Draft

ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

REVIEW OF THE NIOSH SITE PROFILE FOR NUCLEAR MATERIALS AND EQUIPMENT CORPORATION PARKS TOWNSHIP AND APOLLO SITES

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ABBREVIATIONS AND ACRONYMS

Advisory Board, ABRWH, or Board	Advisory Board on Radiation and Worker Health
AEC	U.S. Atomic Energy Commission
Am	americium
AmBe	americium-beryllium
AMAD	activity median aerodynamic diameter
ANL-E	Argonne National Laboratory-East
ATR	Advanced Test Reactor
AWE	Atomic Weapons Employer
BAPL	Bettis Atomic Power Laboratory
B&W	Babcock & Wilcox (Company)
Be	beryllium
Bq/d	Becquerel per day
BZ	breathing zone
BZA	breathing-zone air
CATI	computer-assisted telephone interview
CEP	Controls for Environmental Pollution
CFR	*Code of Federal Regulations*
Co	cobalt
Cs	cesium
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
dpm	disintegrations per minute
dpmα/m^2	disintegrations per minute alpha per square meter
dpm/L	disintegrations per minute per liter
DU	depleted uranium
DWE	daily weighted exposure
EE	Energy Employee
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
FFTF	Fast Flux Test Facility (Hanford)
GA	general air
GSD	geometric standard deviation
h or hr	hour
HASL	Health and Safety Laboratory
HEU	highly enriched uranium
ICRP	International Commission on Radiological Protection

IMBA	Integrated Modules for Bioassay Analysis
Ir	iridium
keV	kiloelectronvolt, 1,000 electronvolts
kg	kilogram
L	liter
LANL	Los Alamos National Laboratory
LEU	low-enriched uranium
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
MAC	maximum allowable concentration
mBq	millibecquerel
MDA	minimum detectable activity (or amount)
MDC	minimum detectable concentration
MDL	minimum detectable level
MeV	megaelectronvolt, 1 million electronvolts
µg/L	micrograms per liter
mR/hr	milliroentgen per hour
mrad	millirad
mrem	millirem
nCi	nanocurie
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH DCAS Claims Tracking System
NRC	U.S. Nuclear Regulatory Commission
NTA	nuclear track emulsion, type A
NUMEC	Nuclear Materials and Equipment Corporation
OCAS	Office of Compensation Analysis and Support, now called Division of Compensation Analysis and Support (DCAS)
ORAUT	Oak Ridge Associated Universities Team
pCi	picocurie
Po	polonium
Pu	plutonium
RaLa	radioactive lanthanum
rem	roentgen equivalent man
RF	resuspension factor
Rh	rhodium
Ru	ruthenium
RU	recycled uranium

SC&A	S. Cohen and Associates
sec	second
SEC	Special Exposure Cohort
Sr	strontium
SRDB	Site Research Database
SS	stainless steel
Tc	technetium
Th	thorium
ThO_2	thorium dioxide
TIB	technical information bulletin
TLD	thermoluminescent dosimeter
TRIGA	Training, Research, Isotope General Atomics (Reactor)
TRU	transuranic
U	uranium
UF_6	uranium hexaflouride
U.S.C.	United States Code
WBC	whole-body count
ZPPR	Zero Power Plutonium [or Physics] Reactor

EXECUTIVE SUMMARY

On September 26, 2008, the National Institute for Occupational Safety and Health (NIOSH) issued ORAUT-TKBS-0041 (ORAUT 2008), which provides data and guidance for dose reconstruction of workers at the Nuclear Materials and Equipment Corporation (NUMEC) Apollo Nuclear Fuel Facility (Apollo Site), located in Apollo, Pennsylvania. The site profile was revised on June 2, 2009 (ORAUT 2009a), to include the NUMEC Parks Township Site located in Parks Township, Pennsylvania. The site profile was revised again on February 26, 2010 (ORAUT 2010), to adjust the minimum detectable concentration (MDC) of plutonium (Pu) in urine and to incorporate updated information and references. On November 26, 2012, during the course of this review, NIOSH issued another revision of the site profile (ORAUT 2012a), which was initiated in response to a change in guidance regarding medical x-ray exposures and assigning doses during the residual period. This report presents a review of the most recent revised site profile, as originally requested by the Advisory Board on Radiation and Worker Health (Advisory Board) during the full board meeting held in Oakland, California, February 28–29, 2012.

The major activities at the Apollo Site included uranium conversion activities in support of commercial nuclear power plants and uranium scrap recovery. The primary function of the Parks Township Site was the fabrication of Pu fuel, the preparation of highly enriched uranium (HEU) fuel, and the production of zirconium/hafnium bars. The Parks Township Site also manufactured americium (Am)-beryllium (Be) neutron sources, Pu-238 pacemakers, and high-activity radiography sources, including cobalt-60 (Co-60) and iridium-192 (Ir-192). The Parks Township Site also handled and processed cesium-137(Cs-137), Am-241, Be-7, polonium-210 (Po-210), Pu-238/239, depleted uranium (DU), thorium (Th), and other transuranic (TRU) and fission product elements for use in source production and radiographic examination programs, including spent fuel examination. Uranium hexafluoride (UF_6) cylinders were also stored at the facility. In summary, both facilities were involved in a very broad range of activities, for which a wide variety of potential internal and external exposures are of concern.

Among the reasons that the Advisory Board requested that SC&A review the NUMEC site profile are that (1) NUMEC is one of the sites for which a Special Exposure Cohort (SEC) was granted and, therefore, the site profile was never reviewed until now, and (2) many dose reconstructions were performed for workers not covered by the SEC. The dose reconstructions were apparently a challenge because of a limited amount of available data. This is an especially interesting site profile because NIOSH clearly made an effort to use the available data (despite their limitations) to reconstruct doses to 117 workers who were not covered by the SEC (see Section 7 of this report). NUMEC and sites like it for which a large SEC was granted, but many dose reconstructions were performed for uncovered claimants, are unique because of the challenges associated with performing dose reconstructions with limited data. **In light of what SC&A learned from this review, SC&A recommends to the Board and the Dose Reconstruction Subcommittee that a special effort be made to review dose reconstructions from sites for which SECs were granted because of the unique challenges associated with performing these dose reconstructions.**

SUMMARY OF PRIMARY FINDINGS

The following presents SC&A's primary findings for the NUMEC Apollo and Parks Township site profile, ORAUT-TKBS-0041 (ORAUT 2012a).

Finding 1: Clarification is needed about the start and end dates of Parks Township Site operations.

Finding 2: The site profile should provide guidance on what level of uranium enrichment should be assumed for those urine bioassay results that are expressed in units of micrograms (µg/L) per liter.

Finding 3: Some guidance is needed on how to perform dose reconstructions prior to 1959, and what approach should be used for missed and unmonitored exposures.

Finding 4: Uranium inhalation recommendations for the Apollo Site need to take into consideration the method discussed by Davis and Strom (2008) for dealing with uncertainties in daily weighted exposure (DWE). This technique was evaluated and found to be appropriate in the site profile review for the Fernald Feed Materials Production Center (Fernald).

Finding 5: Inadequate information is given to replicate NIOSH's determination of median inhalation concentration of uranium. The NIOSH result could not be replicated, and it appears that relevant information has been omitted from the Health and Safety Laboratory (HASL) studies reported in Appendix A to the site profile.

Finding 6: The site profile would benefit from a discussion demonstrating that the Hanford Site fuel grade mix, as opposed to the weapons-grade or commercial-grade plutonium, is limiting for the full range of plutonium mixes and ages that were used at NUMEC. In addition, given the complexity of this subject, a review of actual dose reconstructions would provide greater insight into how this matter is actually being addressed.

Finding 7: The minimum detectable activities (MDAs) for Am-241 lung counting are very low. The counting method should be further explored in order to give them credibility.

Finding 8: The site profile would benefit from a more thorough discussion of the possible use of air sampling data to reconstruct internal plutonium exposures and to take into consideration the additional data provided by Crosby 1967 and NUMEC 1967.

Finding 9: It does not seem appropriate to use ORAUT-OTIB-0054 (ORAUT 2007a) to reconstruct the internal exposures of workers at NUMEC who might have been exposed to mixed fission products because ORAUT-OTIB-0054 states that its guidance "does not apply to determination of intakes where radionuclides have been purposely extracted and concentrated as for heat generation sources, medical uses, or waste handling operations that caused significant alteration to the source term to which workers were exposed." For example, Table 5-1 of the site profile indicates that the fission products handled at NUMEC are sources used for various research and operations purposes and are not actually fuel or spent fuel and would not

necessarily be present in the same ratios as in reactor fuel. Also, the fission product mix given in ORAUT-OTIB-0054 does not contain the same radionuclides as the fission product mixes given for the NUMEC Laundry in the 1975 effluent release report (Williams 1967) and for in-vivo count results in Caldwell 1969. The NUMEC mixes include Co-60, which the ORAUT-OTIB-0054 mix omits, further demonstrating the inapplicability of ORAUT-OTIB-0054 to NUMEC.

Finding 10: Internal dose reconstructions performed for NUMEC personnel might need to be revisited in light of changes to the Fernald site profile (ORAUT 2004) with respect to recycled uranium (RU). Also, additional direction is needed with respect to which workers or operations should be assigned RU intakes.

Finding 11: NIOSH should explain whether the concerns expressed in the Pantex site profile (ORAUT 2007d) about the Helgeson chest count data might also apply to chest count data at NUMEC performed by Helgeson for NUMEC workers.

Finding 12: Table 6-2 and the associated text in Section 6.3.2 of the site profile should be reviewed and modified as needed to correct any oversights, inconsistencies, or errors.

Finding 13: Given our understanding that it is NIOSH's position that external exposures at the Parks Township Site can be reconstructed with sufficient accuracy, it appears that the description of the sources and circumstances responsible for external exposures need to be better developed, if possible.

Finding 14: The site profile should provide justification for why adjustment factors are not required for neutron exposures estimated using nuclear track emulsion Type A (NTA) film, considering that it appears that the neutron energy spectrum likely extended to well below 1 mega-electronvolt (MeV). For example, Table 6-8 of the site profile indicates that the energy range of neutron exposures extended from 0.1 to 2 MeV.

Finding 15: The markedly different photon energies associated with the operations at NUMEC would indicate the possible need for adjustment factors for the results of film badge dosimeters, which are not provided in the site profile.

Finding 16: NIOSH should consider developing a universal coworker model based on NUMEC claimant records, or specify a more consistent basis for assigning external doses beyond the medical x-rays associated with the site.

Finding 17: The site profile should include guidance for deriving non-penetrating doses to skin and other organs from beta emitters associated with surface contamination during the residual period.

Finding 18: General air (GA) samples, as opposed to breathing zone (BZ) samples, should be used as the starting point for reconstruction of radionuclide intake rates during the residual period.

Finding 19: SC&A recommends that NIOSH use a resuspension factor of about 1E-5 per meter to derive the airborne dust loading for the beginning of the residual period, or perhaps simply assume that the average general air dust loading observed during the operational period is applicable to the beginning of the residual period.

Finding 20: The site profile makes no reference to radionuclides other than uranium during the residual period at Apollo.

Finding 21: There is conflicting guidance on how aged plutonium mixtures should be treated during the residual period at Parks Township.

1.0 INTRODUCTION

On September 26, 2008, the National Institute for Occupational Safety and Health (NIOSH) issued ORAUT-TKBS-0041 (ORAUT 2008), which provided data and guidance for dose reconstruction of workers at the Nuclear Materials and Equipment Corporation (NUMEC) Apollo Nuclear Fuel Facility (Apollo Site), located in Apollo, Pennsylvania. This site profile was revised on June 2, 2009 (ORAUT 2009a), to include the NUMEC Parks Township Site located in Parks Township, Pennsylvania. The site profile was revised again on February 26, 2010 (ORAUT 2010), to adjust the minimum detectable concentration (MDC) of plutonium (Pu) in urine and to incorporate updated information and references. The site profile was again revised on November 26, 2012 (ORAUT 2012a), to address changes in NIOSH procedures for performing dose reconstructions during residual periods and medical x-ray examinations required as a condition of employment. This report presents a review of the most recent revised site profile, "Site Profile for Nuclear Materials and Equipment Corporation, Apollo and Parks Township, Pennsylvania" (ORAUT 2012a), hereafter referred to as the "site profile"), as requested by the Advisory Board on Radiation and Worker Health (Advisory Board) during the full board meeting held in Oakland, California, February 28–29, 2012. (Note: The site profile was revised once more subsequent to authorization by the Board for SC&A to review the site profile).

Section 2 of the site profile presents a detailed description of the operations that took place at the two NUMEC sites. In summary, as described in the site profile, the Apollo Site operated under License Number SNM-145 and Source Material License Number C-3762, which the U.S. Atomic Energy Commission (AEC) issued in 1957. The major activities at the Apollo Site included uranium (U) conversion activities in support of commercial nuclear power plants and uranium scrap recovery. From 1958 to 1983, the Apollo Site was used for small-scale research and production of low-enriched uranium (LEU), highly enriched uranium (HEU), and thorium (Th) fuels. By 1963, the majority of the Apollo Site was dedicated to the production of uranium fuel. The Apollo Site facility provided enriched uranium to the naval reactors program and included a plutonium plant and storage area, metals and hafnium complex, and uranium hexafluoride (UF_6) storage facility. Table 2-1 of the site profile summarizes the buildings and time periods in which various operations took place and is useful in identifying the types of exposures and operations that workers might have experienced while working at the Apollo Site, including internal and external exposures to various chemical and physical forms of depleted, natural, and enriched uranium, fission products, transuranic (TRU) elements, plutonium, thorium, and cobalt-60 (Co-60). Most operations involved uranium chemical conversion required to support research and to manufacture fuel for commercial operations, for military purposes, and in support of the weapons complex.

Notable among Apollo Site operations is the receipt of enriched UF_6 in "birdcages," which were used as the starting point to convert the enriched UF_6 to various uranium oxides. The implications of these operations are that, in addition to photon and beta exposures, enriched UF_6 creates the potential for neutron exposures by fission neutrons and alpha/neutron reactions. During the uranium conversion processes, a filter cake was produced that was then dried and perhaps manually handled (not necessarily under a hood), which created an enhanced potential for the production of airborne uranium particulates.

Another notable operation at the Apollo Site was the receipt of thorium dioxide (ThO_2), which was granulated in hoods, pelletized into thorium fuel, and machined under a ventilated hood. In addition, limited quantities [500 kilograms (kg)] of plutonium were handled as part of the Apollo Site research program.

The primary function of the Parks Township Site was the fabrication of plutonium fuel, the preparation of HEU fuel, and the production of zirconium/hafnium bars. The operations were primarily to provide fuel for the Hanford Fast Flux Test Facility (FFTF) and other U.S. Department of Energy (DOE) reactors. The Parks Township Site also manufactured americium-beryllium (AmBe) neutron sources, Pu-238 pacemakers, and high-activity radiography sources, including Co-60 and iridium-192 (Ir-192). The site also handled and processed cesium-137 (Cs-137), Am-241, Be-7, polonium-210 (Po-210), Pu-238/239, depleted uranium (DU), Th, and other TRU and fission product elements for use in source production and examination programs, including spent fuel examination. Uranium hexafluoride cylinders were also stored at the facility.

In summary, the Apollo and Parks Township facilities were involved in a very broad range of activities, for which a wide variety of potential internal and external exposures are of concern.

2.0 SPECIAL EXPOSURE COHORTS

Both the Apollo and Parks Township NUMEC sites have been added to the Special Exposure Cohort (SEC). This site profile review is performed within the context of these SEC assignments and their implications regarding the performance of dose reconstructions for workers not covered within the cohort. Therefore, this site profile review emphasizes those time periods and exposure scenarios that are not covered by the SECs, and also partial dose reconstructions for exposure scenarios that the SEC evaluation report claims can be reconstructed. This section briefly summarizes the SECs, identifying those technical areas that establish the basis for performing partial dose reconstructions and dose reconstructions for time periods that are not covered by the SECs.

2.1 APOLLO SITE SPECIAL EXPOSURE COHORT

According to the site profile, NIOSH issued an SEC for the Apollo Site for the period January 1, 1957, through December 31, 1983 (NIOSH 2007a), for an aggregate number of workdays totaling at least 250 days, within the parameters established for one or more classes of employees in the SEC. NIOSH's reasons for issuing the SEC (i.e., those exposure scenarios and time periods for which NIOSH believes it does not have sufficient data to perform dose reconstructions for all workers with sufficient accuracy) are as follows:

- *Uranium internal exposure before 1960 for lack of bioassay monitoring;*
- *Thorium and plutonium internal exposures for lack of monitoring data, process descriptions, and source term data;*
- *Potential ambient radiation dose from stack releases;*
- *Dose from radium-beryllium and polonium-beryllium neutron source fabrication operations;*
- *Internal doses where the bioassay data was based on NUMEC Apollo contractor, Controls for Environmental Pollution [CEP], from 1978 through 1983, because of concerns on data quality.*

2.2 PARKS TOWNSHIP SITE SPECIAL EXPOSURE COHORT

According to the site profile, NIOSH issued an SEC for the Parks Township Site for the period June 1, 1960, through December 31, 1980 (NIOSH 2008), for an aggregate number of workdays totaling at least 250 days, within the parameters established for one or more classes of employees in the SEC. NIOSH identified the following primary issues for recommending this SEC:

- *Thorium internal exposures for lack of monitoring data and process descriptions;*
- *Internal exposures for work with irradiated fuel and fabrication of radiation sources for lack of monitoring data, process descriptions, and source term data;*

- *Internal dose where bioassay data were based on NUMEC Apollo contractor, Controls for Environmental Pollution, from 1976 through 1980, because of concerns on data quality*

Although NIOSH determined that doses associated with the above exposure scenarios cannot be reconstructed, partial dose reconstructions during this time period can be completed when applicable monitoring data are available. Partial dose reconstructions can also be completed for time periods not covered by the SEC. Therefore, NIOSH concluded that, for individuals with cancers not covered by the SEC or for time periods not covered by the SEC, partial dose reconstructions are possible. Consequently, this review focuses on the data and dose reconstruction methodologies that are available and might be used by NIOSH to reconstruct exposures to workers not covered by the SEC.

3.0 SCOPE AND APPROACH TO THE REVIEW OF THE SITE PROFILE

This review was performed in accordance with the following procedures and guidelines:

- "SC&A Standard Operating Procedure for Performing Site Profile Reviews" (SC&A 2004), which was approved by the Advisory Board.
- "Data Access and Interview Procedure" (ABRWH 2009a), which provides for appropriate onsite coordination and data access protocols in conjunction with the Advisory Board, NIOSH, and DOE.
- "Department of Energy Classification Review of Documents" (ABRWH 2009b), which provides for appropriate security clearance reviews.

3.1 REVIEW SCOPE

The NUMEC Apollo/Parks Township site profile (ORAUT 2012a) serves as site-specific guidance to support dose reconstructions for claimants under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA). It provides the health physicists who conduct dose reconstructions on behalf of NIOSH with consistent general information and specifications to support their individual dose reconstructions. SC&A prepared this site profile review to provide the Advisory Board with an evaluation of whether and how the site profile can support dose reconstruction decisions.

To date, the site profile has not been supplemented by site-specific technical information bulletins (TIBs). SC&A reviewed other documents pertinent to NUMEC, including those cited in the NIOSH Site Research Database (SRDB) and worker interviews performed by NIOSH. SC&A critically reviewed the NUMEC Apollo/Parks Township site profile, as well as supplementary and supporting documents, against the following three evaluation criteria:

- Determine the completeness of the information gathered by NIOSH, with a view to assessing its adequacy and accuracy in supporting individual dose reconstructions.
- Assess the technical merit of the data/information.
- Assess NIOSH's guidelines for the use of the data in dose reconstructions.

SC&A's review of the NUMEC Apollo/Parks Township site profile and supplemental documentation focused on the quality and completeness of the data that characterize the facility and its operations, and on the use of these data in performing dose reconstructions. The scope and depth of the review focused on aspects or parameters of the site profile that would be particularly influential in dose reconstructions, bridging uncertainties, or correcting technical inaccuracies.

Our review carefully considered the radiation environments to which workers were exposed and the levels of exposure the workers received in that environment through time. We also considered the hierarchy of data used for developing dose reconstruction methodologies,

including dosimeter readings and bioassay data, coworker and workplace monitoring data, and process description information or source term data.

3.2 REVIEW PROCESS

SC&A's draft report and preliminary findings will subsequently undergo a multi-step issues resolution process. Issues resolution includes a transparent review and discussion of draft findings with members of the Advisory Board Working Group, petitioners, claimants, and interested members of the public. Prior to and during the resolution process, the draft report is reviewed by the DOE Office of Health, Safety and Security to confirm that no classified information has been incorporated into the report.

All review comments apply to Revision 02 of the Apollo and Parks Township site profile (ORAUT 2012a), which is the most recent published version. NIOSH conducted site expert interviews with former NUMEC Apollo Site and Parks Township Site workers to help obtain a comprehensive understanding of the radiation protection program, site operations, and historic exposure experience that SC&A consulted in the course of this review.

3.3 REPORT ORGANIZATION

This report is organized into the following sections:

Executive Summary
1.0 Introduction
2.0 Special Exposure Cohort
3.0 Scope and Approach to the Review of the Site Profile
4.0 Review of Internal Dose during Operations
5.0 Review of External Dose during Operations
6.0 Review of the Residual Period
7.0 SC&A Review of NUMEC Worker Interviews
8.0 Overview of NUMEC Cases
9.0 References

4.0 REVIEW OF INTERNAL DOSE DURING OPERATIONS

Section 5 of the site profile addresses internal exposure at the NUMEC facilities and the data sources, assumptions, models, and protocols that should be used to reconstruct internal exposures. Section 5.1 of the site profile summarizes the different types of internal exposure scenarios that were present at the NUMEC facilities. Table 5-1 of the site profile summarizes the potential radionuclides and fuel types that an Energy Employee (EE) might have been exposed to at NUMEC sites. The radionuclides include:

- Various chemical and physical forms of uranium over a range of enrichments
- Naturally occurring Th-228 and Th-232
- Mixtures of isotopes of plutonium of various ages and chemical forms
- Technetium (Tc) and TRU
- A variety of fission and activation products

This section presents a review and commentary on the completeness and accuracy of the internal monitoring data as described in the site profile and its supporting documentation.

It is important to keep in mind that the data and protocols for reconstructing internal doses at the Apollo and Parks Township Sites, as described in the site profile and reviewed here, must take into consideration that SECs were granted for both facilities, largely due to concerns about the ability to reconstruct internal exposures with sufficient accuracy. For this reason, this section begins with a reiteration of the SEC, followed by a description of the data and dose reconstruction methods described in the site profile, and then SC&A's review of those data and protocols.

4.1 SEC RESTRICTED MONITORING DATA[1]

The site profile states that bioassay data generated from Controls for Environmental Pollution (CEP) cannot be used in dose reconstructions. SC&A investigated this claim and found that, in 1994, CEP was convicted of data falsification related to the Sandia National Laboratory bioassay program. Following this incident, the U.S. Nuclear Regulatory Commission (NRC) and DOE issued notices warning that CEP data should be questioned. Therefore, CEP data cannot be used for dose reconstruction, but they can be used to determine risk of potential exposure.

4.1.1 Apollo Special Exposure Cohort

The Apollo SEC petition evaluation report (NIOSH 2007a) evaluated the feasibility of reconstructing internal doses at the Apollo Site. It identified a number of internal dose

[1] This section is somewhat redundant with the material provided in Section 2.0. However, we include it here because the quoted material in Section 2.0 was taken directly from the site profile, and the material describing the scope of the SEC provided in this section was taken from the SEC petition evaluation report, which is a little different than the description provided in the site profile. Therefore, we include both sources of information in this report.

monitoring areas where dose could not be accurately reconstructed (in addition to the CEP bioassay issue noted in Section 4.1 above):

- Internal monitoring records from 1957 through 1959 do not appear to exist.
- Information on thorium operations is not available.
- No monitoring data, process description or source term data exist for plutonium or concerning neutron source fabrication.
- Potential elevated ambient radiation levels from stack releases are not well documented.

Based on these findings, NIOSH concluded that the information pertaining to internal dosimetry was inadequate for determining internal exposures with sufficient accuracy.

4.1.2 Parks Township Special Exposure Cohort

The Parks Township SEC petition evaluation report (NIOSH 2008) evaluated the feasibility of reconstructing internal doses at the Parks Township Site. It identified a number of internal dose monitoring areas where dose could not be accurately reconstructed (in addition to the CEP bioassay issue noted in Section 4.1 above):

- Information on thorium operations and monitoring is not available.
- There is a lack of information on fabrication of radiation sources and work with irradiated fuels.

Based on these findings, NIOSH concluded that the information pertaining to internal dosimetry was inadequate for determining internal exposures with sufficient accuracy.

4.2 OVERVIEW OF DATA COMPLETENESS AND ACCURACY

Dose reconstruction for NUMEC workers was significantly complicated by the lack of internal monitoring information because of concerns over data falsification by CEP. Notably absent from the site profile are instructions on how to assign radionuclide intakes for the purpose of reconstructing internal doses for employees who worked at both NUMEC facilities and are not covered by the SEC. Because the facilities were located roughly 5 miles apart, it was fairly common for employees to work at both sites or go between sites. The amount of time workers might have spent at each site (i.e., daily, weekly, monthly, or on occasion) is not apparent from our review of the literature and selected cases. Because the sites' source terms differ, some guidance should be given to dose reconstructors on how to assign this dose, so that it is consistently assigned among cases. Typically, when a claimant worked at multiple facilities, dose reconstructors take into consideration doses that might have been experienced at different locations and at different time periods; however, this does not seem possible for the NUMEC sites, because the frequency of workers going between sites is not well documented.

Another overarching concern is that air concentrations of uranium could not be confirmed by our review. Although NIOSH attempted to quantify these concentrations, SC&A does not believe they are adequately captured in the site profile. This is discussed further in Section 4.11.

4.3 ITEMS REQUIRING CLARIFICATION

There seems to be some uncertainty about the start date of operations at the Parks Township Site. Section 2.2.1 of the site profile indicates that the site was not authorized to begin work until 1961, but Table 2-4 of the site profile indicates that many of the locations were operational in 1960. Additionally, Section 2.2.3.3 indicates that Building C was not used from construction until 1973 and Section 2.2.5 states that all operations in Building C ceased in 1978, yet Table 2-4 indicates that operations in Building C began in 1969 and lasted till 1980.

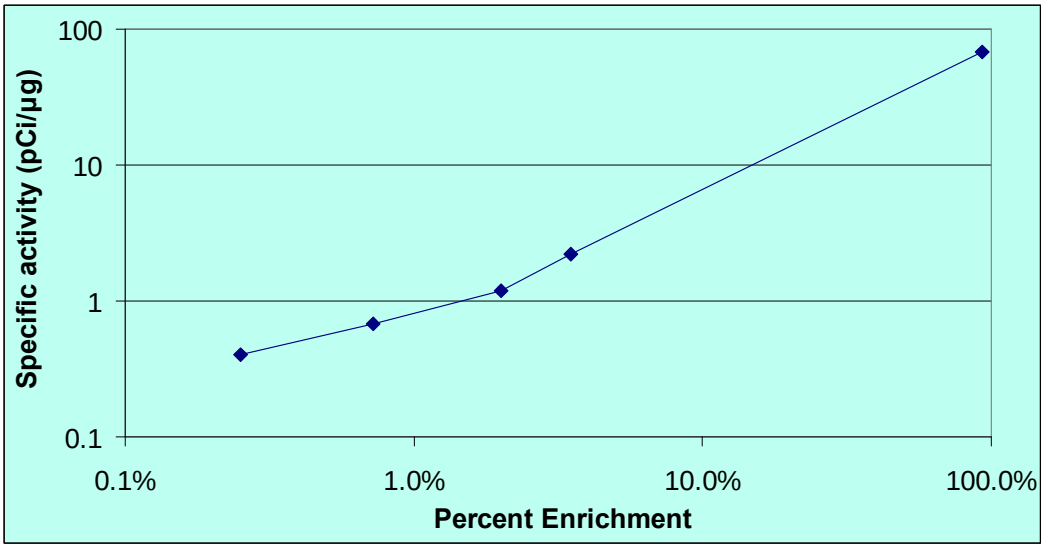
Finding 1: Clarification is needed regarding the start and end dates of Parks Township Site operations.

4.4 URANIUM

The uranium source term is summarized in Table 5-2 of the site profile. It appears that uranium was predominately handled at the Apollo Site, though there was also some risk of uranium exposure at the Parks Township Site. Table 5-2 of the site profile presents the isotopic mix of the various types of uranium (i.e., U-234, U-235, U-236, and U-238) that were handled at NUMEC as a function of enrichment, including natural and depleted uranium and uranium enriched to 2%, 3.5%, and 93%.

4.4.1 Urine Bioassay

Section 5.2.2 of the site profile presents the analytical methods used for the evaluation of uranium in urine and feces samples, the minimum detectable activities (MDAs), and the sampling frequencies for different categories of workers. The site profile explains that about 100 urine bioassays were conducted each month, and the results were expressed in terms of micrograms per liter (µg/L) or disintegrations per minute per liter (dpm/L), depending on the time period and laboratory performing the analysis. The site profile recommends that the dose reconstructor assume the chemical form of the uranium that is limiting for the type of cancer under consideration, which is a claimant-favorable strategy. However, for those urine analysis results expressed in terms of µg/L, no guidance is provided regarding what level of enrichment should be assumed. Figure 1 shows that, at higher levels of enrichment, the number of picocuries per liter (pCi/L) associated with a given µg/L of uranium in urine could be more than 10 times higher than at low levels of enrichment.



Note: Figure 1 shows the sum of the specific activities of the three naturally occurring isotopes of uranium—U-234, U-235, and U-238—for different degrees of enrichment. The data are taken from Table 5-2 of the site profile. Natural uranium and DU were assigned "enrichments" (i.e., mass fractions of U-235) of 0.25% and 0.72%, respectively. Our independent calculations of three of these values show good agreement with the specific activity of natural uranium. However, the NIOSH values for 2% and 93% (HEU) enrichments are 12.5% and 5% higher, respectively, than our values.

Figure 1. Total Specific Activity of Uranium Isotopes as a Function of Enrichment

Finding 2: The site profile should provide guidance about what level of uranium enrichment should be assumed for those urine bioassay results that are expressed in units of µg/L.

Early controls at NUMEC for uranium appear to be minimal. Prior to 1963, it seems likely that large intakes of uranium occurred without acknowledgment and follow-up action. The maximum allowable concentration (MAC) in urine until 1963 was 500 dpm/L for 93% enriched uranium. Attachment A provides the results of an evaluation of the organ doses associated with a MAC of 500 dpm/L of natural uranium. These values are also applicable to various levels of enriched uranium, because the dose conversion factors for the various isotopes of uranium are quite similar. The daily intake rates of Type M and Type S natural uranium that result in 500 dpm/L at the end of a year of chronic exposures are 212 Bq/d and 5,772 Bq/d, respectively. Note that for Type M uranium, the peak annual effective dose is 11.5 rem, and for Type S uranium the peak annual effective dose is 41.8 rem. Clearly, the doses associated with 1 MAC are quite high.

NUMEC also did not use breathing zone (BZ) air samples prior to this time. As a result, large localized intakes of uranium could have been missed without an adequate bioassay program. Health physicists at NUMEC preferred to use fecal sampling, because they found it identified intakes more consistently than urinalysis.

SC&A compared the NIOSH recommendations regarding the reconstruction of internal doses against a random sampling of SRDB files and found the recommended dose reconstruction protocol to be compatible with the monitoring information of the time. However, the site profile is silent on how uranium intake should be reconstructed prior to late 1959, which corresponds to the beginning of the bioassay program. Because uranium processing started nearly 2 years before this date, some guidance should be given to dose reconstructors, if possible.

The site profile does not mention missed dose and could benefit from a discussion on this topic. The site profile mentions that non-radiation workers were monitored annually, yet no guidance is provided with respect to missed dose or assigning doses to workers who were not monitored, but perhaps should have been monitored.

Finding 3: Some guidance is needed on how to perform dose reconstructions prior to 1959, and what approach to use for missed and unmonitored exposures.

4.4.2 Air Sampling

SC&A reviewed the Health and Safety Laboratory (HASL) studies, which involved fixed BZ air sampling for uranium workers during 1959–1961. The studies were used to determine average daily weighted exposure (DWE) for various jobs working with uranium. NIOSH assumed that these data had a lognormal distribution, with the highest DWE representing the upper 95th percentile and the lowest representing the bottom 5th percentile. NIOSH analyzed these data and found the median [210 dpm per cubic meter (m^3) = 94.6 pCi/m^3] of the assumed lognormal distribution. NIOSH recommends assigning this intake rate to all uranium workers.

SC&A considered this method and believes that it is claimant neutral, rather than claimant favorable. It is our understanding that the NIOSH analysis uses average airborne uranium concentration values after removing all high and low BZ air samples. SC&A was unable to replicate the NIOSH median value of 210 dpm/m^3 using the values in Attachment A to the site profile. SC&A reviewed the HASL reports and found that the locker room and laundry areas are omitted from Attachment A. Repeated analysis of general air (GA) samples taken from the changing area of uranium workers showed a 1966 DWE of 563 dpm/m^3 (Schnell 1966). Concentrations of this magnitude are not reflected by the NIOSH-modeled median dose.

Because SC&A was not able to reproduce the median airborne uranium concentration value assigned by NIOSH, even using the omitted values, SC&A elected to compare this recommendation with the recommendations for a uranium facility in the TIB, *Internal Dose Overestimates for Facilities with Air Sampling Programs*, ORAUT-OTIB-0018 (ORAUT 2005a). This document recommends assigning a limiting airborne uranium concentration of 1,330 dpm/m^3, which is substantially higher than the value recommended in the NUMEC site profile. SC&A therefore questions the validity and claimant-favorability of the default airborne uranium dust concentrations adopted for NUMEC.

A NUMEC study (Caldwell et al. 1967) indicates that the fixed BZ air samplers used in the HASL studies likely underestimated dose. Around 1965, NUMEC began using lapel samplers as

a screening technique. Following their use, NUMEC health physicists compared the results of BZ versus GA sampling; Figure 2 summarizes some of these results.

HAZARD INDICABILITY

Lapel Samples (BZ) vs. Fixed Station Samples (GA)

NUMEC URANIUM PLANT

1966 - 67

CONDITION INDICATED	NUMBER RECORDED	FREQUENCY
BZ > MPC GA < MPC	300	.654
BZ > 10 MPC GA < MPC	33	.072
BZ < MPC GA < MPC	54	.118
BZ < MPC GA > MPC	2	.004
BZ > MPC GA > MPC	70	.152

Total BZ Samples	459
Total GA > MPC	72
Total BZ > MPC	403

Source: Caldwell et al. 1967, pg. 14)

Figure 2. Reliability of Air Sampling

NUMEC health physicists determined that the fixed BZ samplers failed to identify greater than permissible exposures roughly 73% of the time. This study also found that more than 50% of the time, personal air samples tested showed concentrations 7 times that of stationary samples. Ten percent of the time, the concentrations differed by a factor of 20. This indicates that the fixed samplers used in the HASL studies several years earlier likely underestimated dose.

It is important to stress that a DWE represents the AVERAGE air concentration experienced by a particular worker on the day that the measurements were taken, without regard to the uncertainty inherent in the measurements or the representativeness of the DWE for all workers in that job type at all times; the HASL air sampling studies made no attempt to characterize the uncertainty in DWEs. Davis and Strom (2008) conducted an uncertainty analysis of DWE for 6 facilities that processed uranium, thorium, and radium and recommend a geometric standard deviation (GSD) of 5 to account for variability and uncertainty in the measurements. This technique was evaluated as part of the SEC petition evaluation review for the Fernald Feed Materials Production Center (Fernald) and found to be appropriate in principle for that site. SC&A believes that the NUMEC site profile would benefit by adopting the recommendations in Davis and Strom (2008) for uncertainty in DWE.

Finding 4: Uranium inhalation recommendations for the Apollo Site need to take into consideration the method discussed by Davis and Strom (2008) for dealing with uncertainties in DWE. This technique was evaluated and found to be appropriate in the site profile review for the Fernald Feed Materials Production Center (Fernald).

Finding 5: Inadequate information is given to replicate NIOSH's determination of median inhalation concentration of uranium. The NIOSH result could not be replicated, and it appears that relevant information has been omitted from the HASL studies reported in Appendix A to the site profile.

4.5 PLUTONIUM

The Parks Township Site received its first shipment of plutonium in June 1960, but did not receive a license to handle it prior to March 1961. This was the first plutonium license ever granted to a commercial facility.

The largest concern for internal exposure at the Parks Township Site is plutonium inhalation. Plutonium operations started on a small scale, doing research and development. Although it is not clear exactly when, the site eventually evolved into large-scale productions, receiving two Zero Power Plutonium (later Physics) Reactor (ZPPR) orders, each the largest plutonium orders of their time.

Section 5.2 of the site profile addresses the various chemical and physical forms of plutonium handled at the facility. It explains that three types of plutonium were handled at NUMEC: reactor grade, weapons grade, and fuel grade. However, because information is lacking about the actual composition of plutonium handled at a given location and at a given time, the site profile recommends assuming Hanford Site (Hanford) reference fuel-grade plutonium (ORAUT 2012c), using the mixture identified in Table 5-3 of the NUMEC site profile.

In order to understand Table 5-3 of the site profile, we needed some background information about the various grades of plutonium that were handled and produced at Hanford. Plutonium mixtures were categorized by their weight percent of Pu-240. When the reactors were operated to produce plutonium for weapons, the target mixture was about 6% Pu-240, a mixture referred to as "weapons grade." When the reactor was operated to produce power, the mixture in the fuel rods when removed from the reactor was nominally 12% Pu-240, a mixture referred to as "fuel grade." There were a few exceptions in radiochemistry laboratories where purified Pu-238 and Pu-239 experiments were performed, for example, in Building 325 C-Cell. There is evidence at Los Alamos National Laboratory (LANL) that plutonium produced at Hanford in the 1940s had less Pu-240, perhaps closer to 3%, but documentation of that at Hanford has not been found (ORAUT 2009b). Tables 5-3 and 5-4 of the Hanford site profile (ORAUT 2012c) give the activity composition of weapons-grade (6%) and fuel-grade (12%) plutonium in 5-year increments up through 20 years. The dose reconstructors are told, when Pu-238 or Pu-239 are measured in the bioassay analysis, to use 20 years, so that the dose is maximized by assuming the longer decay time. When Am-241 is measured and the intake is estimated using in-growth of Am-241 from the decay of Pu-241, the dose is maximized by assuming the shorter decay time of 5 years. The site profile further states that a best estimate of intake can be made by assuming a

10-year decay time, as this is midway between the possible low and high ages of plutonium from Hanford. If the actual age of the fuel is known, then that age can be used in the intake and dose analysis. The Hanford site profile states that, for intakes since about 1999, a 20-year-old fuel-grade mixture could be assumed.

In the 1970s, work at Hanford was using material with much more Pu-241 and with Pu-240 at 26%. In addition, the Plutonium Finishing Plant sometimes recycled plutonium from other DOE sites, the United Kingdom, and commercial reactors, and these materials often had higher Pu-240 and Am-241 content. The Hanford site profile also states that, "use of the 6% mixture is the default starting point for limiting doses based on chest counts" (ORAUT 2012c).

Our review of this section of the Apollo and Parks Township site profile reveals that, overall, the site profile data for the plutonium mixtures are quite accurate. However, it is not appropriate to assume that all the plutonium can be generalized or averaged as NIOSH has done by using a 10-year decay time as a midpoint. This is especially troublesome considering the fact that Hanford handled other percentage mixtures of plutonium over the years, including pure Pu-238 and Pu-239, as well as recycled plutonium from other DOE sites, the United Kingdom, commercial reactors, and ZPPR fuel mixtures; these materials often had higher Pu-240, Pu-241, and Am-241 contents.

The site profile explains that the age of the plutonium should be selected to give the benefit of the doubt to the claimant. This is done by assuming that the age is 20 years when plutonium is measured, and 5 years if the method of analysis is to measure Am-241 in the urine sample. This strategy appears to be fundamentally sound. However, a review of a few actual dose reconstructions would help to judge that this strategy is actually being implemented in a claimant-favorable manner. Furthermore, it is not apparent that the Hanford reference fuel-grade plutonium mix, as opposed to reactor grade or weapons grade, is limiting. SC&A's finding on this point is as follows:

Finding 6: The site profile would benefit from a discussion demonstrating that the Hanford fuel-grade mix, as opposed to the weapons-grade or commercial-grade plutonium, is limiting for the full range of plutonium mixes and ages that were used at NUMEC. In addition, given the complexity of this subject, a review of actual dose reconstructions would provide greater insight into how this matter is actually being addressed.

Section 5.2.1 of the site profile provides guidance for reconstructing plutonium intakes and doses using urine and fecal bioassay data, presumably from non-CEP labs. Tables 5-4 and 5-5 of the site profile present minimum detectable concentrations [MDCs, also often referred to as minimum detectable levels (MDLs) or minimum detectable activity or (MDA)] for urine and fecal analyses, respectively, as a function of date (beginning in October 1961) and radionuclide. The remainder of the section describes the analytical methods that were used to measure plutonium in urine and fecal samples.

SC&A reviewed the MDCs for plutonium in urine bioassays, as reported in Table 5-4 of the site profile, and found that they are reasonable, but that there are some inconsistencies within the site profile itself, and that the values are not entirely consistent with those reported by others. For

example, for the period October 1961–December 1965, the MDC in the site profile is tabulated as 0.28 dpm/L, error of 0.01–0.48 dpm/L. However, Section 5.2.1.2 of the site profile reports a sensitivity of about 0.44±0.20 dpm/L in 1964. This factor of 2 should be reconciled. In addition, for this same time period, LANL ORAUT-TKBS-0010-5 (ORAUT 2009b) reports an MDC that corresponds to 0.18 dpm/L [based on 0.2 dpm per 24 hours (24h) and an assumed excretion of 1.4 L]; for this period, ORAUT-TKBS-0011-5 for Rocky Flats (2007c) reports MDCs of about 0.30 dpm/L [reported values varied from 0.44 dpm/24h (about 0.3 dpm/L) to 0.54dpm/24h]; and International Commission on Radiological Protection (ICRP) Publication 10 (1968) reports a limit of detection of 0.06 pCi/24h (0.13dpm/24h, about 0.1 dpm/L), based on a 1964 paper from Jackson and Taylor (1964).

Observation: For this time period, the reported MDCs for NUMEC are higher than the ones reported by LANL and the one reported in ICRP Publication 10 (1968). The NUMEC MDCs are comparable to the ones reported by Rocky Flats. NIOSH should clarify some of these differences.

For the period January 1966–December 1975, the MDCs for Pu-238 and Pu-239 in the NUMEC site profile are reported as 0.06 dpm/sample, with an error of 0.03 dpm/sample. For the same time period, the MDCs for Pu-238 and Pu-239 at LANL are similar; i.e., about 0.05 dpm/L (based on a MDC of 0.07 dpm/24h, as reported in ORAUT 2009a). However, the MDCs for Rocky Flats were higher at about 0.39 dpm/L (based on 0.54 dpm/24h, as reported in ORAUT 2007c). ICRP Publication 54 (1989) reports an MDA of 0.01 Bq/L (about 0.6 dpm /L) for Pu-238 and Pu-239. This is much greater than the MDAs reported by LANL and NUMEC.

Observation: It is difficult to comment on the NUMEC MDCs for this period of time because there is no description of the process that was used, and the MDCs are very low. On the other hand, LANL reports similar detection limits.

For the year of 1999, the MDCs reported in the site profile varied from 0.0025 to 0.044 pCi/L for Pu-238 and 0.0025 to 0.045 pCi/L for Pu-239/240, without any information on the techniques that were used. It is difficult to believe that NUMEC could achieve the lower-end MDC of 0.0025 pCi/L. For the same time period, the MDCs for Pu-238 and Pu-239 at LANL were 0.008 pCi/24h (about 0.006 pCi/L), as reported in ORAUT 2009a. The MDC for Rocky Flats in 1999 was 0.02 dpm/24h (0.009 pCi/24 hr and about 0.0064 pCi/L), as reported in ORAUT 2007c. ICRP Publication 78 (1997) reports an MDC of 1 mBq/L (0.027 pCi/L).

For fecal analysis, the only reported MDC is 0.1 dpm/sample for the period 1966–1977. No specification of the method used is given. For the same time period, there are no reported MDCs for Pu-238 and Pu-239 feces analysis at LANL (ORAUT 2009a) or at Rocky Flats (ORAUT 2007c). ICRP Publication 54 (1989), reports an MDA of 0.01 Bq/sample (0.6 dpm/sample). ICRP Publication 78 (1997) reports 1 mBq/sample or 0.06 dpm/sample.

Observation: Although possible, the MDC for the period 1966–1977 for feces bioassay appears to be low.

For lung counting, plutonium and americium counting started in 1966 and was conducted on a regular basis in 1968. Table 1 reproduces Table 5-9 from the site profile.

Table 1. In-Vivo MDAs for Pu-239 and Am-241

In vivo MDAs for ^{239}Pu, ^{241}Am.[a]

	^{239}Pu MDA (nCi)			^{241}Am (nCi)		
Year	**Minimum**	Maximum	Counts	Minimum	Maximum	Counts
1968	NR[b]	NR[b]	NR[b]	0.13	0.38	17
1969	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
1970	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
1971	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
1972	9	11.5	3	0.13	0.13	1
1973	5.6	15.6	46	0.11	0.21	28
1974	5.44	21.3	122	0.09	0.22	96
1975	4.8	19.9	133	0.11	0.21	104
1976	5	20.3	109	0.11	0.19	91
1977	4.4	19.6	113	0.09	0.19	88
1978	4.7	19	132	0.1	0.19	100
1979	5.16	24.3	168	0.08	0.26	132
1980	5.03	28.2	132	0.09	0.21	94
1981	7.21	27.8	55	0.12	0.2	31
1982	7.12	34.3	77	0.12	0.21	44
1983	9.41	15.6	6	0.12	0.16	4
1984	8.67	22.32	9	0.12	0.15	5
1985	8.84	31.07	31	0.11	0.22	29

[a] From a review of worker dosimetry records (Boyd 2006a,c,d,g,h,j). Values for 1968 through 1971 are based on the Helgeson system, with remaining values for the University of Pittsburgh system.
[b] NR = none reported.
Source: ORAUT 2012a, Table 5-9

ORAUT-TKBS-0010-5 (ORAUT 2009b) reports MDCs for Am-241 lung counting at LANL for 1977 and for the period 1980–1984. The MDC for both periods is about 0.3 nanocuries (nCi), higher than the NUMEC maximum MDAs for 1972–1985. The MDCs for Am-241 at Rocky Flats were about 1 order of magnitude higher than at NUMEC until 1976, when high-purity germanium detectors were used, and the MDCs were comparable to the NUMEC-listed ones (ORAUT 2007c). ICRP Publication 54 (1989) reports an MDC of 20 Bq (0.54 nCi) for Am-241 lung counting.

Finding 7: The MDAs for Am-241 lung counting are very low, and the counting method should be further explored in order to give them credibility.

At LANL, the lung count MDAs for Pu-239 were much higher than the ones reported for NUMEC. ICRP Publication 54 (1989) reports an MDC of 2,000 Bq (54 nCi) for Pu-239 lung counting, a value similar to the MDCs from LANL and much higher than the MDCs for NUMEC.

Observation: The results of Pu-239 measured directly should be used with caution, as it is very difficult to detect the low-energy emissions from Pu-239.

Air sampling for plutonium in Fab 5 at the Parks Township Site can be used to establish an average or default inhalation intake for plutonium workers. During 1967, approximately 400 BZ samples were taken in the scrap recovery area of Fab 5, and documentation indicates that additional data might exist (Crosby 1967, NUMEC 1967). However, the site profile does not present these data or guidance on how the data might support dose reconstructions.

Finding 8: The site profile would benefit from a more thorough discussion of the possible use of air sampling data to reconstruct internal plutonium exposures and to take into consideration the additional data provided by Crosby 1967 and NUMEC 1967.

4.6 THORIUM

Section 5.2.3 of the site profile addresses thorium exposures, essentially explaining that there are few data, and that it will be difficult to reconstruct these exposures. Additionally, it is unclear if thorium areas were remediated prior to the final decontamination of either site. It appears that, sometime in late 1963 or early 1964, the Apollo Site did work for Bettis Atomic Power Laboratory (BAPL) fabricating ThO_2 pellets (Forscher 1963). When bioassay data are available, they should be used; however, there is a potential that many thorium exposures were missed. The site profile states that air sampling was used rather than urinalysis, because urinalysis is not a reliable method for estimating thorium intake.

The SEC petition evaluation reports for both the Apollo and Parks Township Sites found that there are insufficient information, air sampling, and bioassay data on thorium operations to bound thorium dose. SC&A reviewed the documentation on the SRDB for evidence of thorium work and found only minimal information on thorium processes, time frames, and cleanup. SC&A concurs that sufficient information is not available to accurately characterize thorium dose at either site. SC&A assumes that no attempt has been made or will be made to reconstruct internal thorium exposures for workers not covered by the SEC.

4.7 MIXED FISSION PRODUCTS

Section 5.2.4 of the site profile states that some bioassay data exist (presumably gross beta/gamma analysis of urine samples) that can be used to reconstruct internal exposures to mixed fission and activation products, including Co-60, Cs-137, strontium-90 (Sr-90), Tc-99 (from RU), and ruthenium-106 (Ru-106)/rhodium (Rh). Exposure to mixed fission and activation products was possible at both sites, and the site profile acknowledges that it was difficult to adequately address which areas had a risk of exposure. At the Apollo Site, this exposure was linked to the commercial laundry facility; at the Parks Township Site, this exposure came from Building A. However, SC&A could not locate any specific information on the fission and activation product source terms at NUMEC.

The site profile recommends that, if bioassay data are available (presumably expressed in terms of gross beta/gamma analyses per liter of urine), the dose reconstructor should assume the mix of radionuclides specified in ORAUT-OTIB-0054 (ORAUT 2007a). Though ORAUT-OTIB-0054 was previously given a favorable review by SC&A for its intended purpose, we question its applicability to the NUMEC facilities. For example, in the following excerpt from page 9 of

ORAUT-OTIB-0054, the last sentence indicates that ORAUT-OTIB-0054 might not apply to internal exposures to fission and activation products at NUMEC:

> *This guidance applies to a broad scope of reactor operations including plutonium production reactors (low enrichment, low burnup, Zircaloy or aluminum cladding), research reactors [modest enrichment, modest burnup, stainless-steel (SS) or Zircaloy cladding; e.g., Training, Research, Isotope General Atomics (TRIGA) reactors], high-enrichment, high-burnup reactors [e.g., Idaho National Laboratory's Advanced Test Reactor (ATR), fuel from naval reactors], and fast breeder reactors [e.g., Hanford's Fast Flux Test Reactor (FFTF), Argonne National Laboratory–West's experimental breeder reactors]. It does not apply to radioactive lanthanum (RaLa) operations, which involved very short-cooled fuel but was performed in hot cells. It also does not apply to determination of intakes where radionuclides have been purposely extracted and concentrated as for heat generation sources, medical uses, or waste handling operations that caused significant alteration to the source term to which workers were exposed.*

Finding 9: It does not seem appropriate to use ORAUT-OTIB-0054 (ORAUT 2007a) to reconstruct the internal exposures of workers at NUMEC who might have been exposed to mixed fission products, because ORAUT-OTIB-0054 states that its guidance "does not apply to determination of intakes where radionuclides have been purposely extracted and concentrated as for heat generation sources, medical uses, or waste handling operations that caused significant alteration to the source term to which workers were exposed." For example, see Table 5-1 of the site profile. Also, the fission product mix given in ORAUT-OTIB-0054 does not contain the same radionuclides as the fission product mixes given for the NUMEC Laundry in the 1975 effluent release report (SRDB #20081) and for in-vivo count results in SRDB #19970. The NUMEC mixes include Co-60, which the ORAUT-OTIB-0054 mix omits.

4.8 RECYCLED URANIUM

Joynar (1962) indicates that RU was present at both NUMEC sites. From this document, it appears that most, if not all, of the processing was done at the Apollo Site, and that the Parks Township Site was used for storage. Additionally, Portsmouth Gaseous Diffusion plant received over 300 kg of RU from NUMEC during 1972 (Wilcoxon 1999). Potential contaminates in RU were not consistently monitored as part of the bioassay program.

Section 5.2.5 of the site profile advises dose reconstructors to use ORAUT-TKBS-0017-5 (ORAUT 2004) and ORAUT-OTIB-0060 (ORAUT 2007b) to assign dose to the unmonitored radionuclides associated with RU. SC&A looked at these documents in the context of NUMEC dose reconstruction and found them to sufficiently address assigning dose from RU contaminates. SC&A notes that the site profile does not instruct dose reconstructors when to assign dose from unmonitored radionuclides associated with RU. It is unclear if this should be considered whenever a uranium bioassay is present or if some other criterion should apply. Additionally, the RU section is separated from the uranium section on internal dose assessment, which increases the likelihood that this dose would be missed by dose reconstructors.

In addition, the site profile recommends assuming the mix of radionuclides (relative to uranium observed in bioassay samples) as adopted for use at Fernald. SC&A agrees with this strategy. However, it is important to recognize that the mix of radionuclides comprising RU at Fernald has been modified as a result of the ongoing review of the Fernald site profile (ORAUT 2004) and SEC petition evaluation report (NIOSH 2006).

Finding 10: Internal dose reconstructions performed for NUMEC personnel might need to be revisited in light of changes to the Fernald site profile (ORAUT 2004) with respect to RU. Also, additional direction is needed with respect to which workers or operations should be assigned RU intakes.

4.9 SEALED SOURCES

Records at the Parks Township Site indicate that sealed sources were made, though there appears to be minimal evidence establishing for whom the sources were created, the processes and controls in place, and exposure history. Neutron sources (Po-210/Be) and gamma sources were created in hot cells located in the plutonium facility in Fab 4. SC&A concurs with the findings of the SEC petition evaluation report (NIOSH 2008) that there are insufficient documentation and bioassay records to reconstruct dose from the fabrication of sealed sources. However, if bioassay data exist, an attempt should be made to quantify potential dose, with the caveat that care must be taken when using ORAUT-OTIB-0054 as the methods for reconstructing dose based on gross beta/gamma analysis of urine samples for the reasons discussed above in Section 4.6.

4.10 IN-VIVO COUNTING

Section 5.3 of the site profile addresses in-vivo counting for Pu-239, Am-241, uranium, and some fission products, which began around 1966 following an incident. SC&A found that, prior to March 25, 1968, whole-body counting (WBC) was not used at NUMEC. The facilities hired a mobile unit to assay 33 employees deemed to be at high risk for potential exposures. Of those assayed, 8 (6 for U-235 and 2 for Pu-239) had intakes giving a dose greater than the maximum permissible concentration (Caldwell 1968b). NUMEC believed that the working conditions leading to these intakes were resolved. Assays done on 38 individuals showed persistent problems with uptakes of U-235 and Pu-239 (Caldwell 1968a). Scans became somewhat more commonplace beginning at least as early as 1982. Records show that EEs were permitted to decline WBC scans if they desired.

The site profile further states that from 1966 to 1969, lung counting was performed by the University of Pittsburgh. However, the site profile also states that, "In 1968 and 1971, Helgeson performed whole-body counts on individuals for fission products, ^{235}U, ^{241}Am, with ^{239}Pu estimated from the ^{241}Am results based on expected activity ratios for ^{239}Pu/^{241}Am" (Caldwell 1968b). SC&A is concerned about this statement, because it is known that the Helgeson data were flawed and invalid for uranium chest measurements as late as 1989 or later. NIOSH states in the Pantex technical basis document (ORAUT 2007d, Section 5.2.2.3, page 23) that the Helgeson uranium data in 1989 at Pantex were likewise flawed and biased and could not be used for dose reconstruction. According to "Pantex Plant – Occupational Internal Dose," ORAUT-

TKBS-0013-5, Revision 01 (ORAUT 2007d): "Note: Dose reconstructors should not use data from the Helgeson in vivo counts."

Finding 11: NIOSH should explain whether the concerns expressed in the Pantex site profile (ORAUT 2007d) about the Helgeson chest count data might also apply to chest count data at NUMEC performed by Helgeson for NUMEC workers.

4.11 AIR SAMPLING

Section 5.4 and Attachment A to the site profile address and present the results of five separate HASL reports prepared by the AEC that investigated airborne uranium exposures at the Apollo Site in selected time periods from 1959 to 1961. The following excerpt from the site profile concisely describes these investigations:

> *The air samples consisted of radioactive particulates on filters from breathing zones and general areas during processing. The alpha activity measured on the filter was used to determine the airborne alpha activity concentrations. When multiple samples at a location were collected, the AEC used the mean air concentration in subsequent calculations. The AEC matched air concentration determinations with information about worker categories, locations, tasks, and time at each location or task.*

In addition, Section 5.6 of the site profile describes the uranium and plutonium air sampling programs and discusses investigations that established correlations between the breathing-zone air (BZA) sampling data, the GA sampling data, and bioassay data. The site profile states the following about these investigations:

> *The correspondence between lapel sampler data and early fecal clearance for plutonium showed very good agreement, but fixed-station BZA samplers and general area air sampling usually underestimated airborne concentrations. Fifty percent of the lapel air sample results at Apollo showed concentrations seven times greater than the stationary air samples. The median of the ratio of lapel BZA to GA concentrations results was found to be ~7 at the Apollo and Parks Township sites* [Caldwell et al. 1967).

Though SC&A did not review the results of these investigations, investigations of this type are not common and are considered to be indicative of a thorough health physics oversight program.

The site profile explains that, when used in combination with the results of the bioassay programs, process knowledge, work location, and job descriptions, internal doses can be reconstructed for many workers, and that coworker models can be developed for many workers lacking bioassay data. SC&A concurs with this statement.

4.12 INCIDENTS AT BOTH SITES

Section 5.5 of the site profile explains that dosimetry records should indicate if an individual exceeded the 40 maximum permissible concentration-hours exposure limit over a time period less than 1 work week. If this level of exposure continued for an entire year, the worker would exceed the annual limit for internal exposures. These records, along with other health physics practices described in the site profile, if kept faithfully, would represent a reliable source of data that would allow the reconstruction of internal doses to workers involved in an incident associated with a potential for a relatively high level of internal exposure.

Sections 5.5.1 and 5.5.2 of the site profile list incidents at the two NUMEC facilities. SC&A reviewed the incidents mentioned in the site profile in comparison to the records found in the SRDB. The incidents selectively mentioned in the site profile are seemingly a random sampling; they should not be seen as encompassing all incidents at the sites. Incidents and large overexposures at both sites appear to have been fairly common during the early years of operation. Dosimetry, bioassays, personal BZ air sampling and Computer-Assisted Telephone Interview (CATI) report statements should be used to establish potential incidents and overexposure.

It is noteworthy that the site profile section on the Apollo Site also indicates that none of the incident reports refer to worker exposures attributable to the incidents. In order to explore the degree to which incidental exposures were actually documented, SC&A sampled some cases to determine if any incidents are explicitly addressed as part of the dose reconstruction. Section 8 summarizes the results of these investigations.

5.0 REVIEW OF EXTERNAL DOSE DURING OPERATIONS

Section 6 of the site profile addresses external exposures at the NUMEC facilities and the data sources, assumptions, models, and protocols that should be used to reconstruct external exposures. Section 6.2 of the site profile summarizes the different types of external exposure scenarios that were present at the NUMEC facilities, which included neutron, gamma, and beta exposures associated with manufacturing or handling Pu, Th, HEU, Pu-Be, and fission and activation products. Table 6-1 of the site profile summarizes the sources and types of external exposures. Section 6.3 (Table 6-2) of the site profile describes the types of dosimetry used at NUMEC to detect and quantify these sources of external exposures, and Table 6-3 presents the MDLs for the various dosimeters as a function of time. Adjustments required to convert dosimeter readings to deep dose for photon and neutron exposures and non-penetrating dose for beta exposures are addressed in detail. The following presents a review and commentary on the completeness and accuracy of the external dosimetry data as described in the site profile and its supporting documentation.

5.1 SPECIAL EXPOSURE COHORT RESTRICTED MONITORING DATA

5.1.1 Apollo Special Exposure Cohort

The Apollo SEC petition evaluation report (NIOSH 2007a) evaluated the feasibility of reconstructing external doses at the Apollo Site. It states the following (page 18):

> *NIOSH has concluded that information pertaining to external dosimetry is inadequate to ensure that sufficiently accurate external exposures can be reconstructed for the NUMEC Apollo operations.*

The NUMEC site profile states that data on the neutron source fabrication are lacking. NIOSH concluded that, because of this lack, it cannot accurately bound these doses during operations. However, NIOSH also states that, although external monitoring is inadequate for dose reconstruction, if information is available, it should be used:

> *Although NIOSH has determined in this evaluation that there is a lack of sufficient data to permit estimating and/or reconstructing NUMEC Apollo external doses with sufficient accuracy, NIOSH does intend to use any available external data that may be included in an individual's file (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures) to support a partial external dose reconstruction for non-presumptive cancers and/or cases that have less than 250 working-days of employment.*

SC&A assumes that NIOSH made these statements, which appear to conflict somewhat, because there are external dosimetry data that will be used to support partial dose reconstructions for workers not covered by the SEC. The NUMEC site profile does mention the lack of information relating to neutron source fabrication, but it is not clear that this lack extends into the external dose reconstruction. SC&A conducted a review of the available dosimetry records and

determined that there was sufficient external monitoring to generate a coworker model. This is discussed in further detail below.

5.1.2 Parks Township Special Exposure Cohort

In the Parks Township SEC petition evaluation report (NIOSH 2008), NIOSH did not feel that it was necessary to do an adequacy determination for external dose based on the inadequacies in internal dose data. This is a different approach from what NIOSH did for the Apollo Site. It appears that, based on inspection of the SEC petition evaluation report, NIOSH believes that external exposures at the Parks Township Site can be reconstructed with sufficient accuracy.

5.2 OVERVIEW OF COMPLETENESS AND ACCURACY

The NUMEC dosimetry program was fairly complex, as it needed to address a wide range of energies and types of radiation. For example, the "I" and "R" dosimeters supplied by Landauer, Inc., were complex devices that incorporated several neutron- and gamma-detection components into one overall device. In many ways, the dosimetry program was on a par with the Argonne National Laboratory-East (ANL-E) dosimetry program. These programs were similar in that multiple vendors and technologies were used in a wide variety of radiation fields over several decades. The discussion of external dosimetry in the NUMEC site profile runs 11 pages, compared with 32 pages in the (pre-review) ANL-E site profile (ORAUT 2006). The NUMEC site profile needs additional sections on data discrepancies, common issues, gaps in energy response for neutron dosimetry, and other items.

SC&A observes in general that a more detailed assessment of the external program is needed. For example, were badges worn in multiple locations, and if so, how is the record to be interpreted? How were gaps and inconsistencies in the data handled? For example, if one component of a multi-component badge was lost or damaged or conflicted with the reading from another component of the same badge, how was this addressed? No mention of lead aprons is made in the site profile. Was any protective gear used throughout the history of the site? Likewise, no mention is made of pouches or badge protection in a potentially dirty industrial setting. Contemporaneous photographs showing protective equipment and dosimetry wear practices would be informative. The description of the multi-component badges would benefit from additional discussion of the cutover between components, such as albedo and track etch neutron detection. On a positive note, the Landauer "I" and "R" dosimeters were the most comprehensive dosimeters that Landauer provided at the time and may indicate that NUMEC was using the best available technologies to monitor workplace exposures.

5.3 ITEMS REQUIRING CLARIFICATION

Table 6-2 in the site profile describes the dosimeters used throughout the period in question:

Table 2. Excerpt from Table 6-2 in the Site Profile

1976–present	*Landauer or equivalent TLD (Z1 dosimeter - 1990)*	*Comprised of 3 TLD-700 chips for monitoring beta, X-ray, and gamma exposure. Insensitive to neutron radiation.*

The Landauer "Z1" dosimeter described also contained a CR-39 track etch device for fast neutron detection. This fact should be added to the description, assuming the Z1 was indeed in use for the period described.

Section 6.3.2 of the site profile appears to be inconsistent with Table 6-2:

> *Workers were monitored for neutron exposures with nuclear track emulsion, Type A (NTA) film from commercial venders until about 1968, and with TLDs thereafter. In addition, criticality dosimetry monitoring was done with an array of area critical assemblies that fed into a central system. This system existed from at least 1963; in September 1963, each visitor and employee was issued an indium foil criticality dosimeter as part of each security badge (NUMEC 1963).*

From 1968 forward, the facility did not use only a thermoluminescent dosimeter (TLD) for neutron monitoring, but also track etch, according to Table 6-2 of the site profile. Also, Table 6-2 describes the method for deriving the fast neutron dose that involved subtraction of the thermal dose. It is not clear if this was determined from a cadmium-filtered film badge or not. Table 6-2 lists multiple technologies, including NTA, CR-39, Albedo TLD, and (implied) thermal neutron photographic film. The text in Section 6.3.2 only lists NTA and TLD for routine dosimetry, but mentions indium foil criticality dosimeters that are not addressed in the table.

Finding 12: Table 6-2 and the associated text in Section 6.3.2 of the site profile should be reviewed and modified as needed to correct any oversights, inconsistencies, or errors.

5.4 SOURCE TERM

Table 6-1 of the site profile lists radioactive source manufacturing operations as a potential source of gamma and neutron exposure. Given that large quantities of beta-emitting materials were used to produce sources, there would have been a significant potential exposure to large beta fields, especially during non-routine operations and unusual events. While there is extensive discussion of the fuel manufacture and processing activities, the site profile provides little detail on the source manufacturing operations.

The brief discussion of potential beta radiation fields in Section 6.2.1 is limited and does not mention source production operations. NUMEC produced AmBe and other alpha-N sources, so there would have been exposure potential for the entire manufacturing cycle, including processing, storage, waste handling, maintenance, and transportation. The modest source of neutron exposure, UF_6 cylinders, is mentioned as a potential neutron source in Section 6.5.2.3. Metrics need to be added that account for the quantity and size of sources produced, along with protocols for transfers, storage, and so forth.

In the body of the text, there is no mention of the considerable license limits that NUMEC was authorized to possess for source production (Tables 2-4 through 2-8 of the site profile). Several beta-emitting nuclides, including Ir-192, Cs-137 and Co-60, were used to manufacture sources. Did routine operations protect operators from all beta dose due to the penetrating nature of the gamma emissions? Regardless, there is a concern in the following situations: incidents,

transferring materials in and out of hot cells and gloveboxes, spills, plant and equipment maintenance, and waste handling. In some of these situations, the amount of radioactive material might be low compared with possession limits, but beta exposure would likely be the primary concern for unshielded or minimally contained situations. Given that these situations would involve highly non-uniform fields, some discussion of badging practices, extremity results, and use of local shielding would be helpful. The external dosimetry section needs expansion to include some metrics on the amount of material handled, worker protection, and other relevant information. Issues associated with non-uniform exposures to non-penetrating radiation at this site are highlighted here, because skin cancers are not covered by the SEC. For example:

- What was the throughput of sources, how large were they, and what kinds of facilities were used for processing?
- Were the glovebox gloves lead loaded, and if so, what was their effective attenuation for 17 and 60 kiloelectronvolt (keV) x-rays?
- How was non-uniform exposure addressed, and where was the body dosimeter worn?
- Did all glovebox workers wear wrist badges?
- How was the extremity dose adjusted due to the wear location of the wrist badge, especially for beta dose?
- Did either facility switch to finger TLD rings at any point?

Finding 13: Given our understanding that it is NIOSH's position that external exposures at the Parks Township Site can be reconstructed with sufficient accuracy, it appears that the description of the sources and circumstances responsible for external exposures need to be better developed, if possible.

5.5 NTA NEUTRON DOSIMETRY

From 1958 to 1970, the NUMEC sites used only NTA to monitor non-thermalized neutrons. NTA is only able to monitor neutrons 800 to 1,000 keV and up. No provision is contained in the site profile to address exposures below this energy range. Indeed, Section 6.4.2 expressly states, "However, at this time, the neutron dosimeter readings should be used without correction for this effect." Note that this section also implies that NTA can be used for energies between 500 and 800 keV. The ANL-E site profile and others use an 800- or 1,000-keV threshold. Other sources list 1,000 keV as the threshold for NTA response. As has been the case in a number of site profiles, there is an inconsistent approach to the energy cutoff for NTA neutron dosimetry. We believe that the assumption that NTA film responds down to 500 keV is not justified by the technical data, and is not claimant favorable.

Other site profiles, such as ANL-E's, demonstrate that there needs to be a thorough consideration of the limitations of the NTA technology for the period in question. Given the range of neutron source terms and the uncertainty regarding the response of the dosimeter, an assessment of potentially missed dose is needed. At the very least, a correction factor of 4 may be warranted for plutonium-handling facilities, as was suggested for the ANL-E site profile. Other situations

in which workers might have been exposed to neutrons with energies below 1 MeV should also be evaluated.

Finding 14: The site profile should provide justification for why adjustment factors are not required for neutron exposures estimated using NTA film, considering that it appears that the neutron energy spectrum likely extended to well below 1 MeV. For example, Table 6-8 of the site profile indicates that the energy range of neutron exposures extended from 0.1 to 2 MeV.

According to Section 1.3.1 of the site profile:

> *An SEC has been identified that includes all AWE employees who were monitored or should have been monitored for exposure to ionizing radiation while working at the NUMEC site in Apollo, Pennsylvania, from January 1, 1957, through December 31, 1983, for a number of work days aggregating at least 250 work days or in combination with work days within the parameters established for one or more other classes of employees in the SEC.*

As one of the reasons for granting the SEC, NIOSH determined that it is not feasible to reconstruct doses from radium-beryllium and polonium-beryllium neutron source fabrication operations. However, the site profile states that "partial doses can be estimated for workers for whom applicable monitoring data are available." This statement suggests that it might be possible for NIOSH to perform partial dose reconstructions for workers exposed to other sources at this site who were not included in the SEC class. Furthermore, an SEC was also granted for the NUMEC facility in Parks Township, Pennsylvania, from June 1, 1960, through December 31, 1980. That SEC was based on the inability to reconstruct internal doses. Consequently, NIOSH may attempt to perform partial dose reconstructions for workers exposed to neutron radiation at this site who were not included in the SEC class. The dosimetry methods that might be used to reconstruct neutron doses to workers at either facility who are not included in the respective SEC classes need to be examined.

Dosimeters containing NTA film were used to monitor external exposures to neutron radiation of NUMEC personnel at the Apollo and Parks Township Sites from 1957 through May 1968. The energy response of the NTA film was long known to depend on the neutron spectra to which the badge was exposed. Some sites, such as Mound Laboratory, therefore sought to calibrate the films using sources that were similar to the neutron emitters that were being processed on site. If the neutron spectrum of the calibration source closely matches the spectrum of the neutron sources to which the workers are exposed in the course of their employment, then the NTA film dosimetry records, with proper adjustments for effective dose, can yield reasonable estimates of the doses from external exposure to neutron radiation. If the workers were exposed to sources with neutron emission spectra that were lower in energy than those emitted by the calibration source, the NTA film dosimetry reports underestimated the neutron dose. Conversely, if the neutron spectra in the workplace had higher energies than those of the calibration source, the doses were overestimated.

According to Section 6.4.2 of the site profile:

> *NTA film has a characteristic decreasing response to neutron radiation at energies below about 500 to 800 keV, depending on the extent of photon fogging and the overall process to develop and read the tracks* [ORAUT 2006]. *However, at this time, the neutron dosimeter readings should be used without correction for this effect.*

The site profile gives no justification for this directive to dose reconstructors (i.e., no correction factors are needed). NIOSH needs to examine any existing NTA film calibration records to determine how well the calibration methods corresponded to the actual neutron exposures of workers at the two sites and during various time periods. Absent such information, NIOSH should apply claimant-favorable correction factors. A detailed discussion and analyses of the correction factors for NTA film exposed to various neutron spectra versus the sources used to calibrate the film are presented by R. Anigstein and D. Olsher in SC&A (2010).

5.6 PHOTON DOSE ADJUSTMENTS

Section 6.5.2.2 of the site profile recommends that no adjustments are needed for shallow or deep dose photon exposures. The difference in dosimeter response between Am-241 and plutonium x-rays can be significant, especially where beta is also a consideration. The potential for either over-response to Am-241 or under-response to plutonium x-rays needs to be addressed for various mixtures of radiation and for the differing dosimetry technologies, processors, and time periods.

The site profile discussion of low-energy photon adjustments includes wording that seems irrelevant or misleading (page 57):

> *Table 6-5 summarizes the gamma energy distribution for NUMEC plutonium in comparison with Hanford plutonium. Beta energies are included as well as ^{233}U and ^{241}Am, which have similar overall photon and beta properties.*

Table 6-5 presents this information as follows:

Table 3. Table 6-5 Reproduced from the Site Profile

Energy-photon	**NUMEC plutonium (^{241}Am & ^{233}U)**	**Hanford plutonium**
<30 keV	15	25
30–250 keV	82	75
>250 keV	3	0
Energy-beta	**NUMEC plutonium (^{241}Am & ^{233}U)**	**Hanford plutonium**
>15 keV	100	100

It is unclear what the authors intended by describing all beta energies for Am-241 as being >15 keV, as Am-241 and U-233 are alpha emitters.

The site profile extensively references and excerpts *Gamma Spectrum Measurements and the Interpretation of Absorbed Dose during Plutonium Fuel Fabrication* (Caldwell and Judd 1966), a paper on the use of the Eberline film dosimeter at NUMEC. Section 6.4.1 of the site profile implies that the data in this paper are to be used for the entire history of and all programs at the NUMEC sites. This is problematic, because the data presented in the paper were limited to 6 months for NUMEC's plutonium laboratory and hot cell facility operations, and were only intended to address plutonium dosimetry issues. Aside from the specific discussion of the Caldwell and Judd (1966) paper, the site profile offers no discussion of other sources of exposure or work environments. Section 6.5.2.2 of the site profile recommends no adjustments to the NUMEC recorded shallow and deep doses based (presumably) on the Caldwell and Judd paper, and does not justify the statement that, "The existing recorded doses provide a realistic estimate of the actual doses."

Many other operations took place at NUMEC beyond the plutonium and specific hot cell work described in the contemporaneous Caldwell and Judd (1966) paper. Likewise, a number of differing dosimetry technologies were in use, including several types of film badge holders and possibly film emulsion. The appropriateness of generalizing the Caldwell and Judd data for plutonium work and to the entire NUMEC dosimetry program has not been assessed and needs to be considered.

Finding 15: The markedly different photon and neutron energies associated with the operations at NUMEC would indicate the possible need for adjustment factors for the results of film badge dosimeters, which are not provided in the site profile.

The remaining issues that need to be explored are adequacy of coverage of workers who had the potential to experience the various types of external exposures, and the degree to which a claimant-favorable coworker model has been developed to reconstruct the external doses to workers who were not monitored or adequately monitored, but had the potential to experience external exposures. The following sections address these issues.

5.7 EXTERNAL UNMONITORED WORKER ANALYSIS

Section 6.5 of the site profile provides instructions for reconstructing external exposures to recorded beta, gamma, and neutron exposures. SC&A notes that Table 6-7 of the site profile instructs dose reconstructors to assign zero dose to workers who were not monitored, apparently because NIOSH believes that all workers who had the potential for significant exposure were issued personal dosimeters. The implication is that there is no need for a coworker model for external exposures, including beta and gamma exposures. This is in contrast to the Parks Township SEC petition evaluation report (NIOSH 2008), which states the following:

> *However, during an AEC inspection in 1967 (*[AEC 1967]*), the inspectors noted that the radiation dose rate in an unrestricted area exceeded 2 mrem/hr, thus exceeding regulatory requirements for unrestricted areas. Surveys of unrestricted areas (NUMEC, 1968) were conducted between 1966 to 1968 also indicate periodic dose rates approximately 12 mR/hr in unrestricted areas outside the scrap recovery facility (FAB-5). Although most of the dose rates were relatively*

low (background levels to < 0.5 mR/hr) around the facility, these periodic higher dose rates in unrestricted areas indicate that at various times unmonitored workers could have been exposed to low to moderate doses of radiation. In addition, NIOSH has limited documentation that associates job titles and/or job assignments with specific radiological operations from which to develop a co-worker model for these unmonitored workers.

Additionally, in the interviews conducted by NIOSH with former NUMEC employees, most EEs reported not being monitored despite having exposure risk. These matters are important and are explored in depth in the following sections of this report.

In order to determine the external monitoring coverage of the worker population at NUMEC, SC&A took a random sample of 40 available claimants (20 from the Apollo Site and 20 from the Parks Township Site) who were employed during various operational and residual time periods (1957[2]–1995). These 40 claims were examined to determine which employed years contained external dosimetry records. It should be noted that this study did not attempt to compile actual film badge data to determine any gaps within each monitored year,[3] nor did this study attempt to compare the relative magnitude of film badge results among the different sampled claimant job categories. SC&A's main objective was to determine the degree to which workers were, in fact, monitored.

The number of sampled claimants employed by year, as well as the availability of external monitoring records for those claimants, are summarized in Table 4 and Figure 3.

Table 4. Overview of Claimant Sampling by Year

Year	# of Sampled Claims	# of Sampled Claims with Monitoring Data	% of Sampled Claims with Monitoring Data	Year	# of Sampled Claims	# of Sampled Claims with Monitoring Data	% of Sampled Claims with Monitoring Data
1958	1	0	0.0%	1977	16	7	43.8%
1959	3	0	0.0%	1978	14	9	64.3%
1960	5	0	0.0%	1979	14	7	50.0%
1961	8	3	37.5%	1980	12	5	41.7%
1962	13	2	15.4%	1981	12	4	33.3%
1963	15	2	13.3%	1982	12	7	58.3%
1964	16	6	37.5%	1983	10	4	40.0%
1965	14	4	28.6%	1984	6	2	33.3%
1966	14	3	21.4%	1985	6	2	33.3%
1967	18	7	38.9%	1986	6	4	66.7%

[2] None of the claimants sampled were employed in 1957, so this study begins in 1958.

[3] Based on claimant CATI reports and information in the site profile, routine badging was exchanged on a monthly basis. A worker being identified as having been monitored in a given year does not necessarily indicate that the external dosimetry records were complete for that year.

Table 4. Overview of Claimant Sampling by Year

Year	# of Sampled Claims	# of Sampled Claims with Monitoring Data	% of Sampled Claims with Monitoring Data	Year	# of Sampled Claims	# of Sampled Claims with Monitoring Data	% of Sampled Claims with Monitoring Data
1968	20	8	40.0%	1987	6	4	66.7%
1969	17	6	35.3%	1988	6	3	50.0%
1970	18	7	38.9%	1989	6	6	100.0%
1971	18	8	44.4%	1990	7	4	57.1%
1972	16	6	37.5%	1991	8	4	50.0%
1973	16	7	43.8%	1992	8	3	37.5%
1974	18	10	55.6%	1993	7	3	42.9%
1975	17	9	52.9%	1994	6	4	66.7%
1976	17	8	47.1%	1995	4	3	75.0%

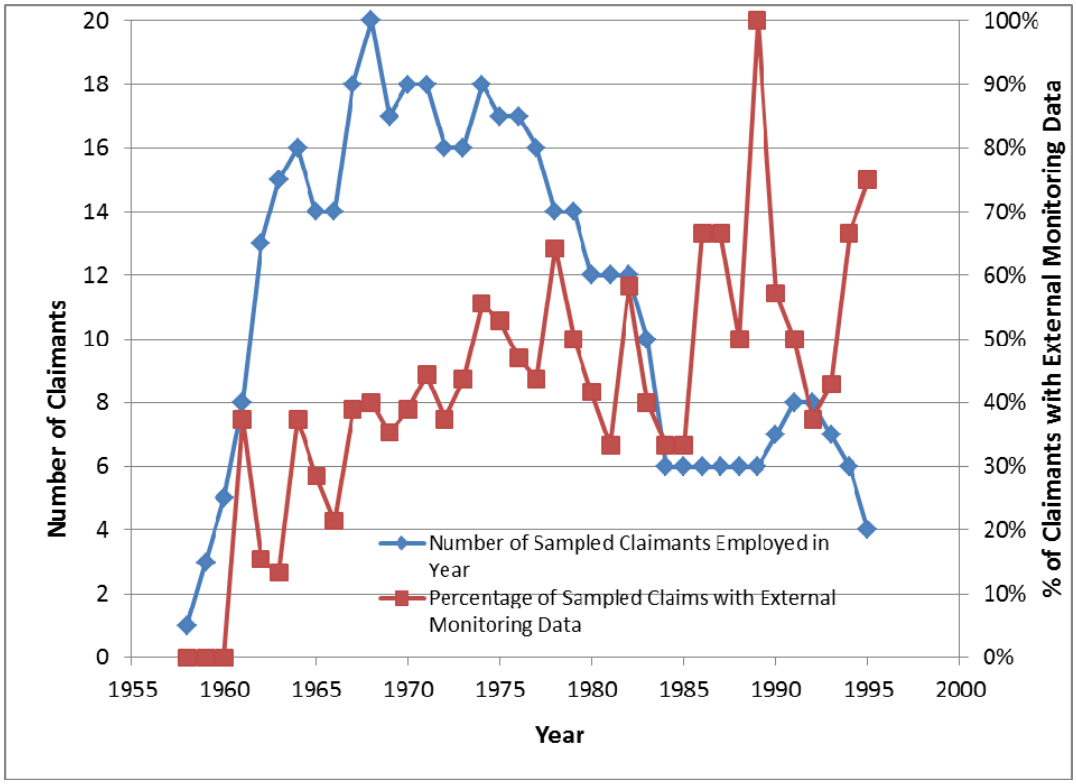


Figure 3. Overview of Claimant Sampling by Year

As seen in Table 4 and Figure 3, the random sample of 40 claimants covers most operational years at NUMEC, as well as the residual period. The percentage of claimants monitored for external radiation was generally in the 30%–70% range and increased as time went on at the site. The average percentage of claimants with external monitoring over the period of interest was approximately 42%; no external monitoring data could be located for the 40 sampled claimants

until 1961. A more detailed description of the claimant population sampled is shown in Appendix B to this report.

As can be seen in Appendix B, SC&A examined a wide variety of job titles at NUMEC in the random claimant sample, including:

- Technicians (nuclear fuel fabrication, laboratory, powder, quality control, health and safety, electronics).
- Operators (liquid waste/waste tank, furnace, dissolver, glovebox, press operator, truck driver).
- Administrative (secretary, receptionist, supervisor, foreman, health and safety manager, accounting clerk).
- Other plant jobs (chemist, chemical engineer, laborer, security guard, janitor, maintenance man).

Therefore, the random sampling appears to represent an appropriate cross section of the types of jobs and associated exposure potential experienced at the site. As shown in Table 4, exactly half (20) of the claims examined had no external monitoring available in their dosimetry file. However, 9 of the 20 claims with no external monitoring did have some internal monitoring (urinalysis or WBC) that might serve as an indicator of exposure potential.

CATI reports for this group of unmonitored workers indicate that 14 of the 20 EEs worked in radiological areas on a routine or semi-routine basis, 2 of the 20 only entered radiological areas on rare occasions, and 2 of the 20 did not enter radiological areas. The remaining CATI reports did not indicate whether the claimants entered radiological areas. Job titles among workers with no available external monitoring included technicians, operators, laborers, furnace, and maintenance workers. All of these job titles would presumably subject the worker to external exposure sources.

The method by which reconstruction of external dose was handled for claimants with no or insufficient external monitoring was not consistent among the sample population. For example, SC&A observed the following external dose reconstruction methods among the sampled claimant population:

- Reconstruction of medical x-ray doses only (reference numbers: 2, 4–6, 10, 13–15, 20, 24, 32, 34, and 40; these reference numbers are described in Appendix A).
- External dose reconstructed based on DOE quarterly or annual dose limits at the time (reference numbers: 29 and 33).
- External dose reconstructed based on "coworker studies for other DOE sites" (reference number: 27), coworker dose from the Rocky Flats Plant (reference number: 30) or simply "coworker studies" (reference numbers: 23, 27, 30, and 39).
- External dose reconstructed based on ORAUT-OTIB-0004 (ORAUT 2005c).

Finding 16: NIOSH should consider developing a coworker model based on NUMEC claimant records or specify a more consistent basis for assigning external doses beyond the medical x-rays associated with the site.

5.8 OCCUPATIONAL MEDICAL EXPOSURE

NUMEC apparently did not have a medical x-ray department during the operational years. Many EEs have blank claimant medical records; however, scans were done and analyzed offsite, which could potentially explain the absence of records in some EEs' files.

It is clear that during at least 1963, annual, new hire, and termination posterior-anterior scans were performed. Additionally, EEs who worked with beryllium received two posterior-anterior examinations per year. There is no evidence indicating that lateral or lumbar scans were used at either site. There is no other site-specific information on x-ray examinations available. Earlier versions of the site profile recommended using ORAUT-OTIB-0006 (ORAUT 2005b) to assign dose. However, Section 3.0 of the site profile concludes that medical exposures should not be assigned if the medical exposures were performed offsite. This is consistent with the new policy in ORAUT-OTIB-0006 that states the following:

> *A recent NIOSH interpretation of the EEOICPA statute is that the statute defines covered radiation as the radiation received by a covered employee at a covered facility during a covered period (NIOSH 2010). This interpretation affects how X-ray dose should be assigned if the X-rays were taken at a site or location that is not defined under the statute as a covered facility, such as offsite locations including private physicians' offices, clinics, or local community hospitals. Except in limited circumstances concerning residual radiation, only radiation that the employee received at a covered facility can be included in dose reconstruction.* [ORAUT 2011b]

ORAUT-OTIB-0079 (ORAUT 2011a) provides additional guidance on offsite x-ray examinations. SC&A confirmed that examinations occurred off site, though the cited file (NUMEC 1963) in the site profile is unavailable on the SRDB. Because there is no evidence to suggest that NUMEC had onsite x-ray examination facilities, and the site profile states that they were performed at a "local clinic or hospital," these examinations are not eligible to be included in the dose reconstruction.

6.0 REVIEW OF THE RESIDUAL PERIOD

The residual period for the NUMEC Apollo Site covers 1984 through 1995, and the residual period for the NUMEC Parks Township Site covers 1981 through 2004. Section 7.0 of the site profile discusses the estimation of exposure during the residual periods.

As of August 23, 1978, NUMEC had completed decommissioning of its HEU processing at the Apollo Site. All process and related equipment were removed by this date. NUMEC indicated that access to the area was controlled to authorized personnel. In 1982, the NRC conducted a confirmatory survey to identify the remaining HEU inventory during decommissioning. The NRC report indicates uranium contamination levels in terms of grams of uranium per unit surface area. The NRC estimated the total grams of uranium remaining on and in the floors, walls, pad, and ceiling at the Apollo Site to be 35,548.55 grams of total uranium, with about 23,743.27 grams of U-235 (NRC 1982).

Decontamination for the Apollo Site was completed from 1984 to June 1992. In June 1992, the NRC approved the Apollo decommissioning plan. Decommissioning occurred from June 1992 to 1995. The NRC staff reviewed the Babcock & Wilcox (B&W) groundwater monitoring data, final termination survey, and a confirmatory survey in 1996. On April 14, 1997, after notifying the Pennsylvania Department of Environmental Protection, the NRC issued a letter to B&W terminating the Apollo license (PDEP 2008).

The Parks Township Site ceased work for DOE operations in 1980. Decontamination and decommissioning of the facilities began in 1978 at Building C and continued through several phases for all facilities. Starting in 1994, B&W began final decontamination and decommissioning at the Parks Township Site to the extent permitted under the terms of its license. In January 1996, B&W submitted a site-wide decontamination and decommissioning plan, with subsequent plan revisions in 1997 and 1998. In October 1998, the NRC approved Revision 3.1 of the plan. Demolition and removal of all facilities were started at that time. All decommissioning activities had been completed by January 2002. All waste had been shipped to a licensed waste disposal facility, and the final status survey had been performed. After B&W completed 2 years of groundwater monitoring that showed that site ground water was within established limits, the NRC terminated the license and released the site for unrestricted use on August 24, 2004 (PDEP 2008).

Because the site profile states that the SEC periods cover the operations periods (i.e., January 1, 1957, through December 31, 1983, for the Apollo Site and June 1, 1960, through December 31, 1980, for the Parks Township Site), the residual period is not covered under the SEC. Hence, reconstruction of doses during the residual period is of particular importance.

6.1 EXTERNAL DOSE

6.1.1 External Dose at the Apollo Site

For the Apollo Site, the site profile recommends that, for workers who have personal dosimetry data during the residual period, the data should be used for dose reconstructions. The site profile

also explains that, since non-Atomic Weapons Employer (AWE) radiological activities continued at the Apollo Site after 1983, the dosimetry readings would place an upper bound on the external exposures from residual radioactivity associated with AWE operations. For workers without personal dosimetry during the residual period, the site profile recommends that dose reconstruction be based on the assumption that workers were exposed to surface contamination levels associated with the average surface contamination measured at the end of the operational period [4.97E6 dpm/m^2 (GSD = 7.91)], and that the contaminant was natural uranium. SC&A refers to this strategy as "the OTIB-0070 approach," because it is compatible with the basic guidance provided in ORAUT-OTIB-0070, Revision 01 (ORAUT 2012b). SC&A concurs with this basic strategy, because it places a plausible upper bound on the average surface contamination that might have been present during the beginning of the residual period, and the external dose conversion factor for natural uranium is limiting as compared to enriched uranium. It also appears that the external dose rate derived in this manner for the residual period at the Apollo Site is assumed to remain constant throughout the residual period, which is also a bounding assumption, because residual surface contamination would be expected to decline by natural attenuation as it ages.

6.1.2 External Dose at the Parks Township Site

For the Parks Township Site, actual recorded dosimetry results are used for the period of 1981–1983, when available, because Apollo was still performing work for DOE during that time. External dose estimates assume either HEU or plutonium exposure, depending on the EE's work location. The site profile advises defaulting to uranium exposure if a work location cannot be determined. SC&A finds this guidance to be claimant favorable, because it assumes a monitored EE may have visited Apollo during the years it was still operational and thus been at risk of DOE-related exposures.

For workers without personal dosimetry during the residual period, NIOSH used the same approach as for the Apollo site uranium external dose. NIOSH used the average surface concentration at the end of the residual period [2.74E5 dpm/m^2 (GSD= 4.97)] to estimate the annual external dose to workers using the OTIB-0070 approach. Assuming the plutonium isotopic composition listed in Table 5-3 of the site profile, NIOSH reported all organ doses were below 0.001 rem. NIOSH concluded no external dose from potential plutonium exposure need be assigned to EEs at Parks Township. SC&A independently calculated plutonium dose using the dose conversion factors from Federal Guidance Report 12, Table III.3 (EPA 1993), and found that the dose to each organ assuming 20-year aged plutonium is less than 0.0001 rem per year. SC&A agrees that external dose from plutonium during the residual period can be omitted from Parks Township dose assessments.

For Parks Township workers that were unmonitored during the residual period, but are thought to have worked in Building C or come in contact with HEU, the site profile advises dose reconstructors to assign the same residual external dose as Apollo. SC&A finds this to be reasonable, because no information on air concentrations of plutonium at Parks Township is available. The Apollo site handled more uranium for longer times than Parks Township, so this is thought to be a bounding approach.

6.1.3 External Beta Dose at Both Sites

No beta exposure is assigned to workers for the residual period at the Parks Township or Apollo Sites. Previous analyses performed in support of SC&A's review of Battelle-TBD-6000 (Battelle 2007) revealed that the skin dose 1 meter above a surface contaminated with residual uranium from beta emission is 100 times greater than the dose from penetrating radiation. Table 5 presents the results of SC&A's previous calculations, as provided in our review of Battelle-TBD-6000.

Table 5. Dose Rates at 1 Meter above a Contaminated Floor, Calculated with MCNP (mrads/hr per dpmα/m^2)

Radiation	Breast	Testes	Skin
Electrons	1.19E-09	2.58E-10	2.13E-08
Gammas	1.17E-10	1.29E-10	1.37E-10
Bremsstrahlung	1.18E-11	1.32E-11	1.11E-11
Total	1.32E-09	4.00E-10	2.15E-08

Source: Battelle 2007.

As shown in Table 5, direct beta rays (electrons) are the major contributors to skin dose. This matter was addressed as part of the Procedures Subcommittee issues resolution process, and NIOSH agreed with this concern and revised the original Battelle-TBD-6000 (Battelle 2006). In fact, Battelle-TBD-6000 was revised (Battelle 2011), and Table 3.10 (page 26) of that revision presents updated beta dose rates from a contaminated floor that are a little higher than the values presented in Table 5 above. Therefore, SC&A believes that this part of the NUMEC site profile needs to be amended in accordance with the guidance provided in the latest version of TBD-6000.

Finding 17: The site profile should include guidance for deriving non-penetrating doses to skin and other organs from beta emitters associated with surface contamination during the residual period.

6.2 INTERNAL DOSE

6.2.1 Apollo Site

The site profile states that when bioassay records exist during the residual period, these records should be used to reconstruct internal doses. The site profile also states that if the bioassay data are from CEP records, they cannot be used to reconstruct internal doses because of CEP's confirmed involvement in data falsification. CEP records can only be used to establish exposure risk. SC&A concurs with this strategy. When bioassay records are not available or cannot be used, the site profile recommends the following coworker model, which is based on modeling resuspension of residual contamination.

In order to reconstruct resuspended uranium particles, the site profile recommends using the median air activity 210 dpm/m^3 that NIOSH derived from the HASL studies done during 1959–

1961. These studies were used to determine the average BZ concentrations experienced by various workers involved in the process of converting UF_6 into uranium dioxide, uranium-zirconium scrap recovery, and coating of uranium products in 1959–1961. As discussed earlier, SC&A has concerns with the methods used by NIOSH to develop the median uranium air concentration for use during operations. However, SC&A considers the use of airborne dust loading and intake rates observed during operations to be a reasonable starting point for bounding the initial airborne dust loading and intake rates during the residual period. SC&A suggests that GA samples, as opposed to BZ samples, be used for the residual period, because BZ samples are more closely associated with the direct generation of aerosols in the BZ of workers during operations. General air (GA) samples are more closely associated with the overall average airborne dust loading and associated intakes that might result from resuspension processes during the residual period.

Finding 18: General air (GA) air samples, as opposed to BZ samples, should be used as the starting point for reconstruction of radionuclide intake rates during the residual period.

Given the average annual airborne dust loading during operations, the site profile estimates the surface contamination level at the beginning of the residual period by assuming the airborne dust settles at a rate of 0.00075 meters per second (m/sec) over the course of 1 year, as follows:

$$210 \text{ dpm/m}^3 \times 31{,}536{,}000 \text{ sec/year} \times 0.00075 \text{ m/sec} = 4.97\text{E}6 \text{ dpm/m}^2$$

Based on previous site profile reviews, SC&A concurs with the deposition velocity of 0.00075 m/sec; this value represents the settling velocity of 5 micron activity median aerodynamic diameter (AMAD) particles. Extensive empirical measurements performed at the Hanford Metals Handling Facility confirm the validity of this assumption (Adley 1952).

The assumption that the buildup accumulates for a period of 1 year seems intuitively reasonable, because it can be assumed that there was some degree of periodic housekeeping that would remove the loose contamination from surfaces during operations.

Given the surface residual contamination, the site profile uses a resuspension factor (RF) of 1×10^{-6}/m to derive the airborne dust loading at the beginning of the residual period, as follows:

$$4.97\text{E}6 \text{ dpm/m}^2 \times 1 \times 10^{-6}\text{/m} = 4.97 \text{ dpm/m}^3$$

The NUMEC site profile was originally prepared before issues related to RFs were addressed by the Procedures Subcommittee (i.e., ORAUT-OTIB-0070) and also by the Battelle-TBD-6000 Work Group. The outcome of those issue-resolution activities was an agreement among the participants (i.e., NIOSH, SC&A, and the Advisory Board) that an RF of 1×10^{-6}/m is appropriate for sites that have been cleaned up, such that there was little removable contamination. However, at facilities where the surface contamination was not cleaned up, such as at Apollo, an RF on the order of 1×10^{-5}/m is more appropriate. Using an RF of 1×10^{-5}/m, the initial airborne dust loading during the residual period would be about 50 dpm/m^3. This aspect of ORAUT-OTIB-0070 (site-specific RF) was not incorporated into the latest revision of the site profile.

Finding 19: SC&A recommends that NIOSH use an RF of about 1E-5/m to derive the airborne dust loading for the beginning of the residual period, or perhaps simply assume that the average GA dust loading observed during the operational period is applicable to the beginning of the residual period.

The site profile further recommends that, as time goes by, the dust loading declines by the factors listed in Table 4-2 of ORAUT-OTIB-0070. This rate of decline in the residual contamination is an attenuation rate of 0.00067/day (0.067%/day). SC&A finds this depletion technique to be consistent with the most current guidance on source term depletion.

SC&A notes that the site profile is silent regarding any residual radioactivity other than uranium, even though the facility worked with thorium, plutonium, and other radionuclides.

Finding 20: The site profile makes no reference to radionuclides other than uranium during the residual period at Apollo.

6.2.2 Parks Township Site

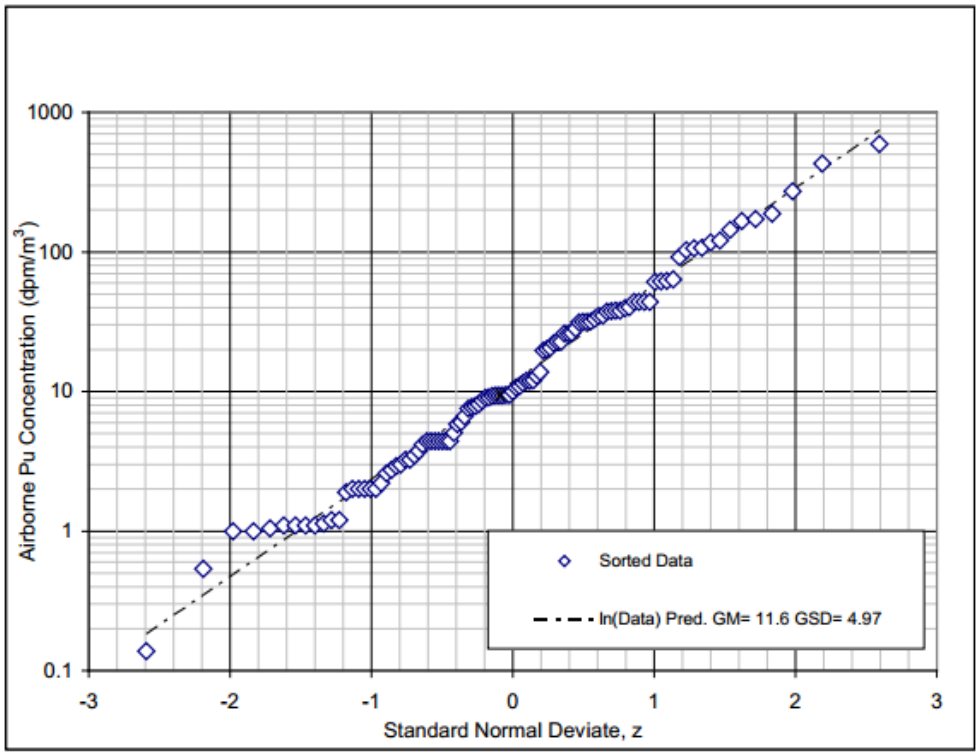
The site profile explains that, when bioassay data are available, they should be used to establish internal dose during the residual period, unless the samples were analyzed by CEP, which did not produce reliable results. CEP results, however, should be used to indicate intake potential.

No formal air monitoring studies were conducted at the Parks Township Site; however, it is known that plutonium was the largest component of the source term at the site. NIOSH compiled 105 GA samples, which were collected from 1966 to 1982. These data were fit to a lognormal distribution, as shown in Figure 4, which was excerpted from Figure 7-1 of the site profile.

Using this distribution, the average daily air concentration was estimated to be 11.6 dpm/m^3 (GSD=7.91). SC&A reviewed the available air monitoring information and found that the methods NIOSH used are appropriate. SC&A did not attempt to reproduce this value, but believes it is reasonable, given the GA sample results. NIOSH then used the average air concentration to estimate the surface concentration of plutonium to be 2.74E5 dpm/m^2 after 1 year of continuous deposition.

$$11.6 \text{ dpm/m}^3 \times 31{,}536{,}000 \text{ sec/year} \times 0.00075 \text{ m/sec} = 2.74\text{E}5 \text{ dpm/m}^2$$

This surface concentration is favorable to claimants at the end of the operating period. The deposited material is assumed to be resuspended and inhaled during the residual period. The amount of resuspension was assumed to reduce with time, due to fixing of the material on surfaces and to depletion. The depletion factors that were applied to each year are described in Table 4-2 of ORAUT-OTIB-0070. The use of the RF of 1×10^{-6}/m is appropriate for sites like Parks Township that have been somewhat decontaminated prior to the residual period.



Source: ORAUT 2012a, Figure 7-1

Figure 4. Parks Township Site General Air Sampling Analysis

Because the plutonium is based on gross alpha GA monitoring results, the activity represents the total alpha activity. NIOSH properly converted the results to represent fractional alpha activity of each radionuclide for ages of plutonium ranging from fresh to 20 years as is listed in Table 7-4 of the site profile. NIOSH instructs dose reconstructors on the age of the plutonium mixtures to assign for each year of residual period for both best-estimate and minimizing cases. On the following page of the site profile (i.e., page 67), however, Table 7-3 assumes 100% of the mixture is Pu-239 for ingestion and inhalation intake. SC&A finds this guidance to be conflicting and believes it could lead to inconsistencies in dose reconstruction. NIOSH should clarify how aged plutonium during the residual period should be accounted for.

Finding 21: There is conflicting guidance on how aged plutonium mixtures should be treated during the residual period at Parks Township.

SC&A noted that on page 67, the following passage should be updated to reflect ingestion intake rather than simply intake.

> *The daily intake rate (dpm/d) is estimated to be 0.2 times the average daily air concentration in units of dpm/m^3. Using the air concentration at the end of operations of 11.6 dpm/m^3, an intake rate of 580 dpm/yr is obtained for ^{239}Pu for 250 workdays per year for the first year of the residual period (1981).*

The site profile also recognizes that work with uranium in Building C could contribute to internal dose for workers during the residual period. Because there was insignificant air monitoring done at Parks Township, NIOSH used the Apollo monitoring results shifted back 3 years (different start years of residual period) to model potential uranium intakes during the residual years. Accordingly, this approach to assigning internal doses to uranium to Parks Township workers for the residual period makes use of surrogate data from Apollo, and must meet the Board's five surrogate data criteria, as follows:

Criterion 1 pertains to the overarching principle, as set forth in 42 CFR Part 82.2, that, when performing dose reconstruction, greatest weight should be given to personnel dosimetry and bioassay data, followed by workplace monitoring data, followed by site-specific coworker data. In keeping with this principal, surrogate data acquired from other sites should also follow this hierarchy. In this case, there are no bioassay data that could be used as a surrogate. As such, it was necessary to make use of the air sampling data from Apollo as the starting point for this dose reconstruction. We believe that this criterion is met.

The second criterion, referred to as "exclusivity constraints," pertains to those applications of other site data where there are no or very little monitoring data available. In those cases, the use of the surrogate data as the basis for individual dose reconstruction would need to be very stringently justified. This judgment needs to take into account not only the amount of surrogate data being relied on relative to data from the site, but also the quality of the surrogate data relative to data available for the site in question. In this case, the use of Apollo data as a surrogate for Parks Township is a bounding approach, because Apollo handled more uranium for longer periods of time than Parks Township. Parks Township was also decontaminated somewhat prior to the start of residual period. If an EE's work location is unknown, the site profile recommends assigning the higher dose of the two models. Since it is unlikely an EE received the highest intake of both uranium and plutonium simultaneously, SC&A finds this method to be claimant favorable and meets criterion 2.

Criterion 3 is concerned with similarities and differences between the site (or sites) where the surrogate data were generated and the site where the surrogate data are being utilized. The uranium operations at Apollo were much more extensive than those at Parks Township. Hence, we believe that this criterion is met in a claimant-favorable manner.

Criterion 4 is concerned with differences between the time periods when the surrogate data were collected and the time periods when the operations took place for which the surrogate data are being applied. The main concern is whether working conditions and processes varied between the different periods. The two facilities were contemporaneous. However, the uranium operations at Parks Township were much more limited than those at Apollo. We believe the intent of this criterion is met.

Criterion 5 is concerned with whether the conditions giving rise to exposures at one facility can plausibly occur at another facility. The nature of the uranium operations at Apollo was considerably more severe than those at Parks Township, and in this regard, one could argue that the circumstances at Apollo might not have been plausible at Parks Township. However, it is

plausible that for some locations and types of operations, the conditions could have been similar for at least some time periods. Hence, we believe that this criterion is met.

7.0 SC&A REVIEW OF NUMEC WORKER INTERVIEWS

A NIOSH team (which included representatives from NIOSH and Oak Ridge Associated Universities) conducted an SEC Outreach meeting during the spring of 2007 and interviewed [**less than nine**] former workers from the NUMEC facilities. SC&A was not present during these interviews, but has reviewed the interview notes documented in the SRDB. The interview notes also include some information obtained from NIOSH team CATI reports. This section is not intended to reproduce the interview notes in detail, but rather to convey their "flavor" and report on a few areas of interest.

[**Less than nine**] of the workers reported working at both the Apollo and Parks Township sites, and the [**redact**] worker was employed at the latter only. The workers' collective employment at NUMEC spanned the period from 1958 through 2000; the shortest tenure was 6 years and the longest 37 years. The interview notes often do not explicitly recount the exact positions that the workers held or exactly where in the plant they worked, but they appeared to have performed a variety of functions in different areas, including in labs and in offices, and handled a variety of radioactive substances; at least one appears to have worked in a production position.

The interviewers asked about personal radiation monitoring instruments and protective equipment provided. Only one worker reported being assigned a dosimeter (e.g., film badge) on a regular basis. Others said that dosimeters were assigned on occasion for specific jobs. Another worker noted that, "most people did not wear badges until sometime in the 1980s." One worker reported that dosimeters were used only in the plutonium facility, and that the labs and uranium facilities were not monitored. One production worker recalled wearing an apparatus on the face close to a hotcell to monitor dose to the worker's eye. The same worker stated that, "radiation exposure was not a concern" at the site.

Several of the interviewees stated that workers were provided coveralls, lab coats, hats, socks, shoes, shoe covers, and respirators as needed, while other workers (presumably those judged not to require such protection by nature of their jobs and locations) stayed in their street clothes in the facility. During the early years, fume and hoods were only located in some laboratory areas (e.g., not in the Spectroscopy Lab) and protective clothing (lab coats) was not provided in all areas. Showers were available in change-out rooms for production workers, but they were not required to use them before leaving the plant. Workers were aware that air monitoring was performed onsite, and one interviewee stated that "radiation people" monitored the air both indoors and outdoors.

The interviewers asked if the interviewees could recall any special medical testing related to their employment, such as an annual chest x-ray or urinalysis. One worker reported having an annual physical that included urinalysis and x-rays, and thought these physicals were limited to engineers. Another production worker recalled having nasal smears and WBCs (white blood cell counts), as well as urine, blood, and fecal sampling. Only one other worker recalled having WBCs done. One of the interviewees, a [**redact**], reported being responsible for checking blood and urine for abnormal cells. This interviewee also [**redact**] (although the interviewee did not elaborate on the reason for the tracking).

The interviewers asked about radionuclides present onsite, specifically thorium. One worker recalled thorium work started around the time the worker was hired (1961) and lasted for 2 to 3 years. The work was done for W.R. Grace under a single contract. Thorium was processed into pellets, sintered, and then processed into tubing. Thorium operations were always dry and used the same equipment and techniques as dry uranium operations. There was much less thorium work done than uranium work.

The interviewers also asked about offices located in the production facility. Most workers were aware of these offices and had visited them. The workers recalled that there were limited access controls and people were free to go anywhere in the facility. There was a double door interlock entryway into the production area, but it could be accessed by lab and office workers. Multiple workers reported "yellow dust" and smoke coming out of production areas on a regular basis. An interviewee noted the following:

> *They would check guys going out of the production area. Anyone found to be contaminated would then be decontaminated. At one point, they started monitoring personnel coming to work from home and found some individuals to be contaminated.*

One interviewee recalled walking through yellow powder in the parking lot on many occasions, and recalled being told that the operators "…would press pellets while smoking cigarettes and eating lunch at the same countertops."

The interviewers asked the workers about any accidents that might have occurred at the plant and were particularly interested in the 1963 fire mentioned in the site profile. Only one worker recalled the event. This worker remembered a "severe explosion" in the D-vault after pyrophoric uranium carbide stored there spontaneously combusted. The [redact] ran in with street clothes and applied Metal-X to put out the fire. The fire lasted 45 minutes to an hour, but the [redact]'s personal decontamination took hours and all the worker's clothes were discarded. The vault was unvented as an engineering control to limit releases. The worker recalled, "…smoke from the fire was heavy and drifted throughout the entire plant to some degree." Contamination from the event spread widely and required a lot of work to clean up. The interviewers noted that this [redact] contained a record of 5 follow-up urinalysis samples. Although certainly not of the same magnitude as the 1963 fire, the [redact] interviewed claimed that accidents occurred in the production area almost weekly, and that workers then ran out spreading yellow dust and wearing contaminated clothing to the nurse's station (the [redact] also noted that three of the seven [redact] came down with breast cancer, which the interviewee felt seemed disproportionately high).

SC&A believes that the NIOSH interview notes are not very thorough or systematic, often lacking adequate time period, location, and job function information associated with interviewee responses. This inadequacy generally hinders determination, for example, of what personnel monitoring occurred where, during what time period, and while performing which job. In addition, interviews would have benefited from the interviewers asking follow-up questions to clarify or elaborate statements. Nonetheless, review of the interview records helped to confirm the working conditions at NUMEC. SC&A found these interviews to sufficiently address the use

of thorium at Apollo and the 1963 vault fire, and we believe that it is unlikely that further interviews would result in any additional significant information, especially since both facilities are part of the SEC. In addition, it is unlikely that worker interviews could address the site profile concerns raised by SC&A elsewhere in this document, which deal primarily with data adequacy and dose reconstruction methodology. Hence, SC&A believes there is no need for additional interviews at this time, although they may still be needed as part of the issues resolution process associated with the NUMEC site profile review.

8.0 OVERVIEW OF NUMEC CASES

Due to the limitations of the data in the site profile and the associated limitations of the guidance provided in the site profile, we elected to incorporate a new section into the review of this site profile. This section describes the efforts made by NIOSH to perform dose reconstructions for NUMEC employees, with the objective of gaining a better understanding of the guidance provided in the site profile and how it was implemented. We made a special effort to investigate cases that might have been associated with accidents. As can be seen by this overview, NIOSH has made a concerted effort to reconstruct doses to workers not covered by the SEC, notwithstanding the limitations of the data. **It is important to emphasize that this overview is not intended as a dose reconstruction review, nor should it be considered a replacement for a dose reconstruction review.**

Table 6 summarizes the claims in the NIOSH OCAS Claims Tracking System (NOCTS) database. In total, 271 claims from individuals who worked at NUMEC are in NOCTS, including individuals who worked only at the Apollo Site, only at the Parks Township Site, or at both sites. There are 66 claims under the SEC, with 56 of those being identified during the two mass pulls and the remaining 10 subsequently identified. The bottom row shows that 117 dose reconstructions were completed by NIOSH and sent to the U.S. Department of Labor (DOL) after the SECs were enacted.

Table 6. Summary of NUMEC Claims in NOCTS

Current Case Status	Apollo	Parks Township	Apollo/ Parks Township	Total
Active	1	0	1	2
Active – Out of Pending	1	0	0	1
Active – Reinstated	1	0	0	1
DOL Return – SEC Pulled	2	0	1	3
DOL Returned – Out of Pending	1	0	0	1
DOL Returned – Pending	1	0	0	1
DOL Returned – Submitted	11	2	5	18
NIOSH Admin Closed	1	0	0	1
Pulled	4	1	1	6
SEC Pulled	45	7	11	63
Submitted	110	33	31	174
Total Cases	178	43	50	271
Mass SEC Pull for Apollo (1957–1983)	37	0	9	46
Mass SEC Pull for Parks Township (1960–1980)	0	7	3	10
Dose Reconstruction Draft Sent after SEC (Apollo: 1/4/2008; Parks Township: 7/3/2008)	63	27	27	117

To determine why dose reconstructions were being performed after the SECs and the basic approach used, given data limitations, SC&A examined [redact] dose reconstructions generated after the SEC dates; [redact] from the Apollo Site, [redact] from the Parks Township Site, and

[redact] from both the Apollo and Parks Township Sites. Each dose reconstruction contained the following explanation of the SEC:

> *To qualify for compensation under the SEC, a covered employee must meet the class definition, have worked at the facility for an aggregate of 250 days, and have one of the 22 specified cancers, which include (with some exceptions) the following cancers: bone, renal, leukemia, lung, multiple myeloma, lymphomas, bile ducts, brain, breast (male and female), colon, esophagus, gall bladder, liver, ovary, pancreas, pharynx, salivary glands, small intestine, stomach, thyroid, and urinary bladder. For claims in which the energy employee worked at the facility but did not meet the above SEC criteria for compensation, a partial dose reconstruction will be completed.*

The dose reconstruction also included the following statement for each claimant:

> *. . . did not meet the criteria for compensation under the SEC. Therefore, NIOSH was required to conduct a partial dose reconstruction for* [the EE's] *claim. As a result of the SEC class for the NUMEC Apollo and Parks Township Plants, NIOSH has determined, and the Secretary of Health and Human Services has concurred, that certain doses cannot be reconstructed. These doses include uranium internal dose before 1960 at the Apollo Plant, internal dose from thorium and plutonium when monitoring data are lacking, internal dose based on bioassay data provided by Controls for Environmental Pollution (1976–1983), ambient dose from stack releases (internal and external), external dose for unmonitored workers, and neutron dose from radium-beryllium and polonium-beryllium source fabrication.*

Table 7 shows the diseases that afflicted the [redact] claimants examined by SC&A. As indicated by the passage quoted above, none of these diseases are included in the SEC.

Table 7. Diseases of the [Redact] Claimants Examined by SC&A

ICD Code	Disease Description
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]
[redact]	[redact]

For these [redact] cases, we reviewed the dose reconstructions from the perspective of which doses were assigned in order to gain a better understanding how NIOSH "navigated" its way around the data limitation and performed partial dose reconstructions as best it could. Tables 8

through 12 summarize how each partial dose reconstruction was performed for those individuals who were not covered by the SEC.

Table 8. External Dose for Individuals Not Covered by the SEC

Claim #	External Dose
[redact]	No external dose monitoring records were found.[a]
[redact]	No dosimetry records were available.[a]
[redact]	Dosimetry records were available for only part of the employment period. Dosimetry results that were less than half the limit of detection stated in the site profile have been treated as missed dose in accordance with the "External Dose Reconstruction Implementation Guideline" (NIOSH 2007b).
[redact]	No dosimetry records were available. Information in the telephone interview record indicates that the claimant was not monitored for external radiation.[a]
[redact]	This worker would be expected to have potential for exposure to only residual external sources of ionizing radiation. This is consistent with the lack of dosimetry records for this claimant. According to the information provided in the site profile, external radiation doses for unmonitored workers at the NUMEC plants during the remediation periods can be reconstructed based on guidance in the site profile. Therefore, the external dose that has been assigned in this assessment was that based on guidance in the site profile. During the remediation periods, dose from occupationally required medical x-rays are not to be included in the dose reconstruction. The external dose assigned for work at the Apollo Site was based on guidance in Section 7.1.1 and Table 7-1 of the site profile, and based on guidance in Section 7.1.2 and Table 7-2 of the site profile for work at the Parks Township Site.
[redact]	No dosimetry records were available.[a]
[redact]	No dosimetry records were available.[a]
[redact]	Dosimeter records were available for part of the claimant's employment at the Parks Township facility covering the period. According to the information provided in the site profile, external radiation doses for workers at the NUMEC plants can only be reconstructed using existing dosimetry records. Therefore, the external dose assigned is limited to the dose based on the available dosimetry records. The dosimetry records only provide information on exposure to penetrating photon radiation.
[redact]	No dosimetry records were available.[a]

Source: Summarized from excerpts of claimant dose reconstruction reports in the NOCTS database.
[a] According to the information provided in the site profile for the NUMEC Apollo and Parks Township Sites, external radiation doses for unmonitored workers at the NUMEC plants cannot be reconstructed because there is insufficient information on radiological activities for dose reconstruction. Therefore, since no estimation techniques can be employed to derive an external radiation dose for a given cancer, the only external dose that has been assigned in this assessment was that received from occupationally required medical x-rays.

Table 9. Missed Dose for Individuals Not Covered by the SEC

Claim #	Missed
[redact]	Not discussed in the dose reconstruction because there are no dosimetry records.
[redact]	Not discussed in the dose reconstruction because there are no dosimetry records.
[redact]	Based on information provided in the site profile, and per the requirements of the *External Dose Reconstruction Implementation Guideline* (NIOSH 2007b), missed dose was assigned based on the dosimeter's limit of detection.
[redact]	Based on information provided in the site profile, and per the requirements of the *External Dose Reconstruction Implementation Guideline* (NIOSH 2007b), missed dose was assigned based on the dosimeter's limit of detection.
[redact]	Not discussed in the dose reconstruction, because there are no dosimetry records.
[redact]	Not discussed in the dose reconstruction, because there are no dosimetry records.
[redact]	Not discussed in the dose reconstruction, because there are no dosimetry records.

Claim #	Missed
[redact]	Based on information provided in the site profile, and per the requirements of the *External Dose Reconstruction Implementation Guideline* (NIOSH 2007b), missed dose was assigned based on the dosimeter's limit of detection. The dose to the [redact] was based on guidance in the technical information bulletin, *Monte Carlo Methods for Dose Uncertainty Calculations* (ORAUT 2005d).
[redact]	Not discussed in the dose reconstruction, because there are no dosimetry records.

Source: Summarized from excerpts of claimant dose reconstruction reports in the NOCTS database.

Table 10. Medical Dose for Individuals Not Covered by the SEC

Claim #	Medical
[redact]	Based on information in the site profile and an assumed pre-employment, annual, and termination x-ray procedures, a total x-ray dose in rem was assigned.
[redact]	Based on information in the site profile and an assumed pre-employment, annual, and termination x-ray procedures, a total x-ray dose in rem was assigned.
[redact]	Based on information in the site profile and an assumed pre-employment (1967 and 1972), annual, and termination (1971 and 1977) x-ray procedures, a total x-ray dose of … rem was assigned.
[redact]	Based on information in the site profile and an assumed pre-employment, annual, and termination x-ray procedures, a total x-ray dose in rem was assigned.
[redact]	During the residual period, medical x-ray doses are not to be included in the dose reconstruction, because the work is not directly related to DOE employment.
[redact]	Based on information in the NUMEC site profile and guidance in the technical information bulletin, ORAUT-OTIB-0079, *Guidance on Assigning Occupational X-Ray Dose under EEOICPA for X-Rays Administered Off Site* (ORAUT 2011a), no medical x-ray dose has been assigned in this dose reconstruction.
[redact]	Based on information in the site profile and guidance in ORAUT-OTIB-0079 (ORAUT 2011a), no medical x-ray dose has been assigned in this dose reconstruction.
[redact]	Based on information in the site profile and guidance in ORAUT-OTIB-0079 (ORAUT 2011a), no medical x-ray dose has been assigned in this dose reconstruction.
[redact]	Based on information in the site profile and guidance in ORAUT-OTIB-0079 (ORAUT 2011a), no medical x-ray dose has been assigned in this dose reconstruction.

Source: Summarized from excerpts of claimant dose reconstruction reports in the NOCTS database.

Table 11. Internal Dose for Individuals Not Covered by the SEC

Claim	Internal
[redact]	Internal dose monitoring records were reviewed. Only a single measurement result was evident for non-naturally occurring radionuclides and showed an activity less than the level of detection for the given radionuclide and bioassay method. The bioassay record shows monitoring for uranium in urine.[b]
[redact]	According to the information provided in the site profile, internal radiation doses can only be determined for workers with applicable monitoring data. Therefore, because no bioassay data are available for this claimant, no estimation techniques can be employed to derive an internal dose.
[redact]	Some measurement results for non-naturally occurring radionuclides showed an activity less than the level of detection for the given radionuclides and bioassay method. The bioassay records include monitoring for plutonium in urine and feces and for uranium in urine and lung.[b]
[redact]	Monitoring records were found. The urine data beyond 1975 were not used in the internal dose analysis, because the sample analyses were performed by CEP and are not to be used in dose reconstructions. The lung counts beyond 1975 are valid and were used in the dose reconstruction, because they were not performed by CEP. All fecal analysis results were taken before 1975 and are considered valid.[b]
[redact]	Because no bioassay data were available, the internal dose is based on guidance for the residual period from the site profile.
[redact]	According to the information provided in the NUMEC site profile, internal radiation doses at the NUMEC Apollo Site prior to 1960 cannot be reconstructed, because there is insufficient information on radiological activities for dose reconstruction during this time period. In addition, internal dose based on bioassay data provided by CEP cannot be used to reconstruct dose (1976–1983). Internal doses can only be determined for workers with applicable monitoring data. Because no bioassay data are available, no estimation techniques can be employed to derive an internal dose.
[redact]	The bioassay records include monitoring (radiometric and fluorometric) for uranium in urine for much of the claimant's employment. Two chest counts were also taken (1971 and 1976) showing U-235 in the lungs at about the detection limit.[b]
[redact]	Most measurement results for non-naturally occurring radionuclides showed an activity less than the level of detection for the given radionuclides and bioassay method. The bioassay records include monitoring for plutonium in urine, with all results being less than the detection limit. The records also include monitoring for uranium in urine with all but one result being less than the detection limit. All of the bioassay sampling results were taken during the employment period at the Park Township plutonium facility.[b] Internal dose analyses were performed for plutonium and uranium.
[redact]	Because no bioassay data are available, no estimation techniques can be employed to derive an internal dose.

Source: Summarized from excerpts of claimant dose reconstruction reports in the NOCTS database.
[b] A computer code, the Integrated Modules for Bioassay Analysis (IMBA), was used to estimate intakes of radionuclides and the subsequent annual organ doses.

Table 12. Incident Dose for Individuals Not Covered by the SEC

Claim	Incidents (also see the next section)
[redact]	The interview summary includes a description of an incident when two piles of powder began to react. One of the piles was then apparently moved to stop the reaction. The potential radiological exposure consequences of this incident cannot be determined from the available information. However, internal dose from an intake of uranium and other associated radionuclides has been applied as described above.
[redact]	No radiological incidents were included in the telephone interview record or in the employment records.

Claim	Incidents (also see the next section)
[redact]	The telephone interview record indicates that the claimant was involved in a spill that resulted in work limitations, fecal and urine bioassay analyses, and testing at Pittsburgh (presumably whole-body or lung counts). The employment records include two incidents in which fecal sampling was performed for plutonium. The potential dose from the stated incidents is included in the assigned dose as far as the bioassay analyses captured the intakes and exposures.
[redact]	The telephone interview record included two incidents. Because all available valid bioassay data have been used to provide an overestimate of intake and internal dose, the potential dose from these incidents has been included in the internal dose assignment to the extent possible under the limitations of the SEC.
[redact]	No radiological incidents were included in the telephone interview record or in the employment records.
[redact]	No radiological incidents were included in the employment records.
[redact]	No radiological incidents were included in the telephone interview record or in the employment records.
[redact]	Because the claimant's partial internal dose resulted in a probability of causation greater than 50%, to expedite this claim per the provisions of 42 CFR 82.10(k)(l), a detailed analysis of the information provided (including any incidents identified) was not conducted.
[redact]	No radiological incidents were included in the telephone interview record or in the employment records.

Source: Summarized from excerpts of claimant dose reconstruction reports in the NOCTS database.

8.1 AMBIENT DOSE

According to the information provided in the site profile for the NUMEC Apollo and Parks Township Sites, onsite ambient radiation doses at the NUMEC plants cannot be reconstructed, because there is insufficient information on environmental releases for dose reconstruction. Therefore, no ambient radiation dose was assigned in any of the NUMEC dose reconstructions.

8.2 RADIOLOGICAL INCIDENTS AND ACCIDENTS AT NUMEC

The site profile briefly describes incidents and accidents that occurred at both the Apollo and Parks Township Sites, and also states that dose reconstructors should try to reconstruct the doses to workers involved in accidents. In order to evaluate the degree to which these guidelines were followed, we reviewed NUMEC cases to confirm that a reasonable effort was made to assign doses to workers who might have been involved in any of the numerous incidents and accidents that occurred at both facilities. We are indebted to the excellent post-accident exposure reports prepared by Roger Caldwell (see the numerous Caldwell citations in the reference list). The following summarizes our observations about the efforts made by NIOSH to reconstruct doses to workers who were involved in accidents at the Parks Township and Apollo Sites and are not included in the SEC.

8.2.1 Parks Township Site

Section 5.5.2 of site profile for NUMEC describes four serious radiological accidents that occurred at the Parks Township Site between January 1966 and December 1967. All of the events associated with these incidents were monitored and recorded in great detail by the Parks Township Site Health Physicist at the time, Roger Caldwell (Caldwell et al. 1969). The records show that all of the employees directly and indirectly involved were carefully monitored with nasal smears and/or bioassays following the accidents. It was found that only the one or two

employees who were directly involved in the accidents were seriously exposed. SC&A reviewed the 25 claims associated with the NUMEC Parks Township Site that are currently in the NIOSH system. One of these employees was directly involved in a major radiological incident at the Parks Township Site, which was described in the CATI report and documented in the DOE records for this case. Using this information, NIOSH calculated potential internal dose to this employee specifically from the documented accident. The documentation of these incidents allows the dose reconstructors to evaluate which workers had potential exposures from these incidents. SC&A determined that these incidents appear to be adequately addressed by NIOSH in the dose reconstructions.

8.2.2 Apollo Site

Section 5.5.1 of site profile for NUMEC describes three radiological incidents at the Apollo Site. Two of the incidents involved a large number of personnel. In April 1974, low-enriched UF_6 was accidently released into the plant. Nasal smears were collected from all of the personnel involved, and they all had readings within the allowable limits. In February 1963, an explosion and fire occurred in the uranium vault involving HEU. This incident is commonly referred to by the workers as "the vault fire." NIOSH states in the site profile that there is no information on worker exposures for this incident. SC&A sampled 10 of the 86 claims associated with the NUMEC Apollo Site that are still under review by NIOSH and DOL. It should be noted that many of the 86 Apollo Site claims have been pulled, due to the fact that they are now compensable under the NUMEC SEC. SC&A reviewed the CATI reports and dose reconstruction reports for 10 sampled cases. [**Redact**] specifically mentioned the vault fire in the CATI reports, and they both stated that the entire plant had to be evacuated and shut down for 2 or 3 days. In all of the sampled Apollo Site cases, the dose reconstructors followed the procedures in Section 1.3.1 of the site profile, which states that "partial doses can be estimated for workers for whom applicable monitoring data are available." For cases in which no internal dose monitoring data are available, NIOSH does not attempt to assign any internal dose. For [**redact**], the employee indicated being involved in the vault fire, but was also regularly monitored with bioassays. Therefore, NIOSH indicated that they were able to capture any exposure that this employee received during the incident. SC&A agrees with this assessment; however, there could be individuals who were exposed during the 1963 fire, but were not monitored. SC&A believes that additional information should be gathered pertaining to the 1963 fire at the Apollo Site, perhaps in the form of site visits, in order to determine the extent and magnitude of worker exposures from this incident.

9.0 REFERENCES

ABRWH 2009a. "Data Access and Interview Procedure," ABRWH-PROC-010. Advisory Board on Radiation and Worker Health, Cincinnati, Ohio. June 2009.

ABRWH 2009b. "Department of Energy Classification Review of Documents," ABRWH-PROC-011. Advisory Board on Radiation and Worker Health, Cincinnati, Ohio. June 2009.

Adley, F.E., Gill, W.E., Scott, R.H., *Study of Atmospheric Contamination in the Melt Plant Building*, USAEC report HW-233352(Rev.), April 4, 1952.

AEC 1967. Letter from L.D. Low (AEC) to Dr. Zalman Shapiro (President of NUMEC), U.S. Atomic Energy Commission. September 5, 1967. [SRDB Ref ID: 27213]

Battelle 2006, "Site Profile for Atomic Weapons Employers that Worked Uranium Metals," Battelle-TBD-6000, Rev. 0, 12/13/2006

Battelle 2007. "Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals," Battelle-TBD-6000. Battelle. May 25, 2007.

Battelle 2011, "Site Profile for Atomic Weapons Employers that Worked Uranium Metals," Battelle-TBD-6000, Rev. 1, June 17, 2011.

Boyd, C.C. Jr., 2006a, "BWXT Records Request," letter with attachments (collection of external dosimetry records 1960–1976, internal dosimetry records 1960–1981, in-vivo counting records 1968–1985, Occupational Exposure Histories 1978) to S. L. Hinnefeld (NIOSH Taft Laboratories), BWXT Services, Lynchburg, Virginia, October 25. [SRDB Ref ID: 27060]

Boyd, C.C. Jr., 2006c, "BWXT Records Request," letter with attachments (collection of internal dosimetry records 1972–1975, 1979–1987, report of exposure to airborne radioactivity 1976, in-vivo reports 1980–1981) to S.L. Hinnefeld (NIOSH Taft Laboratories), BWXT Services, Lynchburg, Virginia, October 25. [SRDB Ref ID: 27062]

Boyd, C.C. Jr., 2006d, "BWXT Records Request," letter with attachments (collection of external dosimetry records 1973, internal dosimetry records 1974, 1977, 1978, occupational exposure histories 1982, 1983, 1985, incident exposure reports 1975) to S.L. Hinnefeld (NIOSH Taft Laboratories), BWXT Services, Lynchburg, Virginia, October 25. [SRDB Ref ID: 27063]

Boyd, C.C. Jr., 2006g, "BWXT Records Request," letter with attachments (collection of *in-vivo* counting results, 1970–1976) to S.L. Hinnefeld (NIOSH Taft Laboratories), BWXT Services, Lynchburg, Virginia, October 25. [SRDB Ref ID: 27066]

Boyd, C.C. Jr., 2006h, "BWXT Records Request," letter with attachments (collection of occupational exposure histories 1970–1976, work restrictions 1975, external exposure records 1975, 1995–1998) to S.L. Hinnefeld (NIOSH Taft Laboratories), BWXT Services, Lynchburg, Virginia, October 25. [SRDB Ref ID: 27067]

Boyd, C.C. Jr., 2006i, "BWXT Records Request," letter with attachments (collection of *in-vivo* count results 1968, 1971–1980, external dosimetry reports 1970, 1976) to S.L. Hinnefeld (NIOSH Taft Laboratories), BWXT Services, Lynchburg, Virginia, October 25. [SRDB Ref ID: 27069]

Caldwell, R.D., 1968a. "Exposure Report," SPM-414 1968. NUMEC, Parks Township, Pennsylvania. April 1968. [SRDB Ref ID: 18150].

Caldwell, R.D., 1968b. "Whole Body Counting Data March–April 1968." NUMEC, Parks Township, Pennsylvania. April 1968. [SRDB Ref ID: 18151].

Caldwell, R.D., 1969. Letter from Roger D. Caldwell (NUMEC) to Lawrence D. Low (AEC) reporting overexposures in the plutonium facility. November 4, 1969. [SRDB #19970]

Caldwell, R.D., and W.C. Judd, 1966. *Gamma Spectrum Measurements and the Interpretation of Absorbed Dose During Plutonium Fuel Fabrication*, Nuclear Materials and Equipment Corporation, Apollo, Pennsylvania. [SRDB Ref ID: 22776]

Caldwell, R.D., T. Potter, and E. Schnell, 1967. "Bioassay Correlation with Breathing Zone Sampling." Apollo, Pennsylvania. [SRDB Ref ID: 29599].

Caldwell, R., T. Potter, and E. Schnell, ca. 1969. *Radiological Emergency Experience in an Industrial Plutonium Plant*, Nuclear Materials and Equipment Corporation, Apollo, Pennsylvania. [SRDB Ref ID: 22778]

Crosby, E., 1967. "Individual Dosimetry Data PU Facility." NUMEC, Parks Township, Pennsylvania. [SRDB Ref ID: 19734].

Davis, A.J., and D.J. Strom, 2008. "Uncertainty and Variability in Historical Time-Weighted Average Exposure Data." *Health Physics*, Volume 94, Number 2, pp. 145–160. February 2008.

EPA (1993). *External Exposure to Radionuclides in Air, Water, and Soil,* Federal Guidance Report No. 12 EPA-402-R-93-081. U.S. Environmental Protection Agency, Washington, DC.

Forscher, F., 1963. "Feasibility Report # 47, BAPL Order 73-T-316512-M (NUMEC 3A358), letter to C.A. Keller". U.S. Atomic Energy Commission, Oak Ridge Operations Office, Nuclear Materials and Equipment Corporation, Apollo, Pennsylvania. October 22, 1963. [SRDB Ref ID: 11965, p. 3].

ICRP 1968. International Commission on Radiation Protection. "Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposures," ICRP Publication 10, 1968.

ICRP 1989. International Commission on Radiation Protection. "Individual Monitoring for Intakes of radionuclides by Workers," ICRP Publication 54, 1989.

ICRP 1991. International Commission on Radiation Protection. "1990 Recommendations of the International Commission on Radiation Protection." ICRP Publication 60, 1991.

ICRP 1997. International Commission on Radiation Protection. "Individual Monitoring for Internal Exposure of Workers, ICRP Publication 78, 1997.

ICRP 2002. International Commission on Radiation Protection. "Basic Anatomical and Physiological Data for use in Radiological protection Reference Values, ICRP Publication 89, 2002.

Jackson, S., and N.A. Taylor, 1964. In: *Assessment of Radioactivity in Man,* Vol. I, IAEA, Vienna, p. 169. 1964, STI/PUB/84.

Joynar, F.E., 1962. "Procedure for Recovery of Uranium Scrap." NUMEC, Apollo, Pennsylvania [SRDB Ref ID: 11959].

NIOSH, 2006. SEC-00046, 10/25/2006.

NIOSH 2007a. NIOSH (National Institute for Occupational Safety and Health), 2007a. "SEC Petition Evaluation Report: Petition SEC-00080," Rev. 0. Office of Compensation Analysis and Support, Cincinnati, Ohio. August 31, 2007. (Apollo Site)

NIOSH 2007b. "External Dose Reconstruction Implementation Guideline," OCAS-IG-001, Rev. 3. Office of Compensation Analysis and Support, Cincinnati, Ohio. November 2007.

NIOSH 2008. "Petition Evaluation Report: Petition SEC-00108," Rev. 0. Office of Compensation Analysis and Support, Cincinnati, Ohio. March 14, 2008. (Parks Township)

NIOSH 2010. "Radiation Exposures Covered for Dose Reconstructions under Part B of the Energy Employees Occupational Illness Compensation Program Act," DCAS-IG-003, Rev. 1. Division of Compensation Analysis and Support, Cincinnati, Ohio. October 5, 2010.

NRC 1982. "Holdup at Babcock and Wilcox's Pennsylvania Operations High Enriched Uranium Facilities." Region 1, U.S. Nuclear Regulatory Commission. May 13, 1982.

NUMEC 1963. "Health and Safety Manual," Third Edition. Nuclear Materials and Equipment Corporation, Apollo, Pennsylvania. [SRDB Ref ID: 11957].

NUMEC 1967. "Individual Dosimetry Data 1967." Nuclear Materials and Equipment Corporation, Parks Township, Pennsylvania [SRDB Ref ID: 19733].

NUMEC 1968. "Unrestricted Area Radiation Surveys from 1966 to 1968." Nuclear Materials and Equipment Corporation. [SRDB Ref ID: 19731].

ORAUT 2004. "Technical Basis Document for the Fernald Environmental Management Project (FEMP) – Occupational Internal Dose," ORAUT-TKBS-0017-5, Rev. 00. Oak Ridge Associated Universities Team, Cincinnati, Ohio. May 28, 2004.

ORAUT 2005a. "Internal Dose Overestimates for Facilities with Air Sampling Programs," ORAUT-OTIB-0018, Rev. 01. Oak Ridge Associated Universities Team, Cincinnati, Ohio. August 9, 2005.

ORAUT 2005b. "Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures," ORAUT-OTIB-0006, Rev. 03. Oak Ridge Associated Universities Team, Cincinnati, Ohio. December 21, 2005.

ORAUT 2005c. "Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities," ORAUT-OTIB-0004, Rev. 03 PC-1. Oak Ridge Associated Universities Team, Cincinnati, Ohio. November 18, 2005.

ORAUT 2005d. "Monte Carlo Methods for Dose Uncertainty Calculations," ORAUT-OTIB-0012, Rev. 00. Oak Ridge Associated Universities Team, Cincinnati, Ohio. February 14, 2005.

ORAUT 2006. "Argonne National Laboratory – East – External Dosimetry," ORAUT-TKBS-0036-6, Rev. 00. Oak Ridge Associated Universities Team, Cincinnati, Ohio. February 9, 2006.

ORAUT 2007a. "Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses," ORAUT-OTIB-0054, Rev. 00 PC-1. Oak Ridge Associated Universities Team, Cincinnati, Ohio. November 19, 2007.

ORAUT 2007b. "Internal Dose Reconstruction," ORAUT-OTIB-0060, Rev. 00. Oak Ridge Associated Universities Team, Cincinnati, Ohio. February 6, 2007.

ORAUT 2007c. "Rocky Flats Plant – Occupational Internal Dose," ORAUT-TKBS-0011-5, Rev. 2. Oak Ridge Associated Universities Team, Cincinnati, Ohio. August 17, 2007.

ORAUT 2007d. "Pantex Plant – Occupational Internal Dose," ORAUT-TKBS-0013-5, Rev. 01. Oak Ridge Associated Universities Team, Cincinnati, Ohio. June 22, 2007.

ORAUT 2008. "Site Profile for Nuclear Materials and Equipment Corporation, Apollo, Pennsylvania," ORAUT-TKBS-0041, Rev. 00. Oak Ridge Associated Universities Team, Cincinnati, Ohio. September 26, 2008.

ORAUT 2009a. "Site Profile for Nuclear Materials and Equipment Corporation, Apollo and Parks Township, Pennsylvania," ORAUT-TKBS-0041, Rev. 01. Oak Ridge Associated Universities Team, Cincinnati, Ohio. June 2, 2009.

ORAUT 2009b. Los Alamos National Laboratory-Occupational Internal Dose, ORAUT-TKBS-0010-5, Rev. 10. Oak Ridge Associated Universities Team, Cincinnati, Ohio. October 15, 2009.

ORAUT 2010. "Site Profile for Nuclear Materials and Equipment Corporation, Apollo and Parks Township, Pennsylvania," ORAUT-TKBS-0041, Rev. 01 PC-1. Oak Ridge Associated Universities Team, Cincinnati, Ohio. February 26, 2010.

ORAUT 2011a. "Guidance on Assigning Occupational X-Ray Dose Under EEOICPA for X-Rays Administered Off Site," ORAUT-OTIB-0079, Rev. 00. Oak Ridge Associated Universities Team, Cincinnati, Ohio. January 3, 2011.

ORAUT 2011b. "Dose Reconstruction from Occupational Medical X-Ray Procedures," ORAUT-OTIB-0006, Rev. 03 PC-1. Oak Ridge Associated Universities Team, Cincinnati, Ohio. June 20, 2011.

ORAUT 2012a, "Site Profile for Nuclear Materials and Equipment Corporation, Apollo and Parks Township, Pennsylvania" ORAUT-TKBS-0041, Rev. 02. Oak Ridge Associated Universities Team, Cincinnati, Ohio. November 26, 2012.

ORAUT 2012b. "Dose Reconstruction during Residual Periods at Atomic Weapons Employer Facilities," ORAUT-OTIB-0070, Rev. 01. Oak Ridge Associated Universities Team, Cincinnati, Ohio. March 5, 2012.

ORAUT 2012c. "Hanford Site-Occupational Dose," ORAUT-TKBS-0006-5, Rev. 5. Oak Ridge Associated Universities Team, Cincinnati, Ohio. November 5, 2012.

PEDP 2008. "Pennsylvania Decommissioning Site Surveys," Pennsylvania Department of Environmental Protection, Commonwealth of Pennsylvania [SRDB Ref ID: 43949].

SC&A 2004. "SC&A Standard Operating Procedure for Performing Site Profile Reviews," Rev. 1. S. Cohen & Associates, McLean, Virginia. May 13, 2004.

SC&A 2010. "Sensitivity of NTA Film to Neutron Sources at Mound Laboratory," Rev. 1. Authors R. Anigstein and D. Olsher, SC&A, Inc., Vienna, Virginia. July 22, 2010.

Schnell, E., 1966. "Elevated Airborne Levels in Change Room September 1966." NUMEC, Pennsylvania. September 22, 1966 [SRDB Ref ID: 18114].

Wilcoxon, R., 1999. "Department of Energy Recycled Uranium Project, Conversion/Enriching Site Portsmouth GDP," p. 19. [SRDB Ref ID: 93873]

Williams, R. 1967. Letter from Robert Williams (NUMEC) to James P O'Reilly (NRC Deputy Director) documenting the radioactive effluents discharged to unrestricted areas for compliance purposes. February 27, 1967. [SRDB #20081]

APPENDIX A: ANALYSIS OF ANNUAL ORGAN DOSE

This attachment presents the annual organ doses in rem to a worker chronically exposed to airborne natural levels of Type M and Type S uranium, which result in an observed concentration of uranium in urine at the end of the year of 500 dpm/L (i.e., the MAC used at NUMEC). Urine excretion rate is assumed to be 1.6 L/d (male's excretion rate from ICRP 89, 2002). The daily intake rate of Type M and Type S uranium are 212 Bq/d and 5,772 Bq/d, respectively.

INTAKE **212 Bq/d** **inhalation** **Type M** **AMAD** **5µm**
considering 1.6 L/d excretion rate

Dose in rem **Natural uranium:** **48.9% U-238 and U-234 and 2.2% U-235**

Time (Years)	1	2	3	4	5	6	7
Adrenals	2.63E-02	2.11E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.50E-02
Bladder Wall	2.80E-02	2.14E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Bone Surface	2.91E+00	2.17E+00	1.27E+00	1.05E+00	9.23E-01	8.19E-01	7.32E-01
Brain	2.62E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Breasts	2.63E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Esophagus	2.63E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
St Wall	2.96E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
SI Wall	3.46E-02	2.11E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
ULI Wall	7.73E-02	2.17E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
LLI Wall	1.78E-01	2.35E-02	1.59E-02	1.52E-02	1.51E-02	1.50E-02	1.50E-02
Colon	1.21E-01	2.25E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Kidneys	2.75E+00	1.09E+00	4.70E-01	3.63E-01	3.11E-01	2.71E-01	2.37E-01
Liver	1.17E-01	1.72E-01	1.62E-01	1.51E-01	1.42E-01	1.33E-01	1.24E-01
Muscle	2.62E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Ovaries	2.63E-02	2.10E-02	1.57E-02	1.52E-02	1.50E-02	1.50E-02	1.49E-02
Pancreas	2.63E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Red Marrow	3.12E-01	2.60E-01	1.62E-01	1.33E-01	1.13E-01	9.77E-02	8.45E-02
ET Airways	5.33E+01	3.21E+01	3.61E+00	4.16E-01	6.00E-02	2.00E-02	1.55E-02
Lungs	9.55E+01	1.42E+01	7.95E-01	1.09E-01	2.67E-02	1.65E-02	1.51E-02
Skin	2.62E-02	2.10E-02	1.57E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Spleen	2.62E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Testes	2.62E-02	2.10E-02	1.57E-02	1.51E-02	1.50E-02	1.50E-02	1.49E-02
Thymus	2.63E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Thyroid	2.62E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Uterus	2.62E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Prostate	2.62E-02	2.10E-02	1.58E-02	1.52E-02	1.51E-02	1.50E-02	1.49E-02
Rem. ICRP-60, 1991	8.06E-02	4.79E-02	2.21E-02	1.89E-02	1.81E-02	1.76E-02	1.72E-02
Eff. Dose:	1.15E+01	1.78E+00	1.47E-01	5.81E-02	4.38E-02	3.92E-02	3.60E-02

INTAKE **5,772 Bq/d** **inhalation** **Type S** **AMAD** **5µm**

Dose in rem **Natural uranium:** **48.9% U-238 and U-234 and 2.2% U-235**

Time (Years)	1	2	3	4	5	6	7
Adrenals	2.62E-02	3.24E-02	3.15E-02	3.19E-02	3.24E-02	3.29E-02	3.34E-02
Bladder Wall	2.49E-02	2.83E-02	2.85E-02	2.97E-02	3.07E-02	3.16E-02	3.23E-02
Bone Surface	2.56E+00	2.89E+00	2.60E+00	2.48E+00	2.34E+00	2.19E+00	2.05E+00
Brain	2.33E-02	2.75E-02	2.79E-02	2.93E-02	3.05E-02	3.13E-02	3.21E-02
Breasts	2.62E-02	3.26E-02	3.16E-02	3.20E-02	3.25E-02	3.29E-02	3.34E-02
Esophagus	2.69E-02	3.37E-02	3.23E-02	3.25E-02	3.29E-02	3.32E-02	3.36E-02
St Wall	1.25E-01	3.35E-02	3.14E-02	3.18E-02	3.22E-02	3.27E-02	3.31E-02
SI Wall	2.73E-01	3.66E-02	3.25E-02	3.24E-02	3.25E-02	3.28E-02	3.31E-02
ULI Wall	1.55E+00	8.42E-02	5.50E-02	4.77E-02	4.29E-02	3.99E-02	3.81E-02
LLI Wall	4.54E+00	2.06E-01	1.07E-01	8.28E-02	6.68E-02	5.62E-02	4.93E-02
Colon	2.83E+00	1.36E-01	7.73E-02	6.27E-02	5.32E-02	4.69E-02	4.28E-02
Kidneys	2.44E+00	1.85E+00	1.49E+00	1.29E+00	1.13E+00	9.99E-01	8.93E-01
Liver	1.06E-01	1.96E-01	2.34E-01	2.57E-01	2.70E-01	2.75E-01	2.75E-01
Muscle	2.47E-02	2.98E-02	2.96E-02	3.05E-02	3.13E-02	3.21E-02	3.27E-02
Ovaries	2.39E-02	2.76E-02	2.80E-02	2.93E-02	3.04E-02	3.13E-02	3.20E-02
Pancreas	2.54E-02	3.10E-02	3.04E-02	3.11E-02	3.18E-02	3.24E-02	3.29E-02
Red Marrow	2.76E-01	3.38E-01	3.14E-01	3.01E-01	2.84E-01	2.64E-01	2.44E-01
ET Airways	2.60E+03	4.01E+03	2.68E+03	1.80E+03	1.20E+03	8.05E+02	5.39E+02
Lungs	3.48E+03	1.16E+03	5.94E+02	4.31E+02	3.20E+02	2.45E+02	1.91E+02
Skin	2.37E-02	2.82E-02	2.85E-02	2.97E-02	3.08E-02	3.16E-02	3.23E-02
Spleen	2.53E-02	3.10E-02	3.05E-02	3.12E-02	3.18E-02	3.24E-02	3.30E-02
Testes	2.32E-02	2.74E-02	2.78E-02	2.92E-02	3.03E-02	3.12E-02	3.20E-02
Thymus	2.69E-02	3.37E-02	3.23E-02	3.25E-02	3.29E-02	3.32E-02	3.36E-02
Thyroid	2.43E-02	2.92E-02	2.91E-02	3.02E-02	3.11E-02	3.19E-02	3.25E-02
Uterus	2.34E-02	2.74E-02	2.79E-02	2.93E-02	3.04E-02	3.13E-02	3.21E-02
Prostate	2.34E-02	2.74E-02	2.79E-02	2.93E-02	3.04E-02	3.13E-02	3.21E-02
Rem. ICRP-60	1.36E+00	2.07E+00	1.39E+00	9.47E-01	6.46E-01	4.46E-01	3.12E-01
Eff. Dose:	4.18E+02	1.39E+02	7.14E+01	5.18E+01	3.86E+01	2.95E+01	2.31E+01

APPENDIX B: REVIEW OF CLAIMANT EXTERNAL MONITORING DATA

For Privacy Act reasons, each claimant was given an arbitrary reference number (1–40) in column 1 to replace the typical claim identification number. Columns 2 through 4 present the claimant's job title, NUMEC work site, and approximate work duration (years); column 5 shows how many of those employed years contain at least some external monitoring data. Column 6 specifies whether the worker had internal monitoring in his or her dosimetry file, such as WBCs or urinalysis samples, which might indicate whether the worker had significant exposure potential. Columns 7 and 8 contain information from the claimant's CATI reports about work locations and badging practices specific to their work experience at NUMEC. Column 9 contains any additional comments or information about the dose reconstruction specific to each claimant.

Specific Information on Job Title, Work Duration, Available Dosimetry, and CATI-Based Information on Badging and Exposure Potential for the 40 Sampled Claimants

Summary of Sampled Claimants						CATI Info		Additional Comments
Ref. Number	**Job Title**	**NUMEC Work Site**	**Approximate Length of Employment (years)**	**Years with Available External Monitoring Data**	**Internal Monitoring Data**	**Work in Radiological Area**	**Badging Practices**	
1	Technician	Parks Township	5.8	6	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
2	Technician	Parks Township	0.5	0	No	Yes	Unknown	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
3	Nuclear Fuel Fabricating Technician	Parks Township and Apollo	7.9	2	Yes	Yes	Routine	External badging records sufficient for partial dose reconstruction; only medical x-rays considered for unmonitored periods
4	Laborer	Parks Township	0.6	0	No	Yes	Intermittent	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only

Summary of Sampled Claimants						CATI Info		Additional Comments
Ref. Number	**Job Title**	**NUMEC Work Site**	**Approximate Length of Employment (years)**	**Years with Available External Monitoring Data**	**Internal Monitoring Data**	**Work in Radiological Area**	**Badging Practices**	
5	Secretary	Parks Township	5.4	0	No	Rare Instances	Routine	Dose reconstruction report states that claimant had 1 year of external monitoring data, although SC&A was unable to locate the data in the DOE_Response files
6	Receptionist	Parks Township and Apollo	3.7	0	No	No	Not Badged	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
7	Security Guard	Parks Township and Apollo	32.7	16	Yes	Yes	Intermittent	External badging records sufficient for partial dose reconstruction; only medical x-rays considered for unmonitored periods
8	Technician	Parks Township	5.7	2	Yes	Yes	Intermittent	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
9	Security Guard	Parks Township and Apollo	31.8	21	Yes	Yes	Routine	External badging records deemed sufficient for partial dose reconstruction
10	Supervisor, Lab Technician	Parks Township and Apollo	10.7	0	Yes	Yes	Not Badged	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
11	Security Guard	Parks Township and Apollo	2.2	3	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
12	Security Guard	Parks Township and Apollo	31.6	19	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval

Summary of Sampled Claimants						CATI Info		Additional Comments
Ref. Number	**Job Title**	**NUMEC Work Site**	**Approximate Length of Employment (years)**	**Years with Available External Monitoring Data**	**Internal Monitoring Data**	**Work in Radiological Area**	**Badging Practices**	
13	Technician	Parks Township and Apollo	0.5	1	No	Yes	Routine	External dosimetry record available only for second month of employment; remaining employment based only on medical x-rays
14	Maintenance Man	Parks Township	1.4	0	No	Yes	Not Badged	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
15	Powder Technician	Parks Township and Apollo	2.9	0	No	Rare Instances	Not Badged	Claimant indicated decontaminating equipment on some occasions, and the remainder of work was with non-radioactive materials; dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
16	Quality Control Technician	Parks Township	2.2	3	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
17	Lab Technician	Parks Township and Apollo	1.5	1	Yes	Yes	Not Badged	External badging records sufficient for partial dose reconstruction
18	Maintenance Man	Parks Township	7.8	4	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
19	Dissolver Operator	Parks Township and Apollo	7.3	0	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval

Summary of Sampled Claimants						CATI Info		Additional Comments
Ref. Number	**Job Title**	**NUMEC Work Site**	**Approximate Length of Employment (years)**	**Years with Available External Monitoring Data**	**Internal Monitoring Data**	**Work in Radiological Area**	**Badging Practices**	
20	Engineer	Parks Township	4.4	0	Yes	Yes	Intermittent	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
21	Press Operator	Parks Township and Apollo	15.9	14	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
22	Health and Safety Manager	Parks Township and Apollo	36.9	26	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
23	Accounting Clerk	Apollo	0.4	0	Yes	No	Not Badged	No film badges exist for this claimant though the claimant worked in administrative capacities; external dose assigned based on “other DOE sites”
24	Operator/ Technician	Parks Township and Apollo	14.9	0	Yes	Yes	Routine	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
25	Health and Safety Technician	Parks Township and Apollo	5.9	2	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
26	Laborer	Apollo	2.0	0	No	Yes	Not Badged	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
27	Janitor	Apollo	7.3	1	Yes	Yes	Unknown	External dose is estimated based on “coworker studies for other DOE sites”

Summary of Sampled Claimants						CATI Info		Additional Comments
Ref. Number	**Job Title**	**NUMEC Work Site**	**Approximate Length of Employment (years)**	**Years with Available External Monitoring Data**	**Internal Monitoring Data**	**Work in Radiological Area**	**Badging Practices**	
28	Secretary	Parks Township and Apollo	8.4	0	No	No	Not Badged	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
29	Chemist	Apollo	0.3	0	No	Yes	Unknown	No DOE response files are contained on NOCTS for this claimant; external radiation dose was assigned based on the DOE annual dose limit at the time
30	Electronics Technician	Apollo	0.7	0	Yes	Yes	Unknown	No external records are available; coworker doses from the Rocky Flats Plant were used instead
31	Glove Box Worker	Parks Township and Apollo	15.5	12	Yes	Unavailable	Unavailable	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
32	Disolver Operator	Apollo	2.8	0	No	Yes	Unknown	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
33	Maintenance Man	Apollo	0.5	0	Yes	Yes	Unknown	No DOE response files are contained on NOCTS for this claimant; external radiation dose was assigned based on the DOE quarterly dose limit at the time
34	Operator/ Truck Driver	Apollo	24.6	0	Yes	Yes	Not Badged	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only
35	Furnace Worker	Apollo	0.7	0	Yes	Unknown	Unknown	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval

Summary of Sampled Claimants						CATI Info		Additional Comments
Ref. Number	**Job Title**	**NUMEC Work Site**	**Approximate Length of Employment (years)**	**Years with Available External Monitoring Data**	**Internal Monitoring Data**	**Work in Radiological Area**	**Badging Practices**	
36	Lab Technician/ Foreman	Apollo	32.0	26	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
37	Chemical Engineer	Apollo	14.2	15	Yes	Yes	Routine	External dose reconstruction not completed due to pending employment confirmation, internal dose sufficient for compensation, SEC approval
38	Liquid Waste Operator	Apollo	34.8	3	Yes	Yes	Routine	Dose reconstruction report states that no credible external dosimetry records are available; external dose is reconstructed based on ORAUT-OTIB-0004 (ORAUT 2005c)
39	Waste Tank Operator	Apollo	16.7	2	Yes	Unavailable	Unavailable	Dose reconstruction report states that external dose is assigned based on "coworker studies"
40	Maintenance Man	Apollo	2.1	0	No	Yes	Not Badged	Dose reconstruction report states that no external monitoring data exist for claimant; external dose reconstruction based on medical x-rays only