burial – Area 5 Low-Level Radioactive Waste Management Site

In 1961, the Area 5 Radioactive Waste Management Site was established for the shallow-land burial/disposal of standard packaged low-level waste, low-level mixed waste, and classified low-level waste from both on- and offsite generators. The category of low-level waste includes material that is "classified" because of its physical shape or specific composition. Classification creates a need for the use of separate disposal units that are controlled with additional security measures. The waste area at Area 5 consists of 23 landfill cells (pits and trenches), 13 greater confinement disposal boreholes, and the transuranic waste storage pad.

Approximately 500,000 Ci of low-level waste had been disposed of in Area 5 pits and trenches by 1996. High-specific-activity wastes were disposed of in the greater confinement disposal units (ORAUT-TKBS-0008-2).

5.2.7.3 Greater Confinement Disposal – Area 5 Radioactive Waste Management Site

NTS adopted greater confinement burial (21 to 40 m [70 to 120 feet] deep) for wastes that were not appropriate for near-surface disposal due to their radioactive exposure levels. Material was disposed of in these disposal units from 1984 to 1989. Specifically, these waste types include certain high-specific-activity, low-level waste (for example, fuel rod claddings and sealed sources), transuranic waste, and some classified material. The developed waste area in the Area 5 Radioactive Waste Management Site includes 13 greater confinement disposal boreholes.

As of 1996, approximately 9.3×10^6 Ci of high-specific-activity waste, primarily tritium, had been disposed of in greater confinement disposal units in Area 5 (ORAUT-TKBS-0008-2).

5.2.8 U1a Underground Complex

The U1a Complex is a mined underground complex in Area 1 that is available for dynamic experiments (including subcritical experiments involving special nuclear material) and hydrodynamic tests that cannot be conducted above the ground because they might contain hazardous materials. Initial work on the U1a Complex began in the late 1960s with the mining of the U1a shaft to a depth of 305 m (1,000 feet) for a nuclear test, but the shaft was not used. Further work took place in the

1980s and early 1990s to develop a complex that could be used to perform experiments likely to remain subcritical. The U1a Complex included a drilled hole (U1g) and connecting mined tunnels. The LEDOUX nuclear test, with a yield of less than 20 kts, was conducted in 1990 in a drift in this tunnel Complex. LEDOUX was contained to prevent radiological releases to the rest of the Complex and the surface environment (ORAUT-TKBS-0008-2).

5.2.9 Analytical Laboratory, Research, and Support Operations

Analytical laboratory, research, and support activities have been, and continue to be, conducted for various projects, which include:

- Containment ponds (tritium)
- Radiological Analysis Laboratories (samples containing tritium, radioiodines, or noble gases)—Mercury: Building 652; Area 6: Buildings CP-95A, CP-50, and the Device Assembly Facility
- Analytical Services Laboratory (tritium, krypton-85, and iodine-129)—Building 650
- Los Alamos National Laboratory (xenon-133, iodine-131, and tritium)—Mercury: Building 701
- Radiographic operations (iridium-192 and cobalt-60)
- Radiochemistry and Counting Laboratories (low-level radioactive sources used as tracers for instrument calibration)
- Contaminated surface soils (cesium, americium, plutonium, and/or tritium)
- Well-logging operations (cobalt-60, iodine-131, cesium-137, radium-226, thorium-228, americium-241, and francium-252)
- Treatability Test Facility—testing technologies to be used for soil decontamination (transuranic materials)
- Decontamination Facility (various radionuclides)
- Radiation Instrument Calibration Facilities (cobalt-60, strontium-90, yttrium-90, cesium-137, radium-226, thorium-227, thorium-228, americium-241, and plutonium-beryllium neutron sources)
- Radioactive Source Storage Areas (various sealed sources)

5.2.10 Summary of Key NTS Facilities

Table 5-1 summarizes key operations as well as the areas and dates of operation.

Table 5-1: Key NTS Areas, Operations, and Dates of Operation

Table 5-1 spans two pages.

Areas	Key Operations	Dates
1-10 and 18-20	**Drillback Operations:** A post-shot hole was usually drilled to the point of the explosion to retrieve debris samples. There was potential for exposure to gaseous and particulate fission and activation products including krypton-85, iodine-131, iodine-133, xenon-133m, and cesium-137 (Allen, 1995).	1961 - 1992
12	**Reentry and Mineback Operations:** After underground tests, a reentry crew was dispatched to the site to retrieve data and note the condition of equipment. Reentries had the potential to cause significant external and internal radiation exposures. The radionuclides of concern for reentry and mineback operations in the event of loss of containment include manganese-54, strontium-90, yttrium-90, ruthenium-103, rhodium-106, iodine-131, iodine-133, cesium-127, and tantalum-182 (Allen, 1995). Another radiation safety concern is the migration of fission or activation products cobalt-60, antimony-124, iodine-131, iodine-133, and cesium-137 into the working areas of the tunnels.	1957 - 1992
12	**Routine Tunnel Operations:** Routine tunnel operations potentially exposed personnel to fission or activation products that remained from tests conducted previously in the tunnel complex. Experience has shown that the external dose levels in routine tunnel work areas were very low. The principal radionuclides of external dose concern were the fission products strontium-90/yttrium-90 and cesium-137 (Allen, 1995).	1957 - 1992
6	**Decontamination Facility:** Equipment, materials, PPC, and devices used in nuclear weapons testing operations sometimes became contaminated with radioactive material and had to be decontaminated on location or were transported to the decontamination facility in Area 6.	1961 - 1992
25-26	**Nuclear Rocket Development:** This area was used for a series of open-air nuclear reactor, nuclear engine, and nuclear furnace tests and for the High Energy Neutron Reactions Experiment. The primary soil contaminants are enriched uranium, cobalt-60, strontium-90/yttrium-90, cesium-137, and europium-152.	1959 - 1973
27	**Device Assembly:** This is where nuclear devices were assembled and contained before delivery to the event site.	-
1-10, 12, and 18-20	**Experiment Emplacement:** The nuclear explosive and measurement devices were moved to the hole and lowered into the detonation position, along with diagnostic materials and instrumentation cables. The assembly was placed on a set of fracture-safe beams that spanned the opening. Any auxiliary equipment was lowered into the hole and the area was secured.	1961 - 1992
1 and 6	**Laboratories and Research and Support:** The U1a Complex is a mined underground complex in Area 1 that is available for dynamic experiments (including sub-critical experiments involving special nuclear material) and hydrodynamic tests that cannot be conducted above the ground because they might contain hazardous materials. Radiological analyses were conducted in laboratories in Building 652 (Mercury) and Building CP-95A, Building CP-50, and the Device Assembly Facility in Area 6.	-

Table 5-1: Key NTS Areas, Operations, and Dates of Operation

Table 5-1 spans two pages.

Areas	Key Operations	Dates
3 and 5	**Waste Management:** Areas 3 and 5 contain Radioactive Waste Management Site (RWMS) Areas for the disposal of low-level radioactive waste. Area 5 contains sites for storage of transuranic and mixed transuranic wastes, as well as the Greater Confinement Disposal Test Unit and 12 accompanying boreholes (only a few contain any waste). Disposal occurs in pits and trenches; concrete pads provide temporary storage of certain wastes. Area 5 is for packaged waste disposal only. The Waste Examination Facility (WEF) houses a HEPA-filtered glovebox used to examine and repack transuranic waste drums.	1961 - Present

Notes:
- Operations span the history of NTS; however, specific start dates are unknown

5.3 Radiological Exposure Sources from NTS Operations

The potential for both internal and external radiation exposure existed at NTS. While the primary materials associated with the testing at NTS were uranium and plutonium, there were significant exposure potentials to various fission and activation products. Due to the nature of operations at NTS (unlike most other DOE facilities, there was no uranium or plutonium production or machining at NTS), when NTS workers received an exposure, it was most likely to be an acute event exposure rather than long-term chronic doses.

After 1962, the United States conducted all of its nuclear weapons tests underground, in order to contain the explosion and the byproducts of the testing. Achieving full containment was a continually evolving process and various types of releases occurred throughout the program.

Although atmospheric weapons testing occurred at NTS prior to 1963, the longer-lived radionuclides that were deposited into the NTS environment as a result of the atmospheric weapons testing persisted into the period of evaluation and must be taken into account. Residual contamination for atmospheric testing is present in Areas 1, 2, 3, 4, 7, 8, 9, and 10 of NTS and on Buckboard Mesa in Area 18. All areas except Areas 22, 23, and 27 have some monitoring and restrictions as a result of these past tests (Allen, 1995). Area 22 includes the main entrance to NTS and a reserved zone providing a buffer between non-defense related research, development, and testing activities. Area 23 is also a reserved zone in the southeastern portion of NTS and containing Mercury, the largest operational support complex onsite. Area 27 is a Critical Assembly zone in the south central part of NTS principally occupied by assembly bays, storage magazines, storage magazines, and three radiography buildings. No nuclear explosive tests occurred in Area 27 (ORAUT-TKBS-0008-2, page 20). These areas were monitored and had no access restrictions resulting from contamination.

5.3.1 Alpha Particle Emissions

The primary alpha particle-emitting isotopes at NTS vary from area to area depending on the operations. Table 5-2 below lists the alpha-emitting radionuclides of concern for NTS.

Table 5-2: NTS Alpha-Emitting Radionuclides	
Isotope	**Major Radiation Energies (MeV)**
Actinium-227	4.95(1.2%), 4.86 (0.18 %)
Americium-241	5.49 (85%), 5.44 (13%)
Americium-243	5.28 (87%), 5.23 (11.5%)
Californium-252	6.12 (82%), 6.08 (15%)
Curium-244	5.81 (77%), 5.77 (23%)
Neptunium-237	4.78 (75%), 4.65 (12%)
Plutonium-238	5.50 (72%), 5.46 (28%)
Plutonium-239	5.16 (88%), 5.11 (11%)
Plutonium-240	5.17 (76%), 5.12 (24%)
Plutonium-241	4.90 (0.0019%) 4.85 (0.0003%)
Plutonium-242	4.90 (76%), 4.86 (24%)
Radium-226	4.78 (95%), 4.60 (6%)
Thorium-228	5.43 (71%), 5.34 (28%)
Thorium-230	4.68 (76%), 4.62 (24%)
Thorium-232	4.01 (76%), 3.95 (24%)
Uranium-233	4.82 (83%), 4.78 (15%)
Uranium-234	4.77 (72%), 4.72 (28%)
Uranium-235	4.58 (8%), 4.4 (57%), 4.37 (18%)
Uranium-238	4.20 (75%), 4.15 (25%)

5.3.2 Beta Radiation Fields

There are about 90 possible fission fragments resulting from nuclear fission. These 90 fragments decay through three stages, on average, to yield a total of about 250 individual fission-produced radionuclides, most of which are beta particle emitters. Many of these beta-emitting fission product radionuclides have very short half-lives – on the order of a few seconds or less – and quickly decay into other nuclides; thus, they were not a direct source of exposure to the proposed class. Beta emission occurs over a distribution of energies ranging from zero to a maximum value; that maximum value is commonly used to characterize the spectrum. Table 5-3 below lists the isotopes of concern at NTS. The maximum energy is indicated in the right column. Where there is a second significant, higher energy range that also occurs as a result of the decay of the isotope, it is indicated in the chart, along with the fraction. The average energy of a beta spectrum is typically about one-third of the maximum energy.

Table 5-3: NTS Beta-Emitting Radionuclides *Table 5-3 spans two pages.*	
Isotope	**Major Radiation Energies (MeV)**
Actinium-227	0.046
Barium-140	1.02
Cerium-141	0.581
Cerium-143	1.39
Cerium-144	0.31
Cesium-134	.662
Cesium-137	1.176 (7%), 0.514
Europium-152	1.48
Europium-154	1.85 (10%), 0.87
Europium-155	0.25

Table 5-3: NTS Beta-Emitting Radionuclides

Table 5-3 spans two pages.

Isotope	Major Radiation Energies (MeV)
Iron-59	1.57 (0.3%), 0.475
Mercury-203	0.214
Iodine-131	0.806 (0.6%), 0.606
Iodine-133	1.27
Iodine-135	1.4
Iridium-192	0.67
Molybdenum-99	1.23
Sodium-22	0.545
Sodium-24	1.389
Nickel-63	0.067
Promethium-147	0.224
Plutonium-241	0.021
Rhodium-100	0.74 (positron)
Rhodium-106	3.54
Ruthenium-103	0.70 (0.3%), 0.21
Ruthenium-106	0.039
Antimony-124	2.31
Antimony-125	0.61
Strontium-89	1.463
Strontium-90	0.546
Tantalum-182	1.71 (0.3%), 0.522
Telluruim-132	0.22
Yttrium-88	0.76 (positron)
Yttrium-90	2.27
Yttrium-91	1.545
Zirconium-95	0.89 (2%), 0.396
Zirconium-97	1.91

5.3.3 Neutron Exposures

A small fraction of the workers at NTS had the potential for neutron exposure. For workers with a possibility of neutron exposure, personnel neutron dosimeters were used to monitor exposure (ORAUT-TKBS-0008-6). Potential sources of neutron exposure at NTS included:

- Direct production from a nuclear detonation,
- Spontaneous fission and subcritical multiplication in fissile materials (e.g., uranium-235, plutonium-239),
- Isotopic sources such as initiators and calibration sources, and
- Reactor testing.

Table 5-4 lists NTS areas and activities with potential neutron exposure to NTS workers.

Table 5-4: NTS Areas and Activities with Potential Neutron Exposure

Area	Activity	Neutron Sources	Beginning	Final
5	Low-level waste storage	Transuranic waste	Before 1962	Present
6	Nuclear device assembly	Fission neutrons	Before 1962	1992
25	NRDS and BREN tower calibrations and operation	Fission neutrons and neutron sources californium-252, PuBe* and AmBe+	1966	1973
26	PLUTO Reactor (nuclear-powered ramjet engine) research	Fission neutrons and neutron sources californium-252, PuBe* and AmBe +	Mid 1960	Late 1960
27	Nuclear explosive assembly using special nuclear material	Fission neutrons and neutron sources californium-252, PuBe* and, AmBe+	Before 1982	1975
Various	Down-hole well-logging	*PuBe or californium-252 isotopic sources	Before 1962	Present
Various	Neutron detection instrument calibration	*PuBe or californium-252 isotopic sources	Before 1962	Present

Notes:
***Plutonium-238 and beryllium**
+Americium-241 and beryllium

Exposure of NTS workers to neutrons from nuclear detonations, while theoretically possible, was realistically infeasible. The closest workers (test personnel) were at CP-2, and later CP-1 in Area 6, more than 6 km from the atmospheric test locations (ORAUT-TKBS-0008-6). If an individual was more than 6 km from a detonation site, the neutron dose would have been less than 1 mrem (ORAUT-TKBS-0008-6, page 39). Negligible neutron exposures were possible in the vicinity of devices being tested or other significant quantities of fissionable materials. The few individuals associated with final assembly, arming, and firing test weapons would have had potential for neutron exposure. During assembly operations, trained personnel were in proximity with the device components and involved with direct hands-on manipulation of the pits. These workers may have been exposed to neutrons emanating from the pits. Most or all workers involved in final assembly, arming, and firing of test devices would have been national laboratory employees and monitored as visitors to NTS (ORAUT-TKBS-0008-6, page 40).

The most significant potential source of neutron exposure was from isotopic neutron sources such as plutonium-238 and beryllium or californium-252. These sources were used in specific activities such as instrument calibration and well-logging. Only a few documented, highly trained and specialized individuals had access to such sources (ORAUT-TKBS-0008-6).

The final source of potential neutron exposure was from reactor test operations. Test operations occurred in specific areas (Areas 25 and 26) designated for that purpose. A concrete building, used as the control point for reactor operation testing, was located approximately two miles from the test cell. Again, as with access to neutron isotopic sources, only a few, highly trained and specialized individuals had access to these areas. The potential for significant neutron exposure due to reactor operations was further mitigated by the fact that the neutron exposures would have been accompanied by much greater gamma exposures, which were utilized as the governing factor for exposure control (ORAUT-TKBS-0008-6). Additional information regarding reactor operations is available in ORAUT-TKBS-0008-6.

5.3.4 Photon Exposures

The residual radiation field following detonation of a nuclear weapon consists of radiation from fission products, activation products, and unfissioned uranium or plutonium. For more information regarding the specific radionuclides of concern, see ORAUT-TKBS-0008-2, Table 2-2. Although the residual radiation intensity depends on a number of factors that can vary from test to test, relatively few radionuclides, common to all tests, are the primary contributors to the photon spectrum. The relative abundance of each radionuclide determines the spectrum. The photon field at NTS is primarily due to photons with energies between 100keV and 2 MeV. There is very little contribution from photons with energies less than 100 keV, with the exception of scattering from large area sources. In those cases, the scattered radiation was determined to have energy of approximately 75 keV and to have contributed as much as 10% of the overall photon spectrum. Exposures at NTS were largely to photons with energies greater than a few hundred KeV (ORAUT-TKBS-0008-6, page 35-36).

6.0 Summary of Available Monitoring Data for the Proposed Class

The primary sources of monitoring data for this evaluation include the NIOSH SRDB and NOCTS. NIOSH is aware of the Historical Records Center (HRC) database maintained by Bechtel Nevada and the Radiation Exposure Monitoring System (REMS) electronic dosimetry system for available internal and external monitoring data. Much of NIOSH's NOCTS database claimant exposure data were retrieved from these sources by DOE Nevada in response to claim data requests.

NTS used facility and individual worker monitoring methods to measure and control radiation exposures. NTS hardcopy radiation exposure records and film from dosimeters are available. There was a considerable effort to consolidate all NTS and Pacific Proving Grounds dosimetry records in what was originally called the Dosimetry Research Project (DRP), now known as the Nuclear Testing Archive. The records are under the control of DOE. In addition to site records, records were retrieved from Los Alamos National Laboratory and various archives when it became evident that data were missing (Personal Communication, 2005).

The SRDB contains copies of many NTS records. Reviews of these records identified personal monitoring data (e.g., film badge exposure results, thermoluminescent dosimeter monitoring results, bioassay results) and area monitoring data.

6.1 NTS Internal Monitoring Data

The primary focus of the dosimetry program at NTS was external monitoring, particularly during atmospheric testing. The assumption, based on animal data showing that internal dose due to inhalation was small in comparison to external dose, was that by controlling the external dose, the internal dose would be limited. Early bioassay screens (e.g., nasal swabs, respirator swipes, and urine samples) were performed if contamination was found or suspected. A positive nasal swab initiated the collection of a urine sample, which was analyzed for tritium, gross beta, and gross gamma. As the bioassay program matured, urine samples were collected in a routine, random screening process. By 1961, members of Rad-Safe, miners, drillers, and tunnel workers were some of the workers included in the routine bioassay program (REECo, 1961). Routine bioassays at NTS included quarterly urine samples, annual whole-body counts, and new/termination whole-body counts (Allen, 1993; Arent, 2004). Non-routine bioassay types included job-specific and occurrence response (University of California, 1965; LRL, 1961; Allen, 1993). Examples of non-routine bioassays include the following analyses:

- Tritium or gamma scan
- Gross fission product (beta)
- Specific radionuclides

Whole-body counts, lung counts, thyroid counts, and biological sampling were performed as soon as practicable after a suspected intake (Allen, 1993). Specific examples include:

- Lung counts following a suspected intake of thorium, uranium, or a transuranic
- Whole-body counts for detecting most gamma-emitting fission and activation products
- Thyroid counts for suspected radioiodine uptakes
- Urine bioassay for detection of pure beta emitters such as strontium-89 and strontium-90
- Urine and feces sampling, as well as lung and whole-body counting to detect and assess intakes of actinides

Details regarding the various analyses used and the associated minimum detectable activities are presented in ORAUT-TKBS-0008-5.

6.2 NTS External Monitoring Data

For nearly three decades, from the start of operations in January 1951 until 1987, personnel dosimeters with photographic emulsions of various types and in various holders (i.e., film badges) were primarily used as the external dosimeter at NTS. The terms “film badge,” or “film badge dosimeter,” refer to the entire dosimeter issued to personnel, which typically consisted of a dental-sized film packet housed in a holder of varying configurations, and was designed to measure radiation and improve the response characteristics of the film badge. Although a number of different film types were used for dosimetry at NTS, they generally had similar characteristics and responses to beta and photon radiation. Uncertainties in dosimetry with this film are largely, if not exclusively, the result of external factors rather than differences among the films (ORAUT-TKBS-0008-6).

Starting in February 1966, thermoluminescent dosimeters were used at the Nuclear Rocket Development Station (NRDS) as part of the effluent monitoring program. These dosimeters contained a calcium fluoride phosphor bound to a helically wound wire in an evacuated glass tube; because of their sensitivity, they were ideal for their intended purpose, but were not entirely suitable for personnel dosimetry. On July 1, 1968, a personnel thermoluminescent dosimeter program was implemented with the cooperation of the Health Services Laboratory of the Idaho Operations Office. The laboratory supplied both lithium-fluoride thermoluminescent dosimeter chips and its experience gained at the National Reactor Testing Station. The first routine use of personnel thermoluminescent dosimeters at NTS began in 1970 at the NRDS (Boone, 1970).

With the advent of DOE requirements to restrict personnel exposures to “as low as reasonably achievable” (ALARA), and with emphasis on accurate dosimetry at low doses, the Environmental Sciences Department personnel began evaluating thermoluminescent dosimeter systems and neutron dosimeters in the early 1980s as part of an effort to replace the then-current film badge and neutron thermoluminescent dosimeters. After evaluating several dosimetry systems, the Panasonic 802 thermoluminescent dosimeter and the neutron thermoluminescent dosimeter were determined to comprise the best combination for NTS exposure conditions. Both were put into use in January 1987 (ORAUT-TKBS-0008-6, page 85).

Details regarding the various analyses used and the associated minimum detectable activities are presented in ORAUT-TKBS-0008-6.

6.3 NTS Air Sampling Data

In 1964, Reynolds Electrical and Engineering Co., Inc. (REECo) established an environmental surveillance program at NTS designed to measure radiological conditions throughout the site. The purpose of the data collected by the program was not to relate to specific tests, but to relate to general site radiation conditions. The short-term objective of the program was to minimize casual personnel exposure to radiation by locating and identifying localized radiological environmental conditions. The long-range objective of the program was to establish baseline environmental data that could provide a reference for comparison with subsequent test activities and radiation measurements (Lewis, 1965).

Since the early 1970s, the environmental surveillance program has routinely monitored atmospheric concentrations of tritium, plutonium-238, plutonium-239, and plutonium-240. These were the radionuclides identified as most significant to the assessment of potential exposure to workers and members of the public. In addition, since the mid-1960s, measurements have been reported for gross alpha and gross beta concentrations.

Tunnel air sampling began in 1957 in locations with the potential for airborne exposure (Arent, 2004). Air samplers operated continuously. Radiological Control Technicians checked and exchanged the filters each shift.

Allen (1993) stated that, in general, air monitoring devices were positioned to provide samples representative of the worker’s breathing zone. However, some work conditions, such as mining and drilling, might have required location of the air monitor intake in the area of highest expected concentration “to ensure that airborne radioactivity possibly breathed by the worker is not overlooked.” Workplace air monitoring was required in occupied areas that had the potential to exceed 10% of any derived air concentration value listed in DOE Order 5480.11 (DOE, 1988).

The surveillance program grew to include, over time, 12 permanent air-sampling stations in the most populated areas of NTS. Initially, the air samplers were low-volume Filter Queen samplers with 8-by-10-inch (Gelman Type E) glass-fiber filter papers. Operating times were determined by integrated electric timers with flow rates determined by calibrated rotometers. Typical flow rates varied from 3 to 6 cubic feet per minute; samples were collected weekly.

In 1971, to achieve lower detection levels, weekly air samples from a given station were batched on a monthly basis and subjected to radiochemical analysis for plutonium-239. This new procedure included acid dissolution with ion exchange recovery and electroplating onto stainless-steel discs, followed by alpha spectroscopy using solid-state surface barrier detectors. Routine analysis for plutonium-238 started in 1989 (McArthur, 1989).

In 1977, a separate sampler was used to collect airborne tritium and tritiated water vapor. The sampler was portable and capable of unattended operation for up to two weeks in desert areas (Scoggins, 1983). A small electronic pump drew air into the sampler at about 0.5 liter per minute, and the tritiated water vapor was removed from the air stream by a silica gel drying column. The dry air then passed through a catalytic converter containing platinum to generate tritiated water vapor from airborne tritium. Another drying column collected the vapor, in which a small volume of distilled water served as a trap for the tritiated water vapor. Appropriate aliquots of condensed moisture were obtained by heating the silica gel. Counting via liquid scintillation techniques allowed for the determination of the airborne tritium and tritiated water vapor activities. The typical minimum detection limit for this analysis was 3×10^{-7} µCi m^{-3}.

The total number of air sampling stations increased over the years to a peak of 52 in 1989 (Wruble, 1990). This number remained fairly constant until a gradual reduction began in 1995 (Kinnison, 1997). This reduction occurred primarily because of a gradual strategy shift from environmental monitoring to demonstration of compliance with National Emission Standards for Hazardous Air Pollutants approved by the U.S. Environmental Protection Agency (EPA).

7.0 Feasibility of Dose Reconstruction for the Proposed Class

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

In determining feasibility, NIOSH begins by evaluating whether current or completed NIOSH dose reconstructions demonstrate the feasibility of estimating with sufficient accuracy the potential radiation exposures of the class (discussed in Section 9.0 of this report). If the conclusion is one of infeasibility, NIOSH systematically evaluates the sufficiency of different types of monitoring data, process and source or source term data, which together or individually might ensure 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 7.6. This approach is discussed in OCAS's SEC Petition Evaluation Internal Procedures, 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-00084 as submitted by the petitioner. (Section 7.4)

7.1 Pedigree of NTS 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 Data Review

NIOSH has access to significant documentation describing the internal dosimetry program and bioassay methods used at NTS. These records frequently include photocopies of original worksheet records, forms, sample transmittal records, and original summary reports generated for distribution to DOE and operational organizations within NTS. NIOSH reviewed a statistically valid number of claimant files constituent to the proposed class for internal monitoring data. Consistency and credibility of available internal monitoring data were checked by reviewing *in vitro* and *in vivo* analytical results. Thirty-one percent of the NTS records reviewed contained urinalysis data, which coincides favorably with the fact that of 1,287 total DOE supplied records for NTS claimants, 32.8 % contained some internal dosimetry data.

Additionally, NIOSH examined the records supplied by DOE for 100 NTS claimants with significant total external whole-body photon exposures (cumulative above 1.0 rem). The nature of the potential exposure scenarios at NTS makes it most likely that significant internal exposure would be associated with significant external exposure. The activities that involved the greatest concentration of loose contamination and the greatest potential for inhalation or ingestion involved re-entry work, tunnel work, and drillback/mineback work. These operations had high potential for external exposure. NIOSH found that all 100 of the individuals identified as having significant external whole-body photon exposures were monitored by bioassay during their employment. Of these 100 workers, 21 were involved with radiation protection or other radiation safety occupations. During a conference call conducted on September 12, 2007, a former Health and Safety Manager at NTS indicated that radiation protection and safety staff were included as part of the re-entry teams and prepared for re-entry events to ensure that workers were protected. Because NTS operations were experimental in nature and the risks associated with exposure were recognized, the pre-planning for these experiments included the involvement of the Health and Safety staff. During tunnel re-entry, air samples were pulled, the ventilation systems were re-energized to purge the air inside the tunnels, and radiation surveys were conducted to ensure that the radiation exposure potential for routine operations was acceptable. Other re-entries (e.g. NRDS re-entries) included radiation surveys to assess the radiation risk associated with recovery work. Based on information stating that the radiation protection and safety staff were consistently part of the team that was first sent into the highest radiation exposure risk areas, the radiation protection and safety staff are considered representative of the NTS workers with the highest potential for internal exposure, and therefore, were a fundamental group of workers included in the routine bioassay program. This substantiates that NTS monitored those workers in positions deemed likely to be internally exposed to radioactive materials.

The 100 individual files that contained bioassay results included job descriptions for laborers/ bull gang workers, miners, tunnel workers, DKY Loco operators, assembly workers, nuclear propulsion workers, engineers, as well as other work groups. A summary of the data showing the recorded external doses, occupations, and internal data is provided in Table 7-1.

Table 7-1: Summary of Recorded External and Internal Dose Based on Employment

Table 7-1 spans 8 pages.

Total External Dose (rem)	Job Title	Internal Data Availability	Internal Data Details	Dates of Employment (by year)
36.21	Iron Worker/Foreman	Yes	20 *in vitro* results, most before 1963 (only 0.055 rem recorded external dose after 1962)	1953-1978
27.729	Radiation Monitor	Yes	100s of *in vitro* results starting in 1959 *in vivo*, 1975-1994	1959-1997
23.19	Radiological Field Operations Manager	Yes	100s of *in vitro* results, 1957-1959 *in vivo*, 1976-1983	1957-1987
18.8	Radiation Technician	Yes	*2 in vitro* results, 1964 *in vivo*, 1964 - 1973	1964-1973
16.784	Laborer	Yes	14 *in vitro* results, 1955, 1960, and 1977 *in vivo*, 1977	1952, 1953, 1954-1956, 1956-1979
16.165	Radiation Services Coordinator/Radiation Field Ops Branch Chief	Yes	About 250 *in vitro* results, 1971-1991 *in vivo*, 1976-1992	1960-1993
15.725	Radiation Safety Supervisor	Yes	52 *in vitro* results, 1957-1963	1957-1966
15.085	Shifter/Miner	Yes	97 *in vitro* results, 1960-1968	1961-1969

Table 7-1: Summary of Recorded External and Internal Dose Based on Employment

Table 7-1 spans 8 pages.

Total External Dose (rem)	Job Title	Internal Data Availability	Internal Data Details	Dates of Employment (by year)
14.594	Health Physicist	Yes	About 250 *in vitro* results, 1963 and 1965-1990 *in vivo*, 1980, 1983, 1986, and 1989-1991	1962-1963, 1978-2005
14.475	Miner/Oiler/Operator	Yes	More than 100 *in vitro* results, 1960-1986 *in vivo*, 1984, 1986	1957-1987 (with breaks)
13.79	Messenger Clerk Monitor	Yes	Over 500 *in vitro* results, 1961-1990 *in vivo*, 1977-1990	1957-1991
13.125	Monitor/Radiation Safety Expert	Yes	584 *in vitro* results, 1957-1994 *in vivo*, 1976-1993	1956-1995
12.265	Tunnel Walker	Yes	Over 75 *in vitro* results, 1962-1966 thyroid count, 1966	1961-1968
12.155	Radiation Monitor	Yes	Approximately 400 *in vitro* results, 1956-1982 *in vivo*, 1969, 1975-1981	1961-1982
11.751	Environmental Safety and Health	Yes (breaks)	Over 300 *in vitro* results, 1964-1993 *in vivo*, 1975-1983	1964-2000
10.42	Shifter/Miner	Yes	16 *in vitro* results, 1959, 1961, 1966, and 1977 *in vivo*, 1977-1987	1958-1987 (with breaks)
9.742	Radiation Safety/Technical	Yes	Over 100 *in vitro* results, 1968-1996 *in vivo* 1975-1995	1967-2007
8.985	Miner	Yes	More than 100 *in vitro* results, 1960-1963	1958-1971
8.753	Machine Tool Operator/ Laborer	Yes	Approximately 60 *in vitro* results, all prior to 1960 (all recorded external dose received before 1963)	1951-1977 (with breaks)
8.375	Tunnel Walker	Yes	Approximately 150 *in vitro* results, 1961-1977 *in vivo*, 1977-1987	1958-1987

Table 7-1: Summary of Recorded External and Internal Dose Based on Employment

Table 7-1 spans 8 pages.

Total External Dose (rem)	Job Title	Internal Data Availability	Internal Data Details	Dates of Employment (by year)
8.015	Labor Foreman	Yes	Approximately 60 *in vitro* results (all before 1960 when external dose was also recorded)	1956-1971 (with breaks)
7.99	Radiation Monitor	Yes	Approximately 175 *in vitro* results, 1965-1976 *in vivo*, 1975 and 1976	1965-1976
7.415	Chemical Technician at NRDS	Yes	*in vivo* results, 1965, 1969, 1 positive cesium result in 1965	1964-1969
7.324	Foreman of the Sanitation Department	Yes	Over 40 *in vitro* results, (all recorded external dose was prior to 1960) *in vivo*, 1982, 1983, and 1984	1953, 1957, 1961-1984
7.32	Laborer/Miner	Yes	Approximately 40 *in vitro* results, all prior to 1960 (external exposure received before 1963)	1952-1987
7.195	Shifter/Miner/Tunnel Walker	Yes	7 *in vitro* results, 1959 and 1972	1958-1986 (with breaks)
6.98	Mucking Operator	Yes	37 *in vitro* results, 1962, 1965, and 1967	1961-1977 (with breaks)
6.725	Laborer	Yes	Bioassay data prior to 1963 (external exposure prior to 1963)	1952-1965
6.58	Monitor	Yes	67 *in vitro* results, 1964-1970	1964-1971
6.475	Monitor, Radiac Repairman	Yes	Plutonium bioassay, 1963	1962-1967
6.285	Shaft Miner/Miner	Yes	10 *in vitro* results, all prior to 1960 (all recorded external dose received before 1963)	1961-1971 (with breaks)
5.915	Miner	Yes	1 *in vitro* result, 1969	1961-1971 (with break)
5.9	Hoist/Universal Operator	Yes	Over 400 *in vitro* results, most before 1963 (only 0.065 rem external after 1962)	1958-1970
5.835	Bull Gang/Laborer	Yes	17 *in vitro* results, 1957 and 1966	1958-1967 (with breaks)
5.67	Machine Operator	Yes	Over 40 *in vitro* results, 1962 1 *in vitro* result, 1963 (only 0.245 rem external after 1962)	1959-1971
5.54	Shifter/Miner/Tunnel Walker	Yes	About 170 *in vitro* results, 1961-1964	1958-1975 (with breaks)

Table 7-1: Summary of Recorded External and Internal Dose Based on Employment

Table 7-1 spans 8 pages.

Total External Dose (rem)	Job Title	Internal Data Availability	Internal Data Details	Dates of Employment (by year)
5.51	Radiation Monitor/Manager	Yes	44 *in vitro* results, 1963-1972	1963-1977
5.43	Nuclear Engineer (NRDS)	Yes	1 *in vitro*, 1965	1963-1973
5.245	Nuclear Engineer	Yes	About 175 *in vitro* results, 1968-1973 and 1975 *in vivo*, 1978-1987	1963-1987
5.18	Wireman	Yes	10 *in vitro* results, 1962 and 1963 (no recorded external dose after 1963)	1962-1994
5.155	Miner/Tunnel Worker - *Smoot*	Yes	Approximately 80 *in vitro* results, 1962 and 1963 (no recorded external dose after 1963)	1961-1964
5.11	Scientist/Industrial Hygienist	Yes	100s of *in vitro* results, 1966-1994 *in vivo*, 1975-1994	1966-1999
4.835	Instrument Mechanic	Yes	4 *in vitro* results, 1973 and 1977, *in vivo*, 1977	1955-1987
4.825	Heavy Equipment Operator - Tunnels	Yes	*50 in vitro* results, 1963-1978 *in vivo*, 1977, 1978, and 1979	1961-1984 (with breaks)
4.765	Diamond Core Driller	Yes	12 *in vitro* results, 1961, 1962, and 1963	1961-1964
4.753	Monitor	Yes	Over 700 *in vitro* results, 1968-2005 *In vivo*, 1969-1991	1962-1994
4.745	Laborer/Bull Gang	Yes	About 100 *in vitro* results, 1957-1990, none other than tritium *in vivo*, 1979, 1980, 1982, 1984, 1986, 1988, and 1990	1957, 1961-1962, 1964-1992
4.735	DKY Loco Operator/Miner	Yes	30 *in vitro* results, 1962, 1972-1977	1958-1978 (with breaks)
4.669	Engineer	Yes	29 *in vitro* results, 1963 and 1977 *in vivo*, 1976, 1980, 1981	1961-1983
4.58	Miner/Tunnel Supervisor	Yes	35 *in vitro* results, 1962, 1966, 1967, and 1977-1980 *in vivo*, 1977, 1984, 1986, and 1987	1962-1987

Table 7-1: Summary of Recorded External and Internal Dose Based on Employment

Table 7-1 spans 8 pages.

Total External Dose (rem)	Job Title	Internal Data Availability	Internal Data Details	Dates of Employment (by year)
4.565	Miner/Tunnel Walker	Yes	Approximately 15 *in vitro* results, 1962 and 1966	1961-1967
4.485	Laborer	Yes	1 *in vitro* result, 1969	1962-1985
4.468	Shifter/Miner	Yes	Approximately 250 *in vitro* results, 1963-1990 *in vivo*, 1977-1990	1962, 1963, 1969-1991
4.305	Miner	Yes	5 *in vitro*, 1961 (no recorded external after 1962)	1961, 1964
4.26	Laborer	Yes	3 *in vitro* results, 1965	1957, 1962-1971, 1971-1973, 1973-1992
4.255	Radiographer	Yes	About 65 *in vitro* results, 1970-1972	1958-1979
4.2	Laborer/Operator	Yes	1 *in vitro* result, 1957 (external dose recorded before 1963)	1954-1968 (with breaks)
4.18	Miner	Yes	24 *in vitro* results, 1966 and 1967	1964-1968
4.085	Ops and Rig Superintendent	Yes	Approximately 250 *in vitro* results, 1965-1986 *in vivo*, 1977-1994	1961-1995
3.9	Nuclear Technician	Yes	3 *in vivo* results, 1966	1963-1967
3.363	Radiation Instrument Technician	Yes	Approximately 300 *in vitro* results, 1966-1992 *in vivo*, 1977-1991	1965-1992
3.075	Laborer	Yes	6 *in vitro* results, 1963	1960, 1961-1982
2.955	Miner/Derrickman	Yes	7 *in vitro* results, 1963 thyroid count, 1965	1961-1965 (with breaks)
2.85	Driller	Yes	Approximately 70 *in vitro* results, many thyroid counts thyroid counts, 1976-1991	1962-1991
2.835	Laborer/Carpenter	Yes	*in vitro* results, 1959 and 1962 *in vivo*, 1979, 1984, 1987, and 1988	1958-1988
2.775	Drill Foreman/Derrickman	Yes	Approximately 100 *in vitro* results, 1962, 1965-1968	1961-1973

Table 7-1: Summary of Recorded External and Internal Dose Based on Employment

Table 7-1 spans 8 pages.

Total External Dose (rem)	Job Title	Internal Data Availability	Internal Data Details	Dates of Employment (by year)
2.765	Miner/Supervisor	Yes	Approximately 30 *in vitro* results, 1962, 1963 (no recorded external dose after 1963)	1958-1983
2.73	Driller Foreman/Operator	Yes	Approximately 15 *in vitro* results, 1962-1973 *in vivo*, 1977-1989	1962-1989
2.64	Driller/Unknown	Yes	1 *in vitro* result, 1962	1957-1980 (with breaks)
2.58	Heavy Duty Repairman/Welder	Yes	1 *in vitro* result, 1970	1958-1974 (with breaks)
2.44	Security	Yes	196 *in vitro* results, 1981-1992 *in vivo*, 1978, 1981, and 1989	1957-1993
2.41	Radiation Monitor	Yes	Over 100 *in vitro* results, 1963-1977 *In vivo*, 1975 and 1977	1963-1977
2.245	Machining at NRDS	Yes	*in vivo* results, 1967, and 1968, positive results	1965-1968
2.225	Bull Gang/Laborer	Yes	2 *in vitro* results, 1961and 1965	1961-1986 (with breaks)
2.225	Bull Gang/Laborer	Yes	8 *in vitro* results, 1970	1965-1994 (with breaks)
2.225	Mechanic/Pipefitter	Yes	12 *in vitro* results, 1964, 1965, and 1973	1963-1973
2.135	Wireman (tunnels)	Yes	49 *in vitro* results, 1962 (most of recorded external exposure occurred in 1962)	1961-1983
2.13	Radiation Safety/Scientist	Yes	1 *in vitro* result, 1966	1957-2001 (with one break)
2.105	Radiation Monitor	Yes	Approximately 190 *in vitro* results, 1966-1975 *in vivo*, 1975	1965-1976
2.095	Oiler, Driller, Universal Operator	Yes	16 *in vitro* results, 1962	1961-1966
2.075	Miner	Yes	11 *in vitro* results, 1962	1961-1969
2.028	Miner	Yes	Approximately 40 *in vitro* results, 1963-1972	1965-1975 (with breaks)
1.95	Electrician	Yes	2 *in vitro* results, 1964 1 *in vivo* result, 1969	1963-1969

Table 7-1: Summary of Recorded External and Internal Dose Based on Employment

Table 7-1 spans 8 pages.

Total External Dose (rem)	Job Title	Internal Data Availability	Internal Data Details	Dates of Employment (by year)
1.945	Miner/DYO Loco Operator	Yes	100s of *in vitro* results and *in vivo* data	1964-1984 (with breaks)
1.85	Miner/Driller	Yes	16 *in vitro* results, 1965, 1970, and 1989 *in vivo*, 1988-1992	1965-1993 (with breaks)
1.715	Driller/Miner	Yes	116 *in vitro* results, 1966, 1972, 1974, 1975, 1977-1982, 1986, and 1989-1990 *in vivo*, 1976-1983	1964-1990 (with breaks)
1.695	Miner	Yes	6 *in vitro* results, 1967, 1968, and 1970, some positive	1961-1971
1.655	Chemist	Yes	5 *in vitro*, 1965 *in vivo*, 1965	1963-1968
1.625	Miner/Bull Gang Operator	Yes	221 *in vitro* results, 1970-1987 *in vivo*, 1977-1986	1967-1987
1.52	Operator/Dinky Loco Operator	Yes	1 *in vitro* result, 1959 (.105 mrem recorded external exposure after 1960)	1957-1967 (with breaks)
1.44	First Aid Man/Monitor	Yes	27 *in vitro* results, 1970-1973	1963-1970 (with breaks)
1.435	Laborer/Iron Worker	Yes	2 *in vitro* results, 1966	1962-1969 (with breaks)
1.3	Assembly of Reactors	Yes	1 *in vitro* result, 1963	1962-1971 (with breaks)
1.3	Miner/Laborer	Yes	2 *in vitro* results, 1965	1964-1975 (with breaks)
1.275	Miner/Tunnel Walker	Yes	67 *in vitro* results, 1972-1990 *in vivo*, 1977-1993	1968-present (with breaks)
1.25	Dozer Operator/Foreman	Yes	1 *in vitro* result, 1966	1955-1975
1.225	Miner/Laborer	Yes	4 *in vitro* results, 1966	1964-1967 (with breaks)
1.155	DKY Loco Operator/Miner	Yes	19 *in vitro* results, 1970-1981 *in vivo*, 1979-1990	1969-1990 (with breaks)
1.1	DKY Loco Operator	Yes	55 *in vitro* results, 1966	1965-1969 (with breaks)

Table 7-1: Summary of Recorded External and Internal Dose Based on Employment *Table 7-1 spans 8 pages.*				
Total External Dose (rem)	**Job Title**	**Internal Data Availability**	**Internal Data Details**	**Dates of Employment (by year)**
1.025	Shifter/Miner/Tunnel Walker	Yes	12 *in vitro* results, 1970 and 1973	1964-1975 (with breaks)

Source: NOCTS

From these reviews of claimant data supplied by DOE, NIOSH has found thousands of available bioassay results.

7.1.2 External Data Review

NIOSH has access to extensive documentation describing the NTS external dosimetry program, including the procedures and controls used to ensure universal monitoring and accuracy in the recordkeeping. Based on the review of the data available, credible and consistent external dosimetry records representative of members of the proposed class are available for dose reconstruction.

As early as 1957, with the decision to progress to universal external monitoring, NTS recognized the potential problems associated with operating a Personnel Radiation Dosimetry program in which large numbers of film badges would be processed for recording radiation dose. Consideration of accounting problems associated with the program, as well as the methods NTS chose to address these issues are documented in the report titled, *Electronic Data Processing as Applied to Personnel Radiation Dosimetry* (Wilcox, 1958). NTS chose to address the majority of the identified concerns through automation processes. In 1957, daily reports were prepared and distributed each morning to approximately 70 organization representatives. Weekly summary dosage reports listing accrued quarterly and annual gamma radiation dosage for all measured personnel were prepared and distributed (Wilcox, 1958; NTS, 1968). These reports are available to NIOSH.

Film packet control was achieved through the use of an Addressograph plate. The plate was used for employee identification and was included in the film packet holder. The plate was stamped with the employee’s name, NTS number, and the number code, which identified the employing organization. When the film packet was exchanged, the plate was used in conjunction with a stamping machine to print the above information on the IBM film packet issue card (NTS, 1968). NTS was very concerned with personnel dosimetry accuracy and implemented rigorous quality assurance controls regarding dosimeter calibration, issuance, and tracking; this concern is documented in detailed procedures (NTS, no date; NTS, 1968; REECo, 1991; NTS, 1978; Wilcox, 1961) and throughout NTS memos and information bulletins. Further, interviews confirmed the prevailing concern with accuracy in the dosimetry records. A personal contact with a REECo Health Physics Manager and member of the Radiation Protection organization at NTS since the mid 1960s is quoted below (Smith, 2007):

> Dose determined from the dosimetry systems (film and TLD) were handled in accordance with the "QA" procedure in place at the time the doses were determined. Systems were calibrated daily and performance checked with each batch. In the film era, results were keypunched by

two different individuals to verify that the results going into the personnel record system were correct. During the TLD era, the reader parameters were checked daily; the computer system's algorithm calculated doses automatically that were sent directly to a disk that upon laboratory verification was sent to the personnel dosimetry records system. These computer parameters were also saved with the raw data. Additionally, as each monthly Dosimetry Report was generated for distribution to organizations, it was again visually checked by the Dosimetry Supervisor. Once their monthly reports were verified, the reports were retained in the database and held for the annual reports and the creation of the then AEC/DOE 190 and 191 reports that were sent to Headquarters.

During the time film badges were in use, personnel radiation exposure records were maintained on cards which contained information available for electronic data processing machines. When a film badge was received for processing, the identically numbered IBM card was pulled and the film badge density, processing batch number, and date of processing was recorded on it. After all the film for a particular processing batch was measured for net optical density and the information recorded on the card, two batch density totals were recorded on adding machine tapes by different individuals. One tape was filed at the Processing Laboratory and the other was transmitted with the information cards to the Machine Accounting Facility. Employees had a dosage “master card” filed numerically by identification number. When the information cards with information for a particular dosimeter exchange arrived at the Machine Accounting Facility, the accumulated personnel gamma radiation exposure was recorded on the master card. Photocopies of the issue cards, summary reports, and other original source information is frequently included as part of the EEOICPA claimant files.

7.2 Internal Radiation Doses at NTS

Emphasis at NTS was placed on monitoring sources of external exposures rather than internal exposures, particularly during atmospheric testing. This emphasis was based on animal data comparing inhalation dose to external dose. The principal source of internal radiation dose for members of the proposed class was from the intake of radionuclides released during venting of belowground weapons testing and from intakes during tunnel re-entry and operations. Other sources include intake of resuspended residual contamination from the aboveground testing period prior to 1962 and from safety testing. Initially at NTS, screening for internal intakes was performed using nasal swabs, respirator swipes, and urine samples when surface or air contamination was found or suspected. A positive nasal swab initiated the collection of a urine sample.

The NTS contractor, REECo, implemented bioassay in 1958 when workers involved in incidents were sampled via nasal swab. By 1961, NTS was conducting routine bioassay for tritium, plutonium-239, gross fission products, and gamma emitters. Early bioassay efforts were conducted after weapons testing and drillbacks. The routine bioassay program was conducted at NTS to verify that workers were not routinely exposed to airborne radioactive materials. REECo used *in vitro* methods until 1967 when whole-body counting was introduced at NTS. Routine *in vivo* counting was implemented at NTS in 1975.

As demonstrated by the data presented in Table 7-1, by 1961, Radiation Safety department staff involved with underground work, were also involved in a routine bioassay monitoring program (REECo, 1961). Other workers and/or worker groups that were on a routine bioassay monitoring program (also identified in Table 7-1) included miners, workers involved in re-entry events, and workers in areas where levels of airborne radioactivity exceeded NTS guidelines (University of California, 1965; Reeves, 1962; REECo, 1961; REECo, date unknown; LRL, 1961). Other types of bioassay monitoring at NTS included special sampling (designated, job specific bioassay monitoring) and incident sampling.

Per discussions with former NTS workers, respiratory protection was used beginning in the early years of site operations. In addition, Radiation Safety Monitors performed fit checks of respirators in the field using smoke tests (Marsh, 1983). By 1962, the use of respiratory protection was part of the NTS procedures for controlling internal exposures to radioactive materials (Reeves, 1962). The NTS respiratory protection program was based on the American Industrial Hygiene Association (AIHA, 1963), U.S. Atomic Energy Commission (Morgan, 1953; Biles, 1973), and International Atomic Energy Agency (IAEA, 1967) principles current at the time.

Protocols for bioassay monitoring remained fairly constant until 1993 when the *DOE Radiological Control Manual* (DOE, 1992) was implemented. With the implementation of the *Radiation Control Manual*, as documented by Allen, 1993, workers classified as Radiation Workers II were routinely monitored for internal intakes of radioactivity by bioassay. These monitored workers were those determined most likely to receive intakes of radioactive material resulting in a committed effective dose equivalent (CEDE) of 100 mrem or more. At any one time, approximately 300 workers were monitored via bioassay. While the total work force numbered as high as 12,000 workers, most workers were classified as non-radiation workers under the *DOE Radiological Control Manual*.

Information available in 2003 indicated that 21 workers had been assessed with annual internal doses of 100 mrem CEDE or more since the start of 1994 (McMahon, 2003). Eleven of those 21 workers received their dose from one project (E Tunnel Project) during 1994. The highest dose calculated for one of these intakes was 1,337 mrem CEDE (French, 1995). Since 1995, the frequency of annual internal doses of 100 mrem or more was approximately 1 in 100 monitored workers. Projects that involved working with plutonium and americium contamination were the only projects that resulted in intakes of 100 mrem or more since 1994. The low frequencies of intakes amounting to 100 mrem CEDE or more in a year to an individual is validation of the NTS radiological control efforts to minimize worker intakes (McMahon, 2003).

Routine bioassays at NTS are documented in ORAUT-TKBS-0008-5 Attachment 5D.4.1. Non-routine bioassay types included job-specific monitoring and occurrence response. Whole-body counts, lung counts, thyroid counts, and biological sampling were performed as soon as practicable after a suspected intake (Allen, 1993). Special, or one-time, bioassay samples were sometimes collected from workers after tasks with limited duration, but high potential for exposure. The special bioassay program was also administered to assess the internal dose delivered by inadvertent and unexpected intakes of radioactive materials (Allen, 1993; McMahon, 2003). By 2000, routine monitoring resembled special bioassay monitoring in that most projects were short term; monitored workers were provided baseline and post-work sampling (McMahon, 2003).

The routine bioassay program at NTS included the collection of urine samples (from workers involved in the drillbacks) after each drillback operation. NIOSH does have data (claimant data, supplied by DOE) sufficient to demonstrate that drillback workers routinely provided bioassay samples. Drillback personnel were primarily exposed to gaseous and particulate fission and activation products. Starting in 1963, engineering devices were used to prevent the escape of radioactive gases and particulates; however, there were still occasional unintended releases (Kimmel, 1963; REECo, 1964).

With the exception of work performed in seepage areas, operations conducted within tunnels are considered to have been performed in dry conditions. The pathways for personnel exposure included loss of containment during drilling or coring and re-suspension of particulate fission or activation products during the coring operations. Radionuclides that would have resulted from loss of containment and were of primary concern for internal dose were iodine-131, iodine-133, and cesium-137. Radionuclides of significant concern to internal dose that would have resulted from re-suspension are listed in Table 7-2.

Table 7-2: Drillback Re-suspension, Reentry/Mineback Re-suspension, Radionuclides of Concern for Dose V. Time After Test

1 day	10 days	100 days	365 days	10,000 days
Zirconium-95	Strontium-89	Strontium-89	Strontium-90	Strontium-90
Zirconium-97	Yttrium-91	Strontium-90	Zirconium-95	Cesium-137
Molybdenum-99	Zirconium-95	Yttrium-91	Ruthenium-106	
Ruthenium-106	Ruthenium-103	Zirconium-95	Cerium-139	
Iodine-131	Ruthenium-106	Ruthenium-103	Cerium-144	
Tellurium-132	Iodine-131	Ruthenium-106	Promethium-147	
Iodine-133	Tellurium-132	Cerium-144		
Iodine-135	Cerium-141			
Cerium-143	Cerium-144			
Cerium-144				

The routine bioassay protocol for drillback workers was to collect quarterly urine samples after each drillback operation. Urine samples obtained from drillback workers were analyzed by gross beta counting. If the beta result indicated potential radiation exposure, a separate aliquot from the same sample was analyzed for gross gamma-counting, using liquid scintillation (Dummer, 1958). In 1961, NTS analyzed urine samples for gross fission products before performing radionuclide-specific analyses (Geiger, 1961). Radionuclide-specific analysis performed at NTS included cesium-137, strontium-89/90, barium, lanthanide rare earths, and less frequently, other fission products that were co-precipitated with alkaline earth phosphate. If significant quantities of radioactive material were not detected, no additional analyses were performed.

Urine samples were analyzed by gamma spectroscopy for gross radioactivity and isotope identification. When specific radionuclides were not identified, gross fission product results were attributed to the radionuclides shown in Table 7-2, taking into consideration the amount of time between potential exposure and the device test.

Whole-body counting was performed for some of the drillback workers either annually or after situations where intakes were considered plausible. These drillback workers included the following specific drilling job categories: radiation monitor, driller operator supervisor, driller operator, rotary drill operator/rotary drill helper, driller helper, derrickman, motorman, fishing tool engineer, and drill helper trainee.

Reentry and mineback operations were similar, in terms of intake potential, to those of drillback operations. There were four pathways for exposure during reentry and mineback operations. The first pathway was based on a loss of containment in the drilling or coring operations during routine drilling, or due to containment equipment failure. The radionuclides of concern included gaseous fission and activation products or their particulate daughters. The second pathway was re-suspension of particulate fission or activation products during the coring operations of the mineback. The third exposure pathway was gaseous fission or activation products seeping through fissures in the rock and reentering the working areas of the tunnel. The final intake pathway existed when the line-of-sight pipe was opened to remove experiment equipment and samples (ORAUT-TKBS-0008-5, page 57-58).

Radionuclides of dosimetric concern from containment loss included tritium, iodine-131, iodine-133, and cesium-137. Additional radionuclides of dosimetric concern from re-suspension are listed in Table 7-2. Radionuclides of dosimetric concern from fissures and line-of-sight pipe openings included tritium, cobalt-60, antimony-124, iodine-131, iodine-133, and cesium-137. The trigger for urine sample bioassay of reentry and mineback workers was air sample results. Tunnel air sampling began in 1957 in locations with the potential for airborne exposure (ORAUT-TKBS-0008-5, page 58). Air samplers operated continuously. Radiation control technicians exchanged and counted the filters each shift. Bioassay was performed only when there was an indication of an effluent release (ORAUT-TKBS-0008-5, page 58). Urine samples collected from these workers were analyzed for gamma activity and tritium. Annual whole-body counts were conducted on a routine basis for specific radiation workers and on a special basis following any situation for which intake was considered likely (once *in vivo* monitoring began). Specific tunnel job categories included Miner, Bull Gang (Underground Laborer), Mucker (Muck Machine Operator), Shifter, Tunnel Walker, and Dinky Locomotive Operator. Specific to other tunnel operations, tritium was the radionuclide of dosimetric concern. When bioassay was collected from these workers, they were analyzed for tritium. Tunnel workers also had the potential to be occupationally exposed to radon and thoron daughters (ORAUT-TKBS-0008-5, page 17).

At the Decontamination Facility, radionuclides of dose concern are the same as those listed in Table 7-3. Workers in this facility were sampled by urinalysis on a quarterly basis and were also provided with annual whole-body counts. Urine samples were gamma-counted and analyzed for gross fission products, plutonium-238, plutonium-239, plutonium-240, and americium-241.

The Test Treatability Facility was a pilot project to bench-test technologies that would be used to decontaminate soil containing transuranic materials. The concentrations of radionuclides in the soils were not intended to exceed a few picocuries per gram of soil. Radionuclides of dose concern were plutonium-238, plutonium-239, plutonium-240, and americium-241. Workers in this facility were sampled by urinalysis on a quarterly basis and received annual whole-body counts. Urine samples were counted on a gamma analyzer for isotopic identification and were analyzed for plutonium and americium (ORAUT-TKBS-0008-5, page 58).

Similarly, the radionuclides of dose concern at the Atmospheric Weapon Safety Tests Areas included plutonium-238, plutonium-239, plutonium-240, and americium-241. Workers in this facility were sampled by urinalysis on a quarterly basis and received annual whole-body counts. Urine samples were counted on a gamma analyzer for isotopic identification and were analyzed for plutonium and americium (ORAUT-TKBS-0008-5, page 58-59).

Table 7-3 lists the radionuclides of dose concern for the Atmospheric Weapons Test Areas. Workers in the routine bioassay program provided urinalysis samples on a quarterly basis and received whole-body counts annually. Some area monitoring personnel received periodic lung counts. Urine samples were analyzed for gamma-emitting radionuclides, gross fission products, plutonium, and americium (ORAUT-TKBS-0008-5).

Table 7-3: Radionuclides of Concern in Atmospheric Weapons Test Areas				
Cobalt-60	Antimony-125	Cesium-137	Europium-155	Plutonium-239
Strontium-90	Barium-133	Europium-152	Lutetium-174	Plutonium-240
Ruthenium-101	Cesium-134	Europium-154	Plutonium-238	Americium-241
Ruthenium -102m				

Source: ORAUT-TKBS-0008-5.

Radionuclides of dosimetric concern for workers at the Low-Level Waste Facility in Area 3 are listed in Table 7-4. Workers in this facility were sampled by urinalysis on a quarterly basis and received annual whole-body counts. Urine samples were analyzed for gross fission products, plutonium, and americium. Table 7-5 lists radionuclides of dosimetric concern for the low-level waste site located in Area 5. Area 5 Radioactive Waste Management shallow-land burial workers were sampled by urinalysis on a quarterly basis and were provided annual whole-body counts. Urine samples were analyzed for gamma-emitters, tritium, gross fission products, plutonium, and americium (ORAUT-TKBS-0008-5).

Table 7-4: Radionuclides of Concern in Crater Disposal-Area 3 RWMS				
Manganese-54	Ruthenium-103	Cerium-144	Uranium-233	Plutonium-240
Cobalt-60	Ruthenium-106	Actinium-227	Uranium-234	Plutonium-241
Strontium -85	Cesium-134	Thorium-228	Uranium-238	Plutonium-242
Strontium -90	Cesium-137	Thorium-230	Plutonium-238	Americium-241
Zirconium-95	Barium-140	Thorium-232	Plutonium-239	Americium-243
Niobium-95	Cerium-141			

Source: ORAUT-TKBS-0008-5.

Table 7-5: Radionuclides of Concern in Shallow Land Burial-Area 5				
Hydrogen-3	Molybdenum-99	Cerium-141	Actinium-227	Uranium-238
Sodium-22	Ruthenium-103	Cerium-144	Thorium-228	Plutonium-238
Manganese-54	Ruthenium-106	Europium-152	Thorium-230	Plutonium-239
Cobalt-57	Antimony-124	Europium-154	Thorium-232	Plutonium-240
Cobalt-60	Antimony-125	Europium-155	Uranium-233	Plutonium-241
Strontium-85	Barium-133	Ytterbium-169	Uranium-234	Americium-241
Strontium-90	Cesium-134	Tantalum-182	Uranium-235	Plutonium-242
Zirconium-95	Cesium-137	Iridium-192	Neptunium-237	Americium-243
Niobium-95	Barium-140	Radium-226		

Source: ORAUT-TKBS-0008-5.

Tests of nuclear reactors for use as propulsion units were conducted above the ground at Area 25. Fission and activation products arising from these tests were dispersed into the environment. The radionuclides of dosimetric concern included tritium, cobalt-60, strontium-90, cesium-137, and europium-152. Workers involved with propulsion tests were sampled by urinalysis on a quarterly basis and received annual whole-body counts. Urine samples were analyzed for gamma-emitters, tritium, gross fission products, plutonium, and americium (ORAUT-TKBS-0008-5, page 61).

Workers assigned to radiography operations (including well-logging) were potentially exposed to sealed iridium-192, cobalt-60, iodine-131, cesium-137, radium-226, thorium-228, plutonium-238, and plutonium-241 sources. Bioassay was performed for these workers only if a loss of source containment was detected. Urine samples were gamma-counted (ORAUT-TKBS-0008-5, page 60).

For technicians and other workers assigned to Radiation Instrument Calibration Facilities, radionuclides of dosimetric concern are listed in Table 7-6. Routine bioassay, including quarterly urine samples and annual whole-body counts, were performed for personnel who regularly worked with calibration sources. Urine samples were analyzed for tritium and plutonium. A special bioassay whole-body count and/or urine sample collection was performed if the loss of calibration source containment was detected.

Table 7-6: Radionuclides of Concern in Radiation Instrument Calibration Facilities

Hydrogen-3	Strontium-90	Radium-226	Thorium-230	Plutonium-239
Cobalt-60	Cesium-137	Thorium-228	Plutonium-238	Americium-241

Source: ORAUT-TKBS-0008-5.

NTS performed several radiochemistry and analytical procedures in addition to analyzing bioassay samples. Radionuclides of dosimetric concern to laboratory staff are listed in Table 7-7. Only personnel routinely handling uncontained radioactive materials were provided urinalysis or whole-body counting. Urine samples were gamma-counted and analyzed for tritium, gross fission products, and plutonium (ORAUT-TKBS-0008-5).

Table 7-7: Radionuclides of Concern in Radiochemistry and Counting Laboratories

Hydrogen-3	Strontium-85	Cadmium-109	Cerium-144	Americium-241
Sodium-24	Yttrium-88	Tin-113	Europium-152	Plutonium-242
Cobalt-57	Strontium-90	Cesium-137	Mercury-20	Americium-243
Cobalt-60	Yttrium-90	Cerium-139	plutonium-239	Curium-244

Source: ORAUT-TKBS-0008-5.

Workers involved with device assembly in Area 27 had the potential for exposure to tritium, uranium-235, plutonium-239, and plutonium-240. NIOSH interviewed 14 former workers or their survivors, none of which reported involvement with device assembly. It is plausible that some NTS employees could have worked in device assembly, but based on the documentation NIOSH has reviewed, NIOSH is confident that very few NTS workers were associated directly with device assembly.

NTS used respiratory protection to limit inhalation of radionuclides when air sampling data exceeded the values listed in Table 7-8. The use of respiratory protection was included as part of the procedures for re-entry work (LRL, 1961; University of California, 1965).

Table 7-8: Respiratory Protection Action Levels

Year	Respiratory Protection
1957	No respirator ≤ 9.6 x 10^3 dpm/m^3 hrs (alpha) per quarter year
	No respirator (short periods) ≤ 100 dpm/m^3 (alpha)
	Respirator required > 100 dpm/m^3 (alpha)
	No respirator ≤ 2.2 x 10^4 dpm/m^3 (beta + gamma)
	Respirator required > 2.2 x 10^4 dpm/m^3 (beta + gamma)
	Note: Respirators using filters have an efficiency up to 99.9% for particles as small as 0.3 micron in diameter
1959	Ultra-filter respirator can be worn to levels < 500 dpm/m^3 (plutonium-239 alpha)
	Full-face mask with dust, fume, and mist canister required in levels from 500 to 10,000 dpm/m^3 (plutonium-239 alpha)
	Air-supplied mask recommended when levels > 10,000 dpm/m^3 (plutonium-239 alpha)
1968	0 to 100 dpm/m^3 (alpha)—no respiratory protection for short-term exposure
	4 x 10^{-11} µCi/cc (beta, gamma)—respiratory protection required
	100 to 100,000 dpm/m^3 (alpha)—high-filtration, full-face respirator (99.9% effective)
	Greater than the above levels—self-contained breathing apparatus

Source: ORAUT-TKBS-0008-5.

In summary, the primary elements of internal dosimetric concern at NTS include plutonium (plutonium-238, plutonium-239, plutonium-240, plutonium-241, plutonium-242), uranium (uranium-233, uranium-234, uranium-235, uranium-236, uranium-238) , americium (americium-241, americium-243), curium (curium-244), strontium (strontium-85, strontium-89, strontium/ yttrium-90), cesium (cesium-137), and tritium (H-3). Iodine was of concern following full criticality experiments (i.e., atmospheric testing and venting). Inhalation would have been the most significant mode of intake, so the lungs are organs of concern in all cases. Cesium and tritium irradiate the whole body relatively uniformly and do not concentrate in any one organ or type of tissue preferentially (ORAUT-TKBS-0008-5).

7.2.1 Bioassay Protocols Performed at NTS

The following subsections summarize monitoring performed at NTS and the extent and limitations of information available for reconstructing occupational internal doses potentially received by members of the proposed class.

7.2.1.1 Discussion of *In Vitro* Bioassay and Radionuclides

Allen (1993) states that periodic urine and/or fecal samples were collected and analyzed for plutonium-238, plutonium-239, elemental uranium, uranium-234, uranium-235, uranium-238, americium-241, strontium-89, strontium-90, tritium, and gross fission products. Common *in vitro* bioassays included:

- Tritium in urine by liquid scintillation beta counting,

- Strontium in urine by beta counting,
- Gross fission products in urine by beta counting,
- Uranium in urine by fluorometric analysis,
- Plutonium and americium in urine by alpha spectroscopy, and
- Radium, uranium, plutonium, and americium in feces by alpha spectroscopy.

NIOSH has documentation that fully describes the procedure, calibration, and interferences for each method used for bioassay, as well as documentation of all minimum detectable activities of the counting techniques.

Tritium—Tritium urinalysis was performed at NTS as early as 1958 (LASL, 1954). The 1958 tolerance for tritium in urine was listed as 85 µCi/L. In 1959, the maximum permissible concentration for tritium was listed as 1.2 mCi in the body, which yielded 0.1 rem per week. Records from 1966 to 1968 show that tritium analysis was conducted with a liquid scintillation spectrometer. In 1971, the urine sample tritium “alert level” was listed as 1×10^{-3} µCi/cc (Unknown author, 1951-1973).

Strontium—In 1961, the NTS laboratory published a sensitivity limit for strontium-90 in urine of 25 pCi/sample (Unknown author, 1951-1973). Starting in 1993, gas-flow proportional beta counting was used to quantify strontium-90 in urine at NTS. That latter method had a minimum detectable activity of 0.8 pCi/L, but the method did not differentiate between strontium-89 and strontium-90. Strontium-90 was monitored on a quarterly basis and as special, or occurrence, samples were taken.

Fission Products—In addition to performing bioassay for strontium, NTS conducted gross beta and gross gamma urinalysis to determine intakes of mixed fission and activation products. The term “gross fission product” was used rather than “gross beta.” This analysis actually was used for all beta-emitting radionuclides except the alkali group (e.g., cesium-134, cesium-137, and potassium-40) (Allen, 1993). The intent was to eliminate naturally occurring potassium-40 from the sample because the concentration of potassium in urine varies widely. By 1958, NTS was performing gross beta analysis by precipitating an aliquot and beta-counting the precipitate (Dummer, 1958). Depending on the beta result, a separate aliquot was used to prepare a sample for gross gamma-counting, using liquid scintillation (Dummer, 1958). In 1961, NTS analyzed urine samples for gross fission products before performing radionuclide-specific analyses (Geiger, 1961). Strontium, barium, lanthanide rare earths, and other fission products were co-precipitated with alkaline earth phosphate from an alkaline solution. The precipitate was assayed without further chemical treatment for total beta-emitters to obviate, in many cases, detailed radiochemical determination. If insignificant quantities of radioactive material were detected, no additional analyses were performed. Analyses for specific radionuclides could be requested if the gross beta activity exceeded the following control limits:

- Exposure to fission product mixture less than three months old – control limit was 1.0 pCi/mL; and
- Exposure to fission product mixture greater than three months or age unknown – control limit was 0.1 pCi/mL.

All radionuclide-specific results that exceeded 20% of the control limit should have been recorded on the worker's bioassay data card. It is possible that results equal to or less than 20% of the control limits were not recorded in the worker's history.
Specific analysis for cesium-137 in urine in 1961 involved sample preparation, cesium-phosphotungstate precipitation, and a specific gamma count (REECo, 1961). NTS used gamma-pulse height analyses to evaluate samples unless there was interference from higher-energy gamma-emitters, in which case NTS separated cesium as cesium-phosphotungstate, followed by pulse-height analysis. The sensitivity was listed as about 10 pCi per sample (REECo, 1961). In 1961, certain samples were examined with a gamma spectrometer to identify gamma-emitting components (REECo, 1961). Quantitative estimates were made in some cases. Special chemical separation schemes were devised as needed, based on the results of the initial pulse-height analysis. Reportedly, almost any gamma component could be identified by a combination of pulse-height analysis, chemical purification, and beta measurements.

Uranium—NTS tested for intake of uranium as early as 1954 (LASL, 1954) using a fluorophotometric method, which measured the yellow-green fluorescence produced by traces of uranium fused in sodium fluoride. The fluorescence method was sensitive to concentrations of uranium from 10^{-5} to 5×10^{-10} gram per 0.25 gram of sodium fluoride, with a precision of $\pm$10%. The tolerance for normal uranium in urine was 100 µg/L (LASL, 1954). An ion exchange method for separating uranium alpha activity in urine and counting was implemented in the late 1950s (Dummer, 1958). Using this method, it took three days to analyze nine samples (Dummer, 1958). Starting in 1958, NTS also used a uranium extraction method in which urine was ashed with nitric acid. Uranium was extracted from the acid and precipitated to platinum plates, fused, and counted for alpha particles using a low-background proportional counter. NTS could complete the analysis for about 25 samples in one day using this method (Dummer, 1958). NTS also performed an analysis for enriched uranium. The highly-enriched uranium analysis also used an alkaline co-precipitation of the uranium, but included several other wet chemistry steps. The resulting sample plate was analyzed by a gas flow proportional detector (Geiger, 1961). NTS also used a fecal analysis technique to monitor exposure to uranium-235.

Plutonium—NTS conducted urinalysis for exposures to plutonium as early as 1954 (LASL, 1954). Plutonium was co-precipitated with lanthanum fluoride on a stainless-steel plate and counted for alpha activity with a low-background proportional counter. Quantities on the order of 2 dpm or 2×10^{-11} gram of plutonium could be determined by this method. In 1961, NTS incorporated an anion exchange, electrodeposition method in which alpha tracks were counted (REECo, 1961; Unknown author, 1951-1973). Starting in 1968, alpha spectrometry was used to count plutonium-239 in urine samples (ORAUT-TKBS-0008-5, page 16) and the permissible bone burden for plutonium-239 was listed as 0.04 µCi (Unknown author, 1951-1973). Allen (1993) stated that plutonium urine and fecal samples were analyzed by alpha spectrometry, which could not differentiate between plutonium-239 and plutonium-240. As a result, urine samples were also analyzed by gamma spectroscopy. The gamma spectroscopy method had a higher minimum detectable activity than that of alpha spectrometry (Bechtel Nevada, 2003).

Americium—Like plutonium, NTS conducted urinalysis for exposures to americium as early as 1954 (LASL, 1954). Americium was co-precipitated with lanthanum fluoride on a stainless-steel plate. The plate was counted for alpha activity with a low-background proportional counter. In 1958, Los Alamos Scientific Laboratory used the same procedure for americium in urine and stated that thorium, plutonium, curium, actinium, and neptunium were carried through this determination. Quantities on the order of 0.5 dpm of americium could be detected by this method (ORAUT-TKBS-0008-5, page 15).

REECo documentation discussed an americium analysis method with steps for separation by precipitation/oxidation, purification by an ion exchange column, electrodeposition of americium-241/243 on a stainless-steel disc, and detection by alpha spectrometry during the period from 1981 through 1983. The procedure states that americium-241 was analyzed using americium-243 as a tracer. In 1993, the lower limit of detection for americium-241 was listed as 0.03 pCi/L with a note indicating that americium cannot be chemically differentiated from californium and curium (Allen, 1993). The routine bioassay was a quarterly urine sample and the special bioassay consisted of an additional urine sample and a lung count.

Radium—By 1958, NTS was using urinalysis to monitor for internal intakes of radium-226. Radium-226 was used at NTS in calibration activities. Using wet chemistry, radium was co-precipitated with barium as the sulfate. Polonium was removed by deposition on silver foil. The precipitate was slurried onto a stainless-steel plate and the alpha activity counted using a methane flow proportional counter. A 24-hour sample was usually collected for radium analysis (Dummer, 1958).

Special Fecal Analyses—Fecal sample analyses were conducted at NTS as a special bioassay, usually if there were indications that internal contamination had occurred or to confirm an intake of certain radionuclides (Allen, 1993). Fecal samples were analyzed by alpha spectroscopy for radium, uranium, thorium, plutonium, and americium (Allen, 1993; Bechtel Nevada, 2003). Alpha spectroscopy began in the late 1970s as a method of measurement. In the 1990s, some environmental projects to remediate plutonium-contaminated sites required periodic fecal bioassay (ORAUT-TKBS-0008-5, page 22).

7.2.1.2 Discussion of *In Vivo* Bioassay and Radionuclides

NTS performed the first *in vivo* analyses in 1961 when direct gamma counting was used to detect iodine-131 in worker thyroids. Counting procedures were written by REECo that document a method to analyze a worker's thyroid when the worker's urinalysis indicated exposure to radioiodine. By the procedure, nasal swabs were obtained to determine if the nose and mouth were contributing gamma activity and thereby falsely affecting the thyroid results. Thyroid counting was performed with the whole-body counting system by positioning the detector over the appropriate area and counting for 40 minutes (Allen, 1993).

In 1964, the Los Alamos Scientific Laboratory performed some *in vivo* analyses on NTS workers. NIOSH has no documentation to indicate where those analyses were performed. After that, Los Alamos Scientific Laboratory did use *in vivo* techniques at NTS to analyze potential intakes of employees who were assigned to NTS (Teasdale, 1985). The only significant time this procedure was used for NTS workers was during the YUBA incident (June 1963), but the information obtained was not included in the dose histories.

Helgeson Nuclear Services performed the first whole-body counting of REECo workers at NTS in 1967. Helgeson used a shadow shield that was transported in a trailer. Helgeson performed *in vivo* analyses at NTS on three different occasions during 1966 through 1967 (ORAUT-TKBS-0008-5, page 24). Some of the radionuclides, identified by body burden, are listed in Table 7-9. No information was provided indicating the type of job categories that were measured.

Table 7-9: Number of Workers[1] Receiving *In Vivo* Monitoring Before 1967

Nuclide	Body Burden			
	≤ 0.02 µCi	≤ 0.05 µCi	≤ 0.1 µCi	≤ 0.5 µCi
Zirconium-Niobium-95	98	43	16	6
Tantalum-182	102	17	3	1
Ruthenium-103, -106	34	1	-	-
Barium-Lanthanum-140	26	2	-	-
Iodine-131	2	-	-	-

Source: Adapted from ORAUT-TKBS-0008-5, page 25.
Notes:
- indicates that data are not available.
[1] By nuclide concentration

In 1967, Pan American Airways introduced a whole-body counter at NTS to analyze potential intakes of workers involved with the NRDS (Teasdale, 1985). The ownership and operation of the whole-body counter was transferred to REECo in 1974. Routine *in vivo* analyses were performed by NTS (REECo) on drillers, miners, and radiation monitoring personnel beginning in mid-1975. In 1977, NTS considered adding lung counting for low-energy X-ray detection, but the additional technique was believed to be cost-prohibitive (ORAUT-TKBS-0008-5). A new *in vivo* facility was constructed and operated from February 1981 through 1999. NTS used whole-body counting to confirm and assess exposures from gamma-emitting radionuclides, as discussed in ORAUT-TKBS-0008-5. Workers were counted while sitting in a chair with the back reclining about 30 degrees from vertical position. That geometry yielded an arc with the detector of 50 cm between the back and seat, providing a full view of the body trunk in relation to the detector. Workers were normally counted for 20 minutes by 1993. ORAUT-TKBS-0008-5 states that whole-body counts were performed for new employees who were likely to be included in the routine bioassay program; for a current employee who changed to a job classification that required a routine bioassay program; annually for employees who were currently on the routine whole-body count and bioassay program; for terminating employees; and for employees who had a suspected intake of radioactive material, particularly gamma-emitting fission and activation products (ORAUT-TKBS-0008-5, page 27)..

7.2.1.3 Air Monitoring Data and Documentation

Workplace air sampling was performed at NTS to monitor workplace conditions rather than to limit intakes of radionuclides; however, the air monitoring devices were positioned to provide samples representative of worker breathing zones. Workplace air monitoring was required in occupied areas that had the potential to exceed 10% of any Derived Air Concentration (DAC) value listed in DOE Order 5480.11 (DOE, 1988).

NIOSH has access to some personal air monitoring records that were provided by DOE for EEOICPA claimants. NIOSH has reviewed the personal air sampling records and area air monitoring data documented during major events at NTS. Air sampling records were associated with each facility and were stored as facility records. Boxes containing workplace monitoring records can be retrieved from

storage; however, locating a specific set of air sampling records would be very time-consuming and would provide only a marginal increase in accuracy for determining dose for the proposed class. These facility records could be obtained from NTS and utilized for the rare claims that require the most precise dose reconstruction for determining probability of causation.
Documentation available in *Operation Hardtack Phase II On-Site Rad-Safe Report* (REECo, 1958) listed air sampling reporting levels for airborne particulates as 2×10^{-6} µCi/m^3 (alpha) and 1×10^{-3} µCi/m^3 (beta). A 1959 Information Bulletin titled *Operational Guides for Above-Ground Drill Sites into Ground Zero Area*s (REECo, 1959) stated that if significant beta-gamma concentrations were indicated, a 1-hour Staplex sample should be collected and nasal swabs should be collected from each person possibly exposed. Records commensurate with these instructions are available for DOE claimants in NOCTS.

Radiological Safety for Underground Nuclear Explosions (Wilcox, 1960) described mining and drilling operations. Mining operations consisted of high-explosive blasting, removal of broken rock, and re-shoring of the tunnels. Radioactive debris from the mining operations was dumped with the mine tailings. In the report, NTS stated that the amount of non-radioactive material in the waste was sufficient to prevent significant radiation levels from accumulating. NTS also stated that airborne radioactivity in the mining work area was reduced by the liberal application of water and by natural water seepage (Wilcox, 1960). *Operation Guides for Tunnel Areas* (Wilcox, 1962) discussed workplace area samples, radon/thoron check methods, and nasal swabs that were taken from tunnel workers. *Operation Storax On-Site Radiological Safety Report* (REECo, 1964) mentioned air sample collection on the drill platform (high and low volume) at breathing level. *Dynamic Environmental Sampling Program* (Kimmel, 1963) discussed air sampling during drillbacks. *Reentry Problems Associated with Radiation from Underground Nuclear Detonations* (Brown, no date) discussed radiological conditions for atmospheric versus underground testing.

7.2.1.4 Radon

In the early 1980s, NTS recognized that the buildup of radon and radon daughter concentrations could pose a potential health problem in tunnels on Rainer Mesa and at other locations at the site. In 1984, Reynolds Electrical and Engineering Company, Inc. conducted radon measurement surveys in G-, T-, and N-Tunnels to determine the radon daughter concentration (Fauver, 1987). Other than radon and thoron that occurred naturally, NTS did not observe other operations that resulted in increased exposures. Radon daughter measurements performed in the N- and T-Tunnels were made in drifts that had been mined in a rock formation known as Tunnel Bed Non-Welded Ash Fall Tuff, which is mostly unconsolidated with slight fractures. The drift sampled in the inclined G-Tunnel was mined in Grouse Canyon Welded Ash Fall Tuff, which is extremely fractured. Concentrations of radon/radon daughters and subsequent measurements made in each of the tunnels were affected by the ventilation rate, the barometric pressures, the relative humidity, temperature inversions, the degree of fracturing in the rock, and the amount of smoke and dust in the air. The concentration of radon daughters in air is measured in units of working levels (WL). The WL was developed for use in uranium mines, but is now also used for environmental exposures. One (1) WL is equal to any combination of short-lived decay products in 1 liter (L) of air that will result in the emission of 1.3×10^5 MeV of potential alpha energy. Assuming that radon is in complete equilibrium with its short-lived decay products, 1 WL equals 100 pCi L^{-1} (i.e., 100 pCi/L each of radon-222 and short-lived decay products polonium-218, lead-214, bismuth-214, and polonium-214) (ORAUT-TKBS-0008-4, page 41). When considering exposure to radon-220 (thoron) and its decay daughters of polonium-216, lead-212, bismuth-212, and thallium-208, 1 WL is equal to 7.47 pCi/L. The advantage of the WL unit is that it allows comparison of different equilibrium levels and different concentrations of radon decay products. The degree of equilibrium is a critical factor for estimating inhalation exposure and is of equal importance to the radon concentration itself (ORAUT-TKBS-0008-4, page 41). The exposure of tunnel workers can be expressed in units of working-level months (WLM), which is an exposure rate of 1 WL for a working month of 170 hours (ORAUT-TKBS-0008-4, page 41). For example, an exposure of 1 WLM would result from exposure to a concentration of 1 WL for one month or 0.5 WL for two months.

Measurements taken in tunnels N, T, and G indicated ranges from 0.001 WL to as high as 0.24 WL. The higher values were observed when tunnel ventilation rates were noted to be low (ORAUT-TKBS-0008-4). The radon daughter concentrations in G Tunnel were an order of magnitude higher than those in N and T Tunnels. The average radon daughter concentration in the rock mechanics drift, which was found to be the worst case, was 0.13 WL. NTS performed additional radon and thoron measurements in 1991 and 1992 in G-, N- and P-Tunnels (Lyons, September 1992, November 1992). While the G-Tunnel complex was not used for production operations during 1992, radon samples were taken to document potential radon WL for a worst-case scenario of complete ventilation failure throughout the complex. The maximum WL for radon daughters was 1.4. No samples were taken during 1992 in T-Tunnel, which was inactive that year. Results of extensive radon sampling in N- and P-Tunnel complexes in 1991 and 1992 are provided in Tables 7-10 and 7-11 (Lyons September 1992, November1992). The average concentrations in N- and P-Tunnels were 0.021 and 0.009 WL, respectively, and the maximum concentrations in N- and P-Tunnel were 0.038 and 0.017 WL, respectively.

Table 7-10: Radon/Thoron Daughter Concentrations for N-Tunnel in 1991 and 1992

N Tunnel location	Radon-222 WL		Radon-220 WL	
	Average	**Maximum**	**Average**	**Maximum**
January–June 1992				
Miner's Lunchroom	0.005	0.007	0.01	0.016
Raytheon Alcove	0.003	0.004	0.005	0.008
Slow Alcove	0.005	0.007	0.008	0.009
24 Bypass Drift	0.005	0.006	0.015	0.015
24 LOS Drift at GZ	0.005	0.007	0.012	0.014
22 Bypass	0.006	0.007	0.013	0.015
July–December 1991				
Miner's Lunchroom	0.005	0.007	0.011	0.018
Raytheon Alcove	0.009	0.03	0.017	0.06
21 LOS at 2 + 50	0.034	0.059	0.029	0.046
15 Assembly Drift	0.006	0.009	0.015	0.021
Slow Alcove	0.004	0.008	0.01	0.025
23 Fast Alcove	0.009	0.014	0.018	0.03
24 Bypass Drift	0.005	0.007	0.012	0.041
24 LOS Drift	0.005	0.01	0.015	0.036
Average	**0.008**	**0.013**	**0.014**	**0.025**

Table 7-11: Radon/Thoron Daughter Concentrations for P-Tunnel in 1991 and 1992				
P-Tunnel location	**Radon-222 WL**		**Radon-220 WL**	
	Average	**Maximum**	**Average**	**Maximum**
January–June 1992				
01 Drift at Access Drift	0.001	0.001	0.002	0.005
01 Fast Alcove	0.001	0.001	0.004	0.006
02 Main Drift at 6 + 00	0.001	0.001	0.002	0.004
04 Reentry	0.001	0.002	0.004	0.005
04 LOS at 12 + 00	0.002	0.002	0.005	0.006
HPD Base Station	0.001	0.001	0.003	0.006
Miner's Lunchroom	0.001	0.001	0.003	0.006
05 Cavity	0.001	0.001	0.003	0.004
July–December 1991				
01 Drift at Access Drift	0.003	0.006	0.004	0.007
01 Fast Alcove	0.003	0.005	0.003	0.006
02 Main Drift at 6 + 00	0.01	0.032	0.01	0.046
04 LOS at VP X-Cut	0.008	0.013	0.012	0.015
04 LOS Drift at GZ	0.005	0.006	0.014	0.02
04 LOS Test Ch.	0.003	0.004	0.005	0.006
04 Bypass at RE#1	0.007	0.013	0.008	0.011
IHD Alcove	0.003	0.009	0.004	0.015
LLNL Alcove	0.003	0.006	0.007	0.02
05 Cavity	0.003	0.006	0.006	0.015
Average	**0.003**	**0.006**	**0.006**	**0.011**

7.2.2 Ambient Environmental Internal Radiation Doses at NTS

In total, more than 900 nuclear tests have taken place at NTS. One result of these tests is that the surface soil in many parts of NTS contains measurable amounts of several long-lived radionuclides. Almost all of the more than 100 aboveground tests contaminated the soil near ground zero. In addition, several underground tests were cratering experiments that threw radioactive rock and soil hundreds of feet, while some deeper underground tests vented radioactive material to the surface. A few safety tests scattered plutonium (and in some cases uranium) over the nearby ground. Finally, there was fallout of radioactive debris from many tests over the northern and eastern parts of the site. The greatest potential for environmental intakes of radioactive materials at NTS is the inhalation or ingestion of resuspended environmental contamination (ORAUT-TKBS-0008-4).

Atmospheric weapon and safety tests from 1951 through 1962 released approximately 1.2×10^{10} Ci to the atmosphere, much of which was from relatively short-lived radionuclides that decayed in a matter of days or weeks. In comparison, underground weapons testing released approximately 2.5×10^{7} Ci to the atmosphere from 1958-1988 (with only 5.4×10^{4} Ci being released between 1971 and 1988) (ORAUT-TKBS-0008-2). The volatile radionuclides (such as radioiodines, noble gases, and tritium) were diluted in the atmosphere and transported offsite. However, a large amount of the nonvolatile, long-lived radionuclides settled into the soil across the site (ORAUT-TKBS-0008-4, page 8). Environmental contamination has also occurred from releases of radionuclides from the low-level radioactive waste sites in Area 3 and Area 5. These releases have involved all radionuclides (other than short-lived fission products) handled at NTS and have affected each of the environmental pathways.

7.2.2.1 Ambient Environmental Radiation—Air Sampling

In 1964, REECo established an environmental surveillance program at NTS designed to measure radiological conditions throughout the site without regard to nuclear tests. The short-term objective of the program was to minimize casual personnel exposure to radiation by locating and identifying localized radiological environmental conditions by type and quantity of contamination. The long-range objective of the program was to establish baseline environmental data that could provide a reference for comparison with subsequent test activities and radiation measurements. The initial surveillance program grew to include, over time, 12 permanent air-sampling stations in the most populated areas at NTS (ORAUT-TKBS-0008-4, page 10).

After the first reporting period (June 1964), the number of sampling stations increased to 13 and caustic scrubbers were added to detect radioiodines. Early particulate samples were typically analyzed only for gross alpha and gross beta by gas-proportional counting. However, if gross beta concentrations exceeded 1×10^{-5} µCi/m^3, researchers conducted an analysis for actinium-227 (the most hazardous beta emitter present). Because no historical evidence exists that actinium-227 has been detected in air or soil samples, the assumption that unidentified beta emitters were actinium-227 would be unreasonable and inappropriate. Therefore, for purposes of dose reconstruction, strontium-90 is assumed to be the unidentified beta-emitting radionuclide with the highest internal dose (ORAUT-TKBS-0008-4, page 10).

Gross gamma screening was also typically performed on samples prepared for gross beta counting. The screening procedures are described in more detail in ORAUT-TKBS-0008-4. After atmospheric testing at NTS ended in 1962, fission products were frequently measured in the atmosphere but were typically correlated with foreign atmospheric weapons testing.

In 1971, weekly air samples from given stations were batched on a monthly basis and analyzed for plutonium-239. This analysis provided a nominal minimum detection limit of 3×10^{-7} µCi m^{-3} (ORAUT-TKBS-0008-4, page 11). Routine analysis of batched samples for plutonium-238 was implemented in 1989.

In 1977, a separate sampler was designed to collect airborne tritium and tritiated water vapor. The sampler was portable and capable of unattended operation for up to two weeks in desert areas.

7.2.2.2 Ambient Environmental Radiation—Soil Sampling

NTS performed extensive characterizations of residual contamination of soils and areas in the 1980s (McArthur, 1983, 1985, 1987, 1988, 1989, 1991). Table 7-12 lists the results of these studies. Table 7-13 lists the total area depositions, which are based on the inventory values in Table 7-12 divided by the respective area size. It should be noted that the results shown in Table 7-13 are representative of areas of NTS shown to contain measurable levels of contamination. This area actually represents only about one-third of the total area within the boundaries of NTS.

Table 7-12: Inventory of Contaminated Soil, Curies										
Area	**Area (mi^2)**	**Am-241**	**Pu-238**	**Pu-239, Pu-240**	**Co-60**	**Cs-137**	**Sr-90**	**Eu-152**	**Eu-154**	**Eu-155**
1	26.5	4.2	6.5	24	1.1	8.8	15	15	0.1	0.5
2	19.7	2.9	8.6	22	1.2	24	46	14	-	0.4
3	32.3	4.6	3.1	37	1	12	33	18	0.1	0.5
4	16	6.6	13	40	1.6	12	13	9.1	-	0.2
5	2.9	0.6	0.1	4.8	0.6	0.4	0.9	10	0.2	0
6	32.3	1.7	3.3	8.4	0.2	2.8	3.5	-	-	0
7	19.3	2.2	0.6	16	1	5.2	9.2	22	0.2	0.3
8	13.9	17	8	110	5.7	42	25	4.4		0.6
9	20	4.2	2.2	89	0.7	8.7	13	23	0.2	0.3
10	20	19	19	110	9.7	84	55	2.2	0.3	5
11	4	3.3	0.5	29	0	0.5	0.3	-	-	-
12	39.6	5.7	8.5	39	1.2	20	17	-	-	-
15	35.3	8	7.8	63	0.3	19	22	-	-	-
16	14.3	0.7	1.5	3.7	0.1	2.9	3.7	-	-	-
17	31.4	2.8	4.5	18	1	15	19	-	-	-
18	27.3	19	5.6	100	0.7	10	17	1.1	0.1	0.8
19	148.3	21	32	140	1.1	36	31	-	-	-
20	6.2	23	30	41	7.9	5.5	4.3	13	1.6	4.8
25	0.9	-	-	-	-	0.2	0.1	0.4	-	-
26	0.2	-	-	-	-	-	-	-	-	-
30	.0.3	3.2	4.5	14	0.8	1.5	1.3	0.7	0.1	0.2

Notes:
Source: McArthur, 1991
- No data are available

Table 7-13: Radionuclide Area Soil Deposition (Bq/m^2)									
Area	**Am-241**	**Pu-238**	**Pu-239, Pu-240**	**Co-60**	**Cs-137**	**Sr-90**	**Eu-152**	**Eu-154**	**Eu-155**
1	2.26E+03	3.50E+03	1.29E+04	5.93E+02	4.74E+03	8.09E+03	8.09E+03	5.39E+01	2.70E+02
2	2.10E+03	6.24E+03	1.60E+04	8.70E+02	1.74E+04	3.34E+04	1.02E+04	0.00E+00	2.90E+02
3	2.03E+03	1.37E+03	1.64E+04	4.42E+02	5.31E+03	1.46E+04	7.96E+03	4.42E+01	2.21E+02
4	5.89E+03	1.16E+04	3.57E+04	1.43E+03	1.07E+04	1.16E+04	8.13E+03	0.00E+00	1.79E+02
5	2.96E+03	4.93E+02	2.36E+04	2.96E+03	1.97E+03	4.43E+03	4.93E+04	9.85E+02	0.00E+00
6	7.52E+02	1.46E+03	3.72E+03	8.85E+01	1.24E+03	1.55E+03	0.00E+00	0.00E+00	0.00E+00
7	1.63E+03	4.44E+02	1.18E+04	7.40E+02	3.85E+03	6.81E+03	1.63E+04	1.48E+02	2.22E+02
8	1.75E+04	8.22E+03	1.13E+05	5.86E+03	4.32E+04	2.57E+04	4.52E+03	0.00E+00	6.17E+02
9	3.00E+03	1.57E+03	6.36E+04	5.00E+02	6.21E+03	9.29E+03	1.64E+04	1.43E+02	2.14E+02
10	1.36E+04	1.36E+04	7.86E+04	6.93E+03	6.00E+04	3.93E+04	1.57E+03	2.14E+02	3.57E+03
11	1.18E+04	1.79E+03	1.04E+05	0.00E+00	1.79E+03	1.07E+03	0.00E+00	0.00E+00	0.00E+00
12	2.06E+03	3.07E+03	1.41E+04	4.33E+02	7.22E+03	6.13E+03	0.00E+00	0.00E+00	0.00E+00
15	3.24E+03	3.16E+03	2.55E+04	1.21E+02	7.69E+03	8.90E+03	0.00E+00	0.00E+00	0.00E+00
16	6.99E+02	1.50E+03	3.70E+03	9.99E+01	2.90E+03	3.70E+03	0.00E+00	0.00E+00	0.00E+00
17	1.27E+03	2.05E+03	8.19E+03	4.55E+02	6.82E+03	8.64E+03	0.00E+00	0.00E+00	0.00E+00
18	9.94E+03	2.93E+03	5.23E+04	3.66E+02	5.23E+03	8.90E+03	5.76E+02	5.23E+01	4.19E+02
19	2.02E+03	3.08E+03	1.35E+04	1.06E+02	3.47E+03	2.99E+03	0.00E+00	0.00E+00	0.00E+00
20	5.30E+04	6.91E+04	9.45E+04	1.82E+04	1.27E+04	9.91E+03	3.00E+04	3.69E+03	1.11E+04
25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E+03	1.59E+03	6.35E+03	0.00E+00	0.00E+00
26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	1.52E+05	2.14E+05	6.67E+05	3.81E+04	7.14E+04	6.19E+04	3.33E+04	4.76E+03	9.52E+03

7.2.2.3 Statistical Modeling of Environmental Data for Dose Reconstruction

With atmospheric testing at NTS ending in 1962, the greatest potential for environmental intakes of radioactive material became the inhalation of radioactive particles re-suspended into the atmosphere and the ingestion of soil previously contaminated by atmospheric nuclear weapons tests and safety tests. NIOSH has developed an ambient environmental data model using NTS annual environmental air monitoring data, as discussed in Section 7.2.2.1, and the extensive soil contamination data gathered between 1983 and 1991 for use in reconstructing internal doses for NTS employees. The data used to develop the model have been professionally critiqued in the *Health Physics Journal* and several DOE reports (Fauver, 1987; Hicks, 1981a, 1981b, 1981c, 1981d; Kinnison, 1997; Lyons September 1992, November 1992; McArthur, 1983, 1985, 1987, 1988, 1989, 1991; Scoggins, 1983; Wruble, 1990).

Air monitoring was limited to analysis of gross alpha and beta measurements, tritium, and isotopes of plutonium (e.g., plutonium-238, plutonium-239, and plutonium-240); the model was developed to include inhalation intakes of other relatively long-lived radionuclides identified in NTS soil, including americium-241, cobalt-60, cesium-137, strontium-90, europium-152, europium-154, and europium-155. Intakes of those latter radionuclides were scaled to those of plutonium based on their relative abundance in NTS soil. Ingestion intake factors were estimated by assuming consumption of the contaminated NTS soil. To ensure that both inhalation and ingestion intakes are not underestimated, the relative abundance of the long-lived radionuclides identified in NTS soil, as determined using the 1991 soil contamination data (McArthur, 1991), were decay-corrected back to 1963. In addition, to ensure that intakes and resultant doses were not underestimated, correction factors were developed to account for potential exposures to short-lived fission and activation products based on test-specific data provided by Hicks. Finally, a correction factor was added to the model for inhalation intakes, which account for the phenomenon of early re-suspension and mass loading (Anspaugh, 2002). The model also incorporates area-specific inhalation and ingestion rates for use when worker's work locations are known. The resulting intake rates are supported by resuspension and air concentration studies performed in the early 1980s that are applicable to work performed outdoors in soil contaminated areas, which showed low air concentrations even after soil disturbances (McMahon, 2003). These studies indicated the highest concentrations were less than 2% of the current derived air concentrations after disturbing soils contaminated with plutonium and americium in the hundreds of pCi/g levels.

The derived ambient model was developed to address the unique character of NTS—a large outdoor testing facility where potential exposure to radioactive materials was primarily based on residual contamination from atmospheric testing—and to augment the lack of internal monitoring data for some radionuclides. For most NTS employees, the occupational internal dose can be equated to the dose they potentially received from the re-suspension of residual radioactivity from the atmospheric testing (i.e. environmental internal dose). For workers who worked primarily indoors (cafeterias, administrative facilities, and maintenance shops) the internal dose calculated from the model represents an overestimate of any actual internal exposure.

Some covered employees stayed onsite continuously for weeks at a time. NIOSH finds that the intake values would provide overestimates for these resident employees as well. Most workers spent a considerable portion of the non-working hours indoors (sleeping, etc.) where ambient air particulate loadings would have been greatly reduced from the outdoor loadings. The model uses the following conservative assumptions that would produce claimant-favorable results for these resident employees:

1) radionuclides fractions were modeled using maximum plutonium annual air concentration measured for all NTS areas between 1971 and 2001, 2) radionuclide scaling factors were based on the highest ratio of soil contamination to plutonium-239 of each of the radionuclides in any of the NTS areas, and 3) fission product intake rates were based on data intakes calculated using short-lived fission and activation product data obtained during from the Storax Small Boy test, which provided the highest fission product doses. Additionally, employees living onsite during their work week would have been housed in Area 12 or Area 23 (Mercury) where air sampling results were less than the NTS site average values. Details, including mathematical and statistical derivations, are provided in Rollins, 2007.

7.2.3 Internal Dose Reconstruction

At NTS, the source term was specific to each research event, and in some cases quantities of specific radionuclides and ratios remain classified. The open literature contains no information about the ratios of plutonium and uranium for these tests. As discussed in ORAUT-TKBS-0008-6, emphasis was placed on monitoring external radiation exposure. During the atmospheric testing period, internal monitoring was only performed based on the worker being identified as contaminated; therefore, a worker who was not suspected of contamination would not have been screened by nasal swab. Nasal swabs were taken on a regular basis from any worker involved in decontamination activities. If contamination was indicated, the individual received bioassay (usually urinalysis). While a statistical hypothesis suggests that up to 40% of workers were monitored, NIOSH does not have documentation of the exact number of workers who were bioassay monitored before 1993. NIOSH will not be able to reconstruct internal radiation doses using bioassay data alone and will necessarily use the ambient environmental data model to reconstruct intakes when worker bioassay data are not available.
The feasibility of reconstructing internal doses will be presented by scenarios and grouped by operation/process as shown in Table 7-14. The feasibility discussions have been broken down by monitored and unmonitored workers. Examples of dose reconstructions will be provided for each scenario.

Table 7-14: Worker Group Internal Dose Scenarios by Process

	Drill-back Operations	**Reentry & Mine Back**	**Routine Tunnel Operations**	**Atmospheric Weapon Safety Tests**	**Nuclear Rocket Development**	**Decontamination Facility**	**Radiochemistry Lab**
Scenario	1	1	2	3	3	3	3
	Test Treatability	**Device Assembly**	**Radiography Operations**	**Well-logging Operations**	**Radiation Instrument Calibration**	**Low-Level Waste**	**All other workers**
Scenario	3	4	3	3	3	3	4

It is likely that some workers would fit into more than one scenario. For such a worker, the dose reconstruction criteria for each scenario, as discussed below, will be applied for the relevant time periods.

While documents discuss the use of respiratory protection at NTS, NIOSH does not take this protection into account when performing dose reconstructions. The assignment of dose considers that respirators were not used, thus assuming a higher internal dose than would be realized if the respiratory protection factors were accounted for.

7.2.3.1 Scenario One

Scenario One includes miners, drillback workers, and other workers associated with underground work who routinely had significant potential for internal intakes of radioactive materials. Occupational radon is not included in the definition of radioactive materials for the purposes of Scenario One, as it is addressed under Scenario Two.

NIOSH has evidence that these workers, associated with Scenario One, were bioassay monitored and that their doses can be reconstructed using worker bioassay data. In the event that a worker was not monitored, a combination of source term data, air monitoring data, and bioassay results (which are available for the 100 workers as given in Table 7-1), can be used in the development of a dose reconstruction method for those workers. As documented in ORAUT-TKBS-0008-2 and during personal communications with former health and safety professionals of NTS and Lawrence Livermore National Lab working at NTS, ventilation was used to exchange air in tunnels, prior to routine operations in the tunnel environment, with the outside air. To ensure that environmental dose from aboveground conditions that could have been brought into the tunnels is accounted for, each underground worker should be assigned ambient dose from the environmental model. Specific procedures for reconstructing these doses are documented in ORAUT-TKBS-0035-5 and Rollins, 2007.

Missed tritium doses should be calculated and assigned using *Technical Information Bulletin: Tritium Calculated and Missed Dose Estimates*, ORAUT-OTIB-0011.

7.2.3.2 Scenario Two

Scenario Two includes underground workers who routinely had the potential for internal intakes of radioactive materials (including radon). Workers in this scenario may have been monitored for some intakes and for some periods of time.

Determining doses for NTS workers involved in the processes listed as Scenario Two in Table 7-14 should use the same approach as Scenario One, with the additional component of adding internal dose received from exposure to radon and thoron progeny. Specific procedures for reconstructing these doses are documented in ORAUT-TKBS-0035-5; Rollins, 2007; and other NIOSH Technical Information Bulletins. Instructions are provided in ORAUT-TKBS-0008-4 and OCAS-TIB-0011 for reconstruction of potential doses received from exposure to radon and thoron. Missed tritium doses should be reconstructed using ORAUT-OTIB-0011.

7.2.3.3 Scenario Three

Scenario Three includes aboveground workers who routinely had the potential for internal intakes of radioactive materials. Workers in this scenario may have been monitored for some intakes and for some periods of time.

Doses for NTS workers involved in the processes listed as Scenario Three in Table 7-14 can be reconstructed with sufficient accuracy. Actual bioassay data provided, including *in vivo* and *in vitro* data for the worker, should be used to determine the inhalation and ingestion intakes of fission products, uranium, plutonium, transuranic radionuclides, and tritium. When bioassay data is not available for workers for some or all of the employment time, inhalation and ingestion intake values and conversion factors provided in the ambient environmental model can be used to reconstruct doses (Rollins, 2007). NIOSH has demonstrated in this evaluation report that workers most likely to have received intakes of radionuclides were also monitored for that exposure. Workers who were not likely to be internally exposed to radionuclides, other than those in the NTS environment, were not monitored for intakes. Internal doses calculated from the ambient environmental model may be used to estimate doses to aboveground workers who were not routinely monitored for intakes. When the worker location is not included in the documentation, NIOSH may apply site-wide maximum values and factors to develop a conservative estimate of ambient environmental dose. Using the ambient environmental model is a conservative approach for estimating internal exposures for workers who were not bioassay monitored because:

- The model considered both resuspension and mass loading of radionuclides;
- Radionuclide fractions were modeled relative to maximum plutonium annual soil concentration measured for all NTS areas between 1971 and 2001. Radionuclide activity data for the soil were decay corrected to January 1, 1963;
- Radionuclide intake scaling factors were derived by comparing the modeled radionuclide fractions to intakes of plutonium calculated from air sampling data; and
- Fission product intake rates were based on intake calculations using short-lived fission and activation product data obtained from the Storax Small Boy test, using factors selected to provide the largest dose to the organ of interest.

In reconstructing missed tritium doses, doses should be calculated and assigned using ORAUT-OTIB-0011.

For workers reported by DOE records to have been involved in one or more release events, any additional intakes beyond those calculated using the ambient environmental model will be derived and used to calculate internal doses received from those events.

Instructions are provided in ORAUT-TKBS-0008-5.

7.2.3.4 Scenario Four

Scenario Four includes workers who have no bioassay monitoring and for whom there is nothing, in the form of documentation or statements provided, to suggest a work history with the potential for internal exposures to radionuclides.

Doses for this group of workers will be bounded using radionuclides shown in Table 7-12, other than the short-lived radionuclides, and by using the corresponding site-wide ambient environmental model intake values and conversion factors (Rollins, 2007). These workers will not be assigned any dose resulting from radon and thoron progeny, from tritium, or from short-lived radionuclides. Specific procedures for reconstructing these doses are document in ORAUT-TKBS-0035-5; Rollins, 2007; and other NIOSH Technical Information Bulletins.

7.2.4 Internal Dose Reconstruction Feasibility Conclusion

Potential for radionuclide intakes existed throughout NTS. NTS sought to limit internal exposures and maintain a bioassay program. NIOSH has demonstrated that employees with the greatest potential for internal intake were monitored and NIOSH has determined that the available bioassay data can be used to reconstruct or bound potential internal radiation doses for those employees. In addition, NIOSH has identified a significant amount of professionally reviewed environmental data that can be used with the bioassay data to reconstruct internal radiation doses. The environmental data were used to model aboveground intakes that may be applied to all NTS workers. NIOSH has also identified the major operational and incident source terms for NTS. Further, NIOSH has sufficient information to adequately assess and bound potential doses that may have occurred due to the radiological operations conducted at NTS for those workers who had a lower potential for the intake of radioactive materials and were not bioassay monitored. NIOSH can reconstruct doses arising from exposure to tritium, uranium, plutonium, mixed fission products and activation products, radon, and thoron using the scenarios presented in Section 7.2.3. The four scenarios, as presented by NIOSH in this document, may be used to reconstruct missed internal dose.

Given the documentation and data currently available to NIOSH, it is possible to accurately reconstruct the internal doses that would have resulted from intake of radionuclides at NTS for the period of January 1, 1963 through September 30, 1992 for all workers.

7.3 External Radiation Doses at NTS

The principal source of external radiation doses for members of the proposed class are described in Section 5 of this report. As documented in ORAUT-TKBS-0008-6, the most plausible external radiological exposure scenarios were directly due to residual radioactive contamination from atmospheric and underground weapons testing, exposure due to experimental reactor tests intended for aircraft and rocket propulsion, and exposure to fission and activation products from test programs (ORAU-TKBS-0008-6, page 9). Occupational external exposures could have included beta, gamma, and neutron radiation, as well as X-rays from required periodic medical examinations.

7.3.1 Process-Related External Radiation Doses at NTS

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

7.3.1.1 Radiation Exposure Environment

NTS workers potentially received occupational exposures from a range of fission and activation products from test programs that were conducted in the early 1950s. The potential external radiation exposures arose primarily from the fission and activation products handled at NTS. In addition, there is a limited potential for neutron exposure from handling transuranic radionuclides, isotopic sources, and reactor operations.

The external dose received by workers at NTS was a function of the physical location of the workers on the site, the work they were involved with, and when they were present onsite relative to the different tests. The analyses of the drillback cores of some shots show a high abundance of activation products and others show mostly fission products.

In April 1957, NTS began a universal external monitoring program, requiring all employees to wear, at a minimum, a film dosimeter for measuring radiation exposure. The external exposure of concern at NTS was primarily due to beta and photon radiation-emitting nuclides.

Beta and Photon Characterization

The beta and photon radiation at NTS is characterized in ORAUT-TKBS-0008-2 and ORAUT-TKBS-0008-6.

As discussed in Section 5.3.4 of this report, most of the 250 individual fission-produced radionuclides are beta-particle emitters. The composition and beta-energy spectrum subsequent to a test is not constant, but for the beta produced by the decay of fission and activation products, the maximum energy typically does not exceed 3 MeV (ORAUT-TKBS-0008-6). Exposure to beta particles with energies below 70 keV imparts no beta dose to the skin because beta particles with energies below 70 keV have insufficient energy to penetrate the keratinized dead outer layer of the skin; therefore, the beta energy range of concern is from 70 keV to 3 MeV.

As further discussed in Section 5.3.4, the residual photon radiation intensity depends on a number of factors that vary from test to test, but relatively few radionuclides comprise the significant contributors to the photon spectrum. The photon energy spectrum then depends on the relative abundance of each of the radionuclides present in the area. At NTS, the radiation field is primarily comprised of photons with energies between approximately 100 keV and 2 MeV (ORAUT-TKBS-0008-6). The special case of exposure to noble gases during post-test drilling can include a significant increase in the exposure to photons with energies below 100 keV (ORAUT-TKBS-0008-6).

Neutron Field Characterization

The potential for neutron exposure at NTS has been limited since the start of site operations. Operations involving potential neutron exposures are classified as weapons-related, isotopic neutron source-related, or reactor operations-related. Section 5.3.3 of this report and ORAUT-TKBS-0008-6 provide more detailed information regarding the potential for neutron exposure at NTS.

Design Laboratory workers in the vicinity of sealed pits (those not associated with high explosives were known as “bare pits”) were potentially exposed to neutrons emanating from the pits. Dose records for Design Laboratory employees were routinely reported to the sponsoring laboratory and are available to NIOSH on an individual basis. All NTS exposures relating to assembly operations can be assessed on a case-by-case basis, using any available dosimetry data and, as necessary, geometrical correction factors and neutron-to-photon dose ratio techniques derived from DOE complex experience with weapons assembly operations.

Workers involved with isotopic neutron sources or with reactor operations were monitored through the use of personnel neutron dosimeters. Additional information regarding the neutron fields that workers were potentially exposed to is available to NIOSH. There is no indication that neutron-spectral measurements were conducted at NTS for radiation protection purposes; however, the

International Atomic Energy Agency (IAEA) has compiled extensive neutron-spectral functions, instrument and dosimeter response functions, and dosimetric quantity response functions. Because the source spectra for NTS operations are limited to those discussed previously in this section, it is possible to adequately determine the spectra by selecting the proper neutron production mechanism, moderation conditions, and scatter conditions from the spectral catalogs that best simulate those conditions for NTS operations.

7.3.1.2 History of Whole-Body External Monitoring

Radiation monitoring and control programs instituted from the beginning of NTS operations included personal dosimetry, area monitoring, source term characterization, and measurements of fallout dispersion (contamination). As NTS test programs progressed, efforts to measure radiation exposures and limit dose improved. Universal dosimetry badging, in the form of film badges, was instituted at NTS in April 1957, and film badges were routinely issued to all persons entering and working at the site. Film badges were exchanged routinely for all individuals and, in addition, upon existing radiation areas if an exposure of 100 mR or more was suspected. In addition to film badges, self-reading pocket dosimeters were issued to persons entering controlled radiation exclusion (radex) areas, which were controlled locations at which an exposure was usually expected. The purpose of issuing pocket ionization chambers to persons entering a radex area was to provide an action alert. A high reading of a pocket ionization chamber triggered the action of collecting and processing the personnel dosimeter being used at the time. Pocket ionization results were not used to assign dose to an individual's record unless the personnel dosimeter integrity had somehow been compromised. The pocket ionization chamber result would have been included in a special investigation of the incident.

Only a small percentage of the workers at NTS were potentially exposed to neutron radiation and this exposure would typically be accompanied by beta and photon radiation. For workers involved in work areas with a possibility of neutron exposure, personnel neutron dosimeters (Kodak NTA film badges, Albedo dosimeters, or Track Etch Detector dosimeters) were used to monitor exposure. Because of the energy dependence of the various personnel neutron dosimeters used at NTS and throughout the DOE complex, the detection limits for neutron dosimeters are dependent on the operational neutron spectra encountered. ORAUT-TKBS-0008-6 contains information regarding the neutron spectra associated with the specific activities having the potential for occupational neutron exposure.

Until the 1966 change to the DuPont Type 556 film pack, the determination of shallow or skin dose by reading the film badges was limited to higher-energy radiation because of the thickness of the lead filter.

For more complete information regarding the history of personnel whole-body monitoring, refer to ORAUT-TKBS-0008-6.

7.3.1.3 History of Extremity Monitoring

Extremity dosimetry has been used at NTS to assess exposure to fingers, hands, forearms and even the head (on rare occasions, recognizing that the head is not considered to be an extremity) that might have occurred during operations in proximity to, or the manual manipulation of, radioactive material and radiation-emitting objects. Few operations at NTS would require extremity monitoring. An example of a NTS worker requiring extremity monitoring might include a radiation technician involved in handling post-test core samples.

The dosimeter (film or thermoluminescent dosimeter) was worn in a position that was intended to represent the highest exposure to the extremity, usually on the inside of the wrist in the case of film, or on the finger near the fingertip in the case of finger rings. The extremity being monitored is normally identified in the dose record using the codes shown in ORAUT-TKBS-0008-5, Table A-2.

The regular use of thermoluminescent dosimeter finger rings was documented in 1967 (ORAUT-TKBS-0008-6, page 30). Extremity monitoring occurred on rare occasions prior to that time (ORAUT-TKBS-0008-6).

Further information on the extremity monitoring program at NTS, as well as guidance on how to treat the dose recorded, is available in ORAUT-TKBS-0008-6).

7.3.1.4 Dosimetry Records

As discussed in Section 6.0 of this document, NTS used facility and individual worker monitoring methods to measure and control radiation exposures. Hardcopy radiation exposure records and film from dosimeters are available from NTS. NTS undertook a considerable effort to consolidate all dosimetry records in what was originally called the Dosimetry Research Project (DRP) (now known as the Nuclear Testing Archive) (Personal Communication, 2005).

7.3.1.5 Application of Co-Worker Data for External Dose Reconstruction

NTS employed a universal badging procedure in April 1957, making co-worker studies for external dose reconstruction after that time unnecessary.

7.3.2 Ambient Environmental External Radiation Doses at NTS

All workers at NTS were monitored for external radiation exposures (as discussed in Section 7.3). Ambient doses resulting from exposures to beta particles and photons were recorded on employee film badges/dosimeters. The geometry used for dosimeter calibration (which is more representative of the occupational Anterior-Posterior (A/P) exposure geometry for radiological workers) is likely very different from that associated with external environmental exposures. Environmental radiation sources are generally highly extended and isotropic as compared to the point sources placed near the dosimeter for calibration. The dose assessment for external environmental exposures requires that attention be given to the angular/directional dependence of the dosimeter, the angular/directional dependence of the dosimetric quantity used for monitoring purposes, and the dose of specific organs relative to the location of the dosimeter. Environmental exposures at NTS are characterized by complex photon spectra due to the presence of a large number of fission and activation product radionuclides. The energy spectrum is further complicated by the attenuation of lower-energy photons by both soil and distance from the source. These considerations relative to external environmental exposures at NTS have been evaluated and addressed for dose reconstruction using data on angular dependence of dose conversion factors. Calculations of the correction factors for organ geometry relative to the dosimeter have been performed for exposure to 1) fallout from atmospheric tests, 2) radionuclides released by underground test leaks, and 3) nuclear rocket and ramjet tests for exposures from time of test to 50 years following the test (ORAUT-TKBS-0008-6, page 46). ORAUT-TKBS-0008-6 notes that the radionuclide and geometry-dependent dose conversion factors were taken from Eckerman et al. (1999). Results of these calculations show that the correction factors for environmental radiation fields found at NTS are not significantly different from unity for most organs; these values are less than 1. Given the low environmental external exposure rates at NTS, it appears that the new DCFs would not have a significant impact on the assigned environmental doses in comparison to the NIOSH dose estimates that are favorable to claimants (ORAUT-TKBS-0008-6, page 46).

As there are no unmonitored employees receiving unmonitored environmental external dose, further consideration of environmental external dose is not necessary.

7.3.3 NTS Occupational X-Ray Examinations

Diagnostic X-ray procedures contributed to the occupational radiation exposure of NTS workers. In general, the dose from these exposures was not measured, considered, or included as part of the overall occupational exposure of the employee, although it was clearly related. The passage of EEOICPA recognized diagnostic medical X-rays administered in conjunction with routine or special physical examinations required for employment as a valid source of occupational exposure.

Unlike occupational exposures incurred during normal work processes, individual diagnostic medical X-ray exposures were not actively monitored, necessitating reconstruction of these exposures. NTS practiced universal badging, whereby employees received film badges on arrival at the Mercury gate for work. In some instances, workers wore those badges during initial employment physicals, which included routine posterior-anterior and lateral chest x-rays. Examination of these badges provided measured doses for those chest X-rays.

Extensive review of available documentation on the occupational medical program at NTS from 1951 to the present revealed that two medical radiographic procedures were commonly administered in connection with pre-employment, periodic, or post-employment medical examinations: the 14- by 17-in. posterior-anterior (PA) chest films and the 14- by 17-in. lateral (LAT) chest films.

Some of the claim file records have lumbar spinal exams that may also have been performed for screening (especially during pre-employment physicals) as opposed to injury. Organ doses for lumbar spinal exams can be found in ORAUT-OTIB-0006.

In the early years at the site, periodic X-ray examinations were provided on an annual basis for workers who were required to wear respiratory protection, upon beginning employment, and on a two-year frequency after that. In the early years, individuals in at-risk groups could have received medical examinations including X-rays at various, perhaps even more frequent, intervals. Such workers can be identified from specific medical records. Other employees neither working with radiation nor required to wear respiratory protection could have had X-rays on a two-year frequency. The X-rays could have been both PA and LAT exposures for most workers when medical examinations were required (ORAUT-TKBS-0008-3).

For NTS, waveform is of minor significance in relation to reconstruction of worker exposure because actual output measurement data are available from 1957 to 1992. Before 1957, machine techniques are not available and estimates of X-ray exposures are based on references providing median dose for 1950 to 1957 (ORAUT-TKBS-0008-3, page 10).

Available data, including direct beam measurements, indicate that X-ray beams used at NTS were well-collimated (ORAUT-TKBS-0008-3, page 11).

Table 7-15: Frequency of PA and LAT Chest X-rays at NTS

Period	Frequency	Comment
1951–1/1/1957[3]	Entrance[1,5]	All employees
	Exit[1]	All employees
	Biennial[2, 5]	For workers respirator qualified[4]
1/1/1957–Present[3]	Entrance[1]	All employees[6]
	Exit[1]	All employees[6]
	Biennial	For workers respirator qualified[4]

Source: Adapted from ORAUT-TKBS-0008-3, page 14.
Notes:
[1]Entrance and exit X-rays were provided from 1951 through January 1, 1957. These X-rays were not required after 1980 unless personnel were in a job class that required an X-ray.
[2]Older workers above age 45 might have been required to have X-ray examinations.
[3]The LAT chest dose is not added to the overall worker dose unless there is a record of the examination in the worker's file.
[4] This exam included pulmonary function to determine lung capacity.
[5]Private contractors might have performed X-ray examinations offsite until the mid-1960s.
[6]Workers normally did not have LAT X-ray examinations and PA examinations might have been optional.

Specific information on the calculation of dose from the two X-ray procedures used at NTS for dose reconstruction can be found in ORAUT-TKBS-0008-3.

7.3.4 External Dose Reconstruction

By April 2007, 1,471 EEOICPA claims from NTS workers had been submitted to NIOSH. Of those 1,471 claims, 1,287 are for energy employees within the proposed class. Dose reconstructions have been completed for 900 of the 1,287 claims.

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

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

7.3.4.1 Photon Dose

Photon radiation dose reconstruction for NTS workers from 1963 through 1992 requires consideration of dosimeter response, photon field characteristics, and determination of any missed dose for monitored workers due to low dose (less than minimum detection level) results. NIOSH has sufficient information regarding the dosimetry used over the history of NTS operations to statistically account for dosimeter response considerations (bias and uncertainty), based on the dosimeter in use at the time of potential exposure (ORAUT-TKBS-0008-6).

For external dose reconstruction, the claimant-favorable assumption that photon energies are between 30 and 250 keV is used along with the external monitoring data provided by NTS when the conditions of exposure are unknown. If there is indication of exposure to freshly produced nuclides (as in the case of early re-entry teams), assuming that 75% of the photon dose was from photons with energies above 250 keV (ORAUT-TKBS-0008-6, page 36) would be reasonable and favorable to claimants. With adequate documentation linking exposures to a particular NTS work area/activity, ORAUT-TKBS-0008-6 provides guidance on a reasonable allocation of the recorded exposure or personal dose equivalent to the energy groups 30-to-250 keV and greater-than-250 keV, based on radionuclide inventories. For the period from 1961 to 1966, a contribution amounting to 25% of the total reported dose is added by NIOSH to the dose estimate for photons in the range of 30 to 250 keV to account for low-energy photons attenuated by the lead filter that covered a portion of the film. From 1966 onward, when the multi-element dosimeter was introduced (ORAUT-TKBS-0008-6, page 54), this addition is no longer necessary.

Missed dose occurs when the dose of record is less than the minimum detection level. Missed photon dose will be assigned based on OCAS-IG-001 and by using the minimum detection level data in Table 6-1 of ORAUT-TKBS-0008-6 to calculate the missed photon dose.

7.3.4.2 Electron Dose

In contrast to gamma rays and neutrons, beta rays have a finite range in matter determined by the energy of the beta particle. The maximum range associated with a beta produced by the decay of fission and activation products typically does not exceed approximately 36 feet. Therefore, an individual at a distance greater than 36 feet from a source of beta radiation would not receive an external dose from that beta radiation. Similarly, a person would receive no radiation dose to the skin from beta particles with energies less than 70 keV, because that is not sufficient energy to penetrate the dead, keratinized superficial layer of the epidermis (ORAUT-TKBS-0008-6, Section 6.3.5.2).

In the event that personal dose records do not include estimates of beta dose, an estimate will be made from the associated photon (gamma + X-ray) exposure or dose equivalent using beta-photon ratios. Three common geometries associated with beta exposures are (1) standing on a contaminated surface, (2) immersion in contaminated clouds, or (3) exposure to discrete sources (ORAUT-TKBS-0008-6, page 46).

External beta doses from standing on contaminated ground or other surfaces will be calculated by applying a beta-to-gamma dose ratio to an estimated upper-bound gamma dose, which is determined from film badge data or dose reconstruction (ORAUT-TKBS-0008-6, page 47).

Immersion in a contaminated fallout debris cloud was a less likely circumstance than exposure to fallout after deposition on the ground or other surface given access controls employed by the site. However, exposure of workers to plumes of radioactive gas probably occurred following releases from underground tests. External beta doses from immersion in a contaminated cloud or plume can be calculated by applying a beta-to-gamma dose ratio to an estimated upper-bound gamma dose, which is determined from film badge data or dose reconstruction (ORAUT-TKBS-0008-6, page 47).

If the potential exposure was likely due to discrete sources of beta-emitting nuclides, application of beta-photon ratios associated with such conditions can be used. The beta-photon ratio can be estimated from the radionuclide inventories known to be associated with a particular activity (ORAUT-TKBS-0008-6, page 48).

More specific guidance is provided in ORAUT-TKBS-0008-6 on how to determine the best beta-to-photon ratio to be applied to estimate the beta dose from the relevant photon dose. Guidance is also provided using VARSKIN calculations to estimate dose to the skin resulting from contamination.

7.3.4.3 Neutron Dose

There is no indication that neutron-spectral measurements were conducted at NTS for radiation protection purposes. The spectra at NTS have been generally unmoderated and rich in fast neutrons; however, in some operational situations considerable scattering could have occurred, resulting in some softening. The International Atomic Energy Agency (IAEA) has compiled extensive neutron-spectral functions, instrument and dosimeter response functions, and dosimetric quantity response functions. Attachment A of ORAUT-TKBS-0008-6 presents additional detail regarding neutron-spectral characteristics. Because the source spectra for NTS operations are limited to those discussed in Section 5.3.3, adequate simulation can be obtained by selecting the proper neutron production mechanism and moderation and scatter conditions from the spectral catalogs that best simulate those for NTS operations. Guidance for the selection of parameters to determine the appropriate neutron characteristics is provided in ORAUT-TKBS-0008-6. The primary *Hp(10)* (personal dose equivalent for penetrating radiation of significance to the whole-body dose – 10 millimeters or greater in depth) contributions at NTS fall in the energy ranges 100 keV-to-2 MeV and 2 MeV-to-20 MeV. Therefore, for dose reconstruction efficiency purposes, NIOSH makes the claimant-favorable assumption that neutron energies are within the 100-to-2,000 keV range (ORAUT-TKBS-0008-6, page 50).

NTA film, used until 1979, could underestimate doses by 55% or more because the detection threshold for the film is about 0.8 MeV (ORAUT-TKBS-0008-6, page 46). A bias correction factor of 2.5 is applied to account for potential under-response in lower-energy neutron fields. The bias should also correct for the ratio of *dose equivalent H*-to-*personal dose equivalent Hp(10)* conversion coefficients of 2 in the 0.1-to-2 MeV energy range (ORAUT-TKBS-0008-6, page 50). If the fractional neutron contribution in the 2-to-20 MeV range is well-known (e.g. unmoderated isotopic sources), the correction for the ratio of *dose equivalent H-to-personal dose equivalent Hp(10)* conversion coefficients of 1.35 in the 2-to-20 MeV range should be applied (ORAUT-TKBS-0008-6, page 46). These two factors combine to yield a bias for NTA film-based dose assessment if the spectrum is not well-known.

The Track Etch Dosimeters (TEDs) had a lower energy threshold than NTA film, about 100 keV, so the underestimate due to energy response would be no greater than 15%, resulting in a bias of 0.87

(ORAUT-TKBS-0008-6, page 51). ORAUT-TKBS-0008-6 provides additional guidance regarding the recommendations for reconstructing neutron dose based on measuring by TED and by albedo dosimeter.

If workers were unmonitored for fast neutrons, based on NTS personal dosimeter issue practices, and if there was no indication of exposure based on the thermal-neutron-sensitive component, it is highly unlikely that neutron exposure occurred. If a worker's duties did not involve access to fissile materials or isotopic neutron sources, then neutron exposures or missed dose due to neutron will not be considered in dose reconstruction. Otherwise, for other-than-thermal neutrons, missed neutron doses will be assigned based on the number of indications of non-positive dosimetry cycle results found in the DOE records (ORAUT-TKBS-0008-6, page 52).

7.3.4.4 Medical X-ray

There is no indication or suggestion in the data and documentation from the Medical X-ray program at NTS that the time or exposure parameters as documented in ORAUT-TKBS-0008-3 might be subject to error. Based on documentation and expert interviews, NIOSH believes chest photofluorography was not performed on the NTS workers. Chest photofluorography resulted in much greater doses than would a standard radiographic procedure. Determination of the occupational X-ray dose will be based on the documentation of frequency provided by DOE for the worker. If that documentation is insufficient to determine the frequency of X-ray examinations, the frequency indicated in Table 7-15 would be considered conservative and used to determine the X-ray component of external dose.

7.3.5 External Dose Reconstruction Feasibility Conclusion

Based on the information presented in this section regarding available external exposure monitoring data, or the availability of data that support the ability to evaluate personnel external exposures, NIOSH has determined that it has access to extensive data for the members of the proposed worker class evaluated in this report, and has access to sufficient information to either: (1) estimate the maximum external radiation dose for every type of cancer for which radiation doses are reconstructed that could have been incurred under plausible circumstances by any member of the worker class; or (2) estimate the external radiation doses to members of the worker class more precisely than a maximum dose estimate.

7.4 Evaluation of Petition Basis for SEC-00084

The following subsections evaluate the assertions made on behalf of petition SEC-00084 for NTS. Petition SEC-00084 originally cited all four of the bases as defined by the program, those being: (F.1) radiation exposures and radiation doses potentially incurred by members of the proposed class were not monitored; (F.2) radiation monitoring records for members of the proposed class have been lost, falsified, or destroyed; (F.3) a report from a health physicist or other individual with expertise in radiation dose reconstruction documenting the limitations of existing DOE or AWE records on radiation exposures at the facility; and (F.4) a scientific or technical report, issued by a government agency of the Executive Branch of Government or the General Accounting Office, the Nuclear Regulatory Commission , or the Defense Nuclear Facilities Safety Board, or published in a peer-reviewed journal, that identifies dosimetry and related information unavailable for estimating the radiation doses of employees covered by the petition. Of these bases, both F.1 and F.3 were accepted by NIOSH as applicable to qualify the petition for evaluation. During the Qualification Review of the ten affidavits and fourteen supporting documents provided with the petition, NIOSH reviewed several affidavits asserting that the external monitoring program was circumvented by personnel deliberately removing their film badges in radiological control areas, which could potentially have led to unmonitored radiation exposure. Several reports included information on the limitations of existing DOE records were a part of the submission as support for basis F.3.

Additionally, the petitioners indicated that the petition is based on unmonitored, unrecorded, or inadequately monitored and recorded exposure incidents. The petition identifies eight of the ten "unexpected releases of radioactivity" that are listed in ORAUT-TKBS-0008-6 as incidents. These eight were specifically identified as having occurred during the period addressed by this petition. While these releases were monitored, recorded, studied extensively, and are well-documented sources of exposure, they are specifically excluded from the scope of ORAUT-TKBS-0008-6. These events were not unmonitored, unrecorded, or inadequately monitored or recorded exposure incidents. These releases triggered significant attention from scientists and health physics personnel and are well-documented in surveys, investigations, and subsequent reporting. These events have also been of interest to the epidemiological community observing the health effects associated with DOE facilities, which have been included in related studies and reports. Exposures due to these releases are reflected in personal dosimetry records and investigation reports. The exclusion of these releases from the scope of ORAUT-TKBS-0008-6 has no bearing on the EEOICPA radiological dose reconstruction. Any external dose resulting from these releases would be included in the assessment of total dose as ambient external dose.

7.4.1 Evaluation of Major Topics Detailed in Petition SEC-00084

The following major topics were detailed in petition SEC-00084. Italicized statements are from the petition; the comments that follow are from NIOSH.

7.4.1.1 Hot Particle Dose

SEC-00084: *Large hot-particle doses have not been evaluated. As a result, NIOSH is unable to adequately estimate external dose to gonads and skin, and internal dose to the gastrointestinal tract for many personnel, including early NRDS reentry personnel, early tunnel reentry personnel, and workers exposed to particles and gases from vented underground tests and drillback activity. This is a NTS complex-wide issue.*

Highly radioactive particles, also known as "hot particles" were produced by some NTS operations. Hot particle exposure is not easily identifiable from the records because it cannot be distinguished from the dosimeter response, and if it was not detected during the normal personnel survey, the particles would usually be removed by normal washing or changing of clothes.

Indications of potential exposure to hot particles have been and must continue to be evaluated by NIOSH on a case-by-case basis. Significant potential for exposure to hot particles is limited to the immediate area surrounding the NRDS following reactor tests. Access to the reactor test areas was strictly controlled and documented. Hot particle deposition issues for this area (specific to cancers of the skin and shallow organs) will be addressed consistent with EEOICPA radiological dose reconstruction project guidance for assigning shallow dose in individual cases.

Hot particle exposures associated with NRDS nuclear rocket re-entries are, as necessary, considered using the models and methods described in *Hazards to Personnel Re-entering the Nevada Test Site Following Nuclear Reactor Tests,* NRDL-TR-68-149 (NRDL, 1968). Supporting information relevant to the reactor test series and specific to an employee's potential exposure history, as included in the employee's work file from NTS, can be used in conjunction with the NRDL models and methods to develop a large particle GI tract or shallow dose (skin) assessment. All documentation, relevant to dose reconstruction, included in the worker file (e.g. notations in the whole-body count records) will be considered in the characterization of the reactor test scenario and the assessment of any potential large particle exposure to the organ(s) of interest.

7.4.1.2 Defeating the Universal Badging Policy

SEC-00084: *It was common practice that workers, apparently at the direction of management, did not wear and/or hid dosimeter badges to prevent registering doses that would cause them to exceed project, monthly, or cumulative doses. Consequently, film badge data will underestimate the exposure of individuals and groups of workers.*

There are indications that workers, and possibly groups of workers, did not wear assigned dosimeter badges at various times because they did not want to damage the badge and/or they were approaching the dose limit for the work period. NIOSH has documented interviews with former workers, former security personnel, health and safety personnel, and management staff to attempt to verify and evaluate this practice so as to ascertain its impact on the dosimetry records of the proposed class. These interviews were specifically tailored to determine the extent of noncompliance and focused on the job descriptions indicated by the affidavits provided in support of the petition. The interviews included specific questions about dosimetry noncompliance and were primarily conducted with former employees rather than with survivors, as former employees would have the most direct knowledge of the extent of this issue. Analysis of these interviews, as well as the Computer Assisted Telephone Interview records is depicted in Table 7-16. Table 7-16 indicates the percentage of interviewees that indicated that they purposely did not wear their dosimetry badge on the job (by job title).

This analysis suggests that noncompliance with badging policies was not systematic or widespread as to affect the feasibility of dose reconstruction. When noncompliance with the badging policy is reported during the CATI or other claimant communication, NIOSH will apply reasonable dose estimations based on other records of exposure, such as log books or access log records with Pocket Ionization Chamber (a.k.a. PIC or pencil dosimeter) results. In addition, NIOSH has developed a methodology that incorporates the evaluation of an individual's previous dose results in the estimation of dose for those individuals who may have been noncompliant with the badging policy because they believed they were reaching the upper limits of their allowable dose limit for the period. NIOSH has determined that this is a claimant issue rather than an SEC issue, such that issues relating to defeating the badging policy will have to be addressed on a case-by-case basis.

Table 7-16: Results of Interviews regarding Defeat of the Universal Badging Policy				
Job Title	**Number of CATI Results Reviewed**	**Number of Additional Interviews**	**Number of Interviews by Job Category**	**Number of Interviewees Indicating Monitoring Defeat**
Administrative	9	1	10	1
Drill Worker/Engineer	32	1	33	3
Tunnel Worker/Miner	66	1	67	1
Plumber/Pipefitter	48	1	49	0
Carpenter/Welder	36	0	36	1
Surveyor/Civil Engineer	7	0	7	2
Laborer	71	0	71	2
Other	932	10	942	3
Total	**1,201**	**14**	**1,215**	**13 (1.1% of total)**

7.4.1.3 Resuspension

SEC-00084: *Resuspension models and factors are not scientifically defensible and a credible bounding dose estimate has not been developed. Doses may be underestimated by an order of magnitude due to the lack of data on "hot spots," the failure to use a time dependent model, incomplete radionuclide lists, lack of adequate soil data for resuspension analysis/calculation, using data not appropriate for retrospective dose reconstruction, and using data collected in areas after "hot spots" were cleaned up to estimate doses prior to the cleanup. Due to these and numerous other uncertainties, NIOSH cannot develop a plausible upper bound dose estimate.*

The assertion by the petitioners that resuspension modeling and factors are inappropriate to determine dose from "hot spots" refers to an older proposed methodology for internal dose assignment using resuspension; the older methodology has been superseded by NIOSH. The greatest potential for environmental intakes of radioactive material results from inhalation of radioactive particles resuspended into the atmosphere and from ingestion of soils previously contaminated by atmospheric nuclear weapons tests and safety tests. The inhalation intakes of all potentially inhaled radionuclides will be estimated based on the highest recorded plutonium air sampling data provided in NTS Annual Environmental reports, in conjunction with extensive soil contamination data gathered between 1983 and 1991. The air monitoring data were limited to gross alpha and beta measurements, tritium, and isotopes of plutonium; therefore, inhalation intakes of other relatively long-lived radionuclides identified in NTS soil are scaled to those of plutonium, based on their relative abundance in NTS soil. The relative abundances of the long-lived radionuclides identified in NTS soil contamination data have been decay-corrected to 1963. In addition, to ensure that intakes and resultant doses are not underestimated, correction factors have been developed to account for potential exposures to short-lived fission and activation products based on test-specific data. Further, a correction factor has been developed for inhalation intakes to account for the phenomenon of early resuspension. The NIOSH methodology is time-dependent and appropriate for retrospective dose reconstruction, and uses appropriate soil data.

No documented radiological decontamination of "hot spots" took place between the end of atmospheric testing and the 1970s when air sampling data became more widely available. Interviews with former employees indicated that the areas previously used for atmospheric testing had been cleaned up, meaning that damaged structural materials, old vehicles, bridges, etc., that were subjected to close-range airbursts, were disposed of. These cleanup activities would not lower the radionuclide inventory available for worker internal exposure.

7.4.1.4 Record Verification and Validation

SEC-00084: *DOE records used by NIOSH have not been subject to verification and validation-leading to errors. For instance, DOE claims to have dosimeter readings for workers when they were no longer employed at the site, and also claims that workers were no longer at the site when DOE or NIOSH documentation indicates that they were.*

NIOSH has performed a data validation review as part of this evaluation to confirm that the source data are representative and support the point that NIOSH can bound exposures (or reconstruct dose with sufficient accuracy) for members of the proposed worker class – please refer to Section 7.1.1 and 7.1.2 of this report. In all reviewed cases, any alleged errors are clearly explained. The NTS procedure of issuing dosimeters to visitors, including former workers returning to the site for tours, auctions, medical monitoring, etc., led to "readings" after the completion of the former worker's employment. In some cases, the inclusion of internal dose—up to the diagnosis of cancer—in claimant records, including dose delivered beyond the completion of employment by radionuclides resident in their body, appears as a record error to individuals unfamiliar with dose reconstruction.

The issues specific to individual claims and individual dose reconstruction analysis are handled on a case-by-case basis during the evaluation of the claim and do not represent an SEC issue and do not indicate a problem with NIOSH's ability to bound the dose for the proposed worker class evaluated in this report.

7.4.2 Evaluation of Specific Petitioner Statements in SEC-00084

This subsection presents specific affidavit statements made on behalf of petition SEC-00084. The italicized statements are from the petition; the comments that follow are from NIOSH.

7.4.2.1 Specific Affidavit Statement 1

SEC-00084: *NIOSH TBD-6 (External Dose) states that National Institute of Occupational Safety and Health (NIOSH) has no method to estimate dose for workers involved in eight underground tests that "vented" during the proposed class period (e.g., Baneberry, Camphor, Diagonal Line, Riola, Agrini, Midas Myth, Misty Rain, and Might Oak) as well as for those affected by drillbacks prior to 1965. As a result of this exemption, dose cannot be reconstructed for workers exposed in these eight events or the pre-1965 drillbacks.*

External dose associated with workers exposed to these ventings and drillbacks is captured similarly to all other external doses onsite, i.e., by the external dosimetry mechanisms employed over the history of the site. The primary focus of the radiation protection program at NTS was external dosimetry and all employees were monitored for external exposure. ORAUT-TKBS-0008-6 provides guidance on assigning appropriate external exposure.

7.4.2.2 Specific Affidavit Statement 2

SEC-00084: *Workers were scrupulous about keeping work related information confidential…making it impossible for survivors to provide the necessary information to enable NIOSH to adequately reconstruct dose.*

NIOSH acknowledges that survivors often do not have information regarding specific duties and responsibilities of their relatives who worked at NTS, as is the case for survivors for all other facilities in the U.S. Nuclear Weapons program. While, in accordance with the Privacy Act, there may not be published documentation of employee access records related to individual tests at the site, historic information and records have been made available to NIOSH by the site for the dose reconstruction process.

The role of the EEOICPA radiological dose reconstruction program is to determine the probability of causation for individual workers (i.e., whether the cause of the worker's cancer was at least as likely as not a result of occupational exposure to radiation), using claimant-favorable dose reconstruction parameters, not to provide a precise regulatory compliance assessment of the worker dose. This permits the application of overestimating or underestimating dose reconstruction efficiency techniques in the performance of an EEOICPA radiological dose reconstruction. While information on all aspects of a worker's job may not have been available to the claimants, that is no indication that the employee's radiation dose cannot be bounded adequately to make a determination of causation.

7.4.2.3 Specific Affidavit Statement 3

SEC-00084: *DOE has documented that the nuclear rocket and ramjet engine tests regularly released significant amounts of radionuclides that were detected hundreds of miles away, and therefore each test is a discreet incident.*

Discrete incidents, as defined by the EEOICPA program, are unplanned events that result in radiation exposures, which may be related to an unexpected failure in control procedures, likely to have involved exceptionally high-level exposures (comparable to those from a criticality incident), versus routine operations which might also result in radiation exposures.

NIOSH has evaluated the releases associated with the nuclear rocket and ramjet engine tests and determined that they do not constitute discrete incidents, per this definition and guidance on health endangerment. The magnitude of the exposures is not commensurate with exposures as considered in the definition of "incident." These exposures (tests) were not significantly higher than those experienced by other workers in the course of routine NTS operations. Detection of these releases at considerable distance from the releases is, in these cases, indicative of comprehensive attention and monitoring, highly sensitive detection equipment, and careful analysis; it is not indicative of the magnitude of the release or potential unmonitored exposure to the proposed class.

7.4.2.4 Specific Affidavit Statement 4

SEC-00084: *NIOSH lacks a method to estimate internal dose through 1967.*

NTS internal dose reconstruction for the 1963 through 1967 timeframe covered by the petition is covered by ORAUT-OTIB-0018 and ORAUT-OTIB-0014. The guidance included in these OTIBs will be applied in a tailored manner to each case as appropriate, using the time-dependent Hicks data for short-lived radionuclides. Guidance for internal dose reconstruction, as discussed in Section 7.2, will be documented in the NTS Site Profile currently in the revision cycle, and will explain how to interpret these data in a claimant-favorable manner.

7.4.2.5 Specific Affidavit Statement 5

SEC-00084: *Whole body counts are unavailable until 1967, yet this data is used to extrapolate dose for workers who did different tasks in very different circumstances or only because of which area paid them.*

Whole-body counting was not generally introduced at any DOE sites until the late sixties and early seventies because the technology had not been sufficiently developed to provide reliable results. Internal monitoring was provided prior to 1967 by urinalysis.

While whole-body counting results are not widely available for NTS claimants, there are adequate urinalysis data, which are used in conjunction with area monitoring and source term information to reconstruct internal dose for the determination of causation. NIOSH does not use employee whole-body counts to directly extrapolate dose for employees who had different job descriptions. Whole-body counts (from 1967 forward) are primarily useful to confirm dose reconstruction results, rather than a necessary component of the dose reconstruction.

7.4.2.6 Specific Affidavit Statement 6

SEC-00084: *Exposure to radon is improperly estimated. There is no discussion of radon in Gravel Gerties, which could be substantial through 1985.*

The design of Gravel Gerties was tested at NTS in 1957 and 1982. Three tests were conducted in 1957, two of which used uranium as a surrogate for plutonium and one that was conducted using high explosives without any radioactive materials at all. A fourth test of the design was conducted in 1982, again using uranium as a surrogate. These four tests used the same test structure, which was cleaned up and restored with new gravel for each subsequent test.

The Gravel Gertie structure located in Area 5 was never used operationally, for the assembly and disassembly of weapons, at NTS. Radon exposure during construction would have been consistent with the environmental levels of radon found at NTS. Radon exposure, while setting-up the initial tests in this prototype design, would have been insignificant to the measured internal dose. If individual claim records indicate individual claimants spent significant amounts of time in the test Gravel Gerties, the radon exposure associated with those claims will be evaluated on a case-by-case basis, consistent with the guidance found in ORAUT-TKBS-0008-4.

7.4.2.7 Specific Affidavit Statement 7

SEC-00084: *Radon doses for G-tunnel are not claimant favorable, and NIOSH's proposal to use radon from the Pantex facility in Amarillo, Texas lacks a technical basis.*

NIOSH does not propose to use Pantex radon data to estimate radon exposures for the G-Tunnel. Based on comments from the Advisory Board and its contractor, the NTS Site Profile is currently undergoing revision to reflect an increased value of 0.16 working levels in the G-Tunnel for periods prior to 1985. The revised NTS Site Profile will instruct dose reconstructors, for cases where location of underground work is not known, to use the G-Tunnel value of 0.16 working level prior to 1985, and the value of 0.05 working level from 1985 forward.

7.4.2.8 Specific Affidavit Statement 8

SEC-00084: *Although NTS workers were assigned to work on classified projects in locations such as Area 51, NIOSH has not assessed their radiation exposure or developed methods to do so in its site profile.*

NIOSH is not responsible for determining what is or is not covered employment at a facility. It is the responsibility of the Department of Labor (DOL) and DOE to define what is a covered facility and what constitutes covered employment.

7.4.2.9 Specific Affidavit Statement 9

SEC-00084: *Internal radiation exposure assessments rely on average air concentration values when the individual worker's location is not known. If the work location is unknown, there is no basis for dose estimates. Averages for workers whose locations are known will not lead to a bounding dose estimate.*

NIOSH will always rely on available bioassay data as the primary record for internal dose reconstruction. In the absence of sufficient bioassay data for the individual, NIOSH will then rely on air concentration values, using the highest recorded plutonium air sample across NTS when a worker's location is not known. The methodology to assess internal dose due to environmental exposures has been revised to determine internal dose based on air sampling data available for NTS.

7.4.2.10 Specific Affidavit Statement 10

SEC-00084: *Many workers were unmonitored for iodine-131 exposures from 33 tests which vented approximately 1,065 kCi of iodine-131. NIOSH has no method to estimate unmonitored worker exposures.*

NIOSH has developed guidance for workers that will bound potential organ doses from radioiodine exposures using air monitoring data. The ratios found in ORAUT-TKBS-0008-5, Table 5-2 and the highest concentration measured in Area 12 Camp after the Baneberry release have been used to develop a sample calculation that will be included in the NTS Internal Site Profile currently in the revision cycle. These sample calculation values can be used to determine iodine intake for an individual who may have been present during Baneberry. Similar calculations can be performed for other test releases using available air concentration data and when an iodine-131 intake is suspected based on the records available to NIOSH.

7.4.2.11 Specific Affidavit Statement 11

SEC-00084: *The presence of high-fired oxides resulting from atmospheric weapons testing has not been investigated. High-fired plutonium oxides are less soluble than other oxides and, therefore, are retained in the lungs longer than other oxides and can take significantly longer to show up in a bioassay. These doses are not addressed in the TBD or dose assessments and it could take decades to construct an adequate dose model to estimate these exposures.*

Super S plutonium is addressed in ORAUT-OTIB-0049 and is evaluated at NTS starting in 1963. This issue is relevant to individual dose reconstruction analysis (on a case-by-case basis) and does not represent an SEC issue, as the comment or issue does not speak to NIOSH's ability to bound the dose (or reconstruct the dose with sufficient accuracy) for the proposed class evaluated in this report.

7.4.2.12 Specific Affidavit Statement 12

SEC-00084: *There is no extremity dosimetry for bomb assembly workers.*

As discussed in Section 7.3.1.3 of this report, extremity dosimetry has been used at NTS to assess exposure to the finger, hand, forearms, and even the head (on rare occasions) that might have occurred during operations in proximity to, or the manual manipulation of, radioactive material and radiation-emitting objects.

The lack of extremity doses for some device assembly workers at NTS is surmountable. Extremity dose can be approximated using available dosimetry data in concert with geometrical correction factors and ratio correction techniques. Based on these techniques, this issue is not considered an SEC issue, but rather a site profile individual dose reconstruction issue.

7.4.2.13 Specific Affidavit Statement 13

SEC-00084: *Workers report that monitoring and other records for NTS activities were lost or destroyed.*

A complete set of internal and external dosimetry records are maintained in the NTS archives located at the Desert Research Institute. During its interviews with workers, NIOSH specifically raised the question of lost or destroyed records. The responses indicated that the workers had heard claims of lost or destroyed records from the media outlets, but none had personal knowledge of any such records. One individual, a Former Workers Medical Surveillance Program employee who was also formerly a Records Manager at NTS, was able to specify the types of records reported in the media to have been buried. The records were administrative records, including timekeeping, mine rescue reports, access reports, log books, forms, injury reports, personnel rosters, and safety meeting records. The buried records did not, according to this interviewee, contain radiation protection or dosimetry records. Therefore, NIOSH has concluded that there is insufficient support for the claim that NTS monitoring records applicable to reconstructing personnel dose have been lost or destroyed.

7.4.2.14 Specific Affidavit Statement 14

SEC-00084: *There was not an adequate internal dosimetry program in place from 1963 through 1967. Full radionuclide coverage was not in place until 1967. Some tritium, plutonium, and mixed fission products were bioassayed prior to 1967.*

In addition to individual bioassay data, NTS internal dose reconstruction for the 1963 through 1967 timeframe includes the use of ORAUT-OTIB-0018 and ORAUT-OTIB-0014 beginning in 1963. NTS routine bioassay programs, by activity, are documented in ORAUT-TKBS-0008-5 Attachment 5D.4.1. Workers were assigned to an activity-specific bioassay program (urine samples) based on having a high potential for intake. Each program was tailored to the conditions associated with the work; Workers may have been assigned to the bioassay program based on air monitoring, risk analysis of the activity, or other indications of potential internal exposure (e.g. personal contamination surveys). NIOSH uses bioassay data from employees at highest risk of internal exposure to determine bounding dose estimates of the potential intakes received by unmonitored members of the proposed class. Guidance, explaining how to interpret gross fission product bioassay results from 1963 forward, will be incorporated in the revised NTS Site Profile (currently in the revision cycle); this guidance supports NIOSH's position that it can bound doses (reconstruct dose with sufficient accuracy) for members of the proposed worker class.

7.4.2.15 Specific Affidavit Statement 15

SEC-00084: *NIOSH erroneously reduces potential environmental doses for workers who remained continuously on site (lived on site), claiming without sufficient support that they spent most of their off-duty time indoors. This reduction should only be done if NIOSH can prove conclusively that workers indeed spent a large portion of their time indoors, and that they worked in building that were sealed, positively pressured, and/or were air conditioned, rather than in trailers, tents, or old buildings that relied on open windows and doors for cooling and ventilation, or that potentially drafted in air from the outside when the windows and doors were closed.*

While most applications of internal dose based on environmental concentrations assume a standard number of hours of occupational exposure, this can be adjusted, on a case-specific basis, to reflect more than 40 hours per week when documentation indicates the individual was living or staying onsite during the week. This issue is relevant to individual dose reconstruction analysis (on a case-by-case basis) and does not represent an SEC issue, as the comment or issue does not speak to NIOSH's ability to bound the dose (or reconstruct the dose with sufficient accuracy) for the proposed class evaluated in this report.

7.4.2.16 Specific Affidavit Statement 16

SEC-00084: *Moreover, it is documented that ambient monitoring using thermoluminescent dosimeters had failed.*

NIOSH does not rely on TLD measurements of environmental radiation conditions to determine ambient dose for dose reconstruction. Ambient dose, the dose due to non-occupational background radiation, was being measured and subtracted from the dose of record to account for strictly occupational dose before 1957. Ambient external dose is not assigned separately, during dose reconstruction, after 1957. The ambient external exposure is captured by the dosimetry badge worn universally at NTS.

7.5 Other Issues Relevant to the Petition Identified During the Evaluation

During the feasibility evaluation for SEC-00084, a number of issues were identified that needed further analysis and resolution. The issues and their current status include:

- ISSUE: No external environmental measurements took place between 1968 and 1976. NIOSH proposes to use a maximum dose from 1967 as a surrogate. SC&A argues that extrapolating from 1967 is inappropriate because there were no large unplanned vented tests that year. However, significant radionuclide deposits from vented tests from 1968 through 1970 may have caused external doses during that time period and several years after to be higher than doses in 1967. For example, of the ten large underground tests excluded from the NTS Site Profile, three of the 10 occurred in the 1968 through 1976 time period (Baneberry, 1970; Camphor, 1971; and Diagonal Line, 1971.)

  APPROACH: Unexposed control films and thermoluminescent dosimeters were processed with personnel dosimeters, and the readings from these control dosimeters were subtracted from the personnel dosimeter readings to obtain a net reading for determining worker exposure. Beginning on April 1, 1957, all employees entering NTS were required to wear dosimeters while inside NTS. Because the control dosimeters were maintained in environmentally controlled, low background areas (e.g., Building 111 in Mercury), exposures resulting from elevated ambient environmental levels due to testing activities in other areas of the site would have been recorded by the dosimeters and included in the individual exposure records. The assignment of ambient external dose will be applied consistent with ORAUT-PROC-0060, *Occupational Onsite Ambient Dose Reconstruction for DOE Sites*.

- ISSUE: Bioassay performed every few months would not detect the presence of relatively short-lived radionuclides, such as sodium-24 and neptunium-239. Workers entering contaminated areas within days of a test that vented may have been exposed to a variety of short-lived radionuclides. The TBD does not specify a procedure for evaluating exposures to such radionuclides for monitored workers.

  APPROACH: Data contained in the Hicks reports confirm that neptunium-239 was not a significant contributor to dose at NTS. The relative importance of sodium-24 to total internal dose during reentry activities occurring in the first week after the event is understood; guidance to adjust dose due to sodium-24, as appropriate, has been documented in a draft methodology that will be incorporated in the revised NTS Site Profile that is currently in the revision cycle. NIOSH defines missed intakes as those which could have been incurred at levels less than the minimum detectable activity for bioassay.

- ISSUE: Use of 1967 external dose data for 1963-1966 is not claimant-favorable. There was no test in 1967 with measurable offsite fallout. Relatively short-lived radionuclides, which were likely present in 1963-1966, would have substantially decayed away by 1967.

APPROACH: Ambient external dose is not assigned to monitored individuals. The ambient external exposure is captured by the dosimetry badge worn universally at NTS. This issue is relevant to individual dose reconstruction analysis (on a case-by-case basis) and does not represent an SEC issue because the comment or issue does not speak to NIOSH's ability to bound the dose (or reconstruct the dose with sufficient accuracy) for the proposed class evaluated in this report.

7.6 Summary of Feasibility Findings for Petition SEC-00084

This report evaluates the feasibility for completing dose reconstructions for employees at NTS from January 1, 1963 through September 30, 1992. NIOSH found that the available monitoring records, process descriptions and source term data available are sufficient to complete dose reconstructions for the proposed class of employees.

Table 7-17 summarizes the results of the feasibility findings at NTS for each exposure source during the time period from January 1, 1963 through September 30, 1992.

Table 7- 17: Summary of Feasibility Findings for SEC-00084

January 1963 through September 1992

Source of Exposure	Reconstruction Feasible	Reconstruction Not Feasible
Internal	X	
- Uranium	X	
- Plutonium	X	
- Gross Fission Products	X	
External	X	
- Gamma	X	
- Beta	X	
- Neutron	X	
- Occupational Medical X-ray	X	

8.0 Evaluation of Health Endangerment for Petition SEC-00084

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

NIOSH has determined that internal and external doses can be estimated with sufficient accuracy using the available bioassay data, dosimetry data, and knowledge of the source term and exposure scenarios at NTS. NIOSH determined that it is feasible to estimate radiation dose for members of the proposed class with sufficient accuracy based on the sum of information available from available resources. Modification of the class definition regarding health endangerment and minimum required employment periods, therefore, is not required.

9.0 NIOSH-Proposed Class for Petition SEC-00084

Based on its research, NIOSH accepted the petitioner-requested class to define a single class of employees for which NIOSH can estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all employees of the Department of Energy (DOE) or any DOE contractor or subcontractor who worked in any areas of the Nevada Test Site from January 1, 1963 through September 30, 1992. The class was accepted because it encompasses all workers from the period of operations currently outside the currently defined Special Exposure Cohort class for NTS through the point in time when NTS received DOELAP (DOE Laboratory Accreditation Program) accreditation.

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-00084. 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 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 that it would be feasible to reconstruct the dose for the class proposed in this petition.

10.0 References

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

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

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

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

OCAS-IG-001, External Dose Reconstruction Implementation Guideline, Rev. 02; Office of Compensation Analysis and Support (OCAS); August 25, 2006; SRDB Ref ID: 29929

OCAS-IG-002, *Internal Dose Reconstruction Implementation Guideline*; Office of Compensation Analysis and Support (OCAS); August, 2002; SRDB Ref ID: 22402

OCAS-TIB-0011, *Lung Dose Conversion Factor for Thoron WLM*, Rev. 02; Office of Compensation Analysis and Support (OCAS); January 13, 2006; SRDB Ref ID: 22409

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

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

ORAUT-OTIB-0011, *Tritium Calculated and Missed Dose Estimates*, Rev. 00; Oak Ridge Associated Universities (ORAU); June 29, 2004; SRDB Ref ID: 19430

ORAUT-OTIB-0014, *Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace*, Rev. 00; Oak Ridge Associated Universities (ORAU); June 22, 2004; SRDB Ref ID: 19432

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

ORAUT-OTIB-0018, *Internal Dose Overestimates for Facilities with Air Sampling Programs*, Rev. 01; Oak Ridge Associated Universities (ORAU); August 09, 2005; SRDB Ref ID: 19436

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

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

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

ORAUT-TKBS-0008-1, *Nevada Test Site—Introduction*, Rev. 00 PC-1; Oak Ridge Associated Universities (ORAU); July 20, 2006; SRDB Ref ID: 29994

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