Draft

ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

REVIEW OF THE SITE PROFILE FOR THE STANFORD LINEAR ACCELERATOR CENTER

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Project Manager: ________________________ Date: ___________ John Mauro, PhD, CHP	Reviewer: John Mauro

Record of Revisions

Revision Number	Effective Date	Description of Revision
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ACRONYMS AND ABBREVIATIONS

ACL	Administrative Control Limit
Advisory Board or ABRWH	Advisory Board on Radiation and Worker Health
AEC	U.S. Atomic Energy Commission
ALARA	As Low as Reasonably Achievable
AMAD	Activity Median Aerodynamic Diameter
AMS	Air Monitoring System
ANL-E	Argonne National Laboratory-East
AWE	Atomic Weapons Employer
BDE	Beam Dump East
BF_3	Boron Trifluoride
BNL	Brookhaven National Laboratory
Bq	Becquerel
BSOIC	Beam Shutoff Ion Chamber
BSY	Beam Switch Yard
CAM	Continuous Air Monitor
CEDE	Committed Effective Dose Equivalent
CERN	European Organization of Nuclear Research
CF	Correction Factor
CFR	*Code of Federal Regulations*
Ci	curie
cm	centimeter
DAC	Derived Air Concentration
DE	Dose Equivalent
DOE	U.S. Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
dpm	disintegrations per minute
DU	Depleted Uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EPA	U.S. Environmental Protection Agency
ES&H	Environmental Safety and Health
ESA	End Station A
eV	electron volts
FFTB	Final Focus Test Beam
ft	foot
FRC	Federal Records Center
g	gram
GERT	General Employee Radiation Training
GeV	Gigaelectron volts

GM	Geiger Mueller
GR	Giant Resonance
GSD	Geometric Standard Deviation
HEPA	High Efficiency Particulate Air
HHS	Health and Human Services
HPI	Health Physics Instrument
hr	hour
Hz	Hertz
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiological Units and Measurements
in	inch
IREP	Interactive RadioEpidemiological Program
l	liter
keV	kiloelectron volt
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LCLS	LINAC Coherent Light Source
LiF	Lithium fluoride
LINAC	Linear Accelerator
LLNL	Lawrence Livermore National Laboratory
LLD	Lower Limit of Detection
m^3	cubic meter
mA	milliamp
MAPEP	Mixed Analyte Performance Evaluation Program
MBq	Megabequerels
MDD	Minimum Detectable Dose
MeV	megaelectron-volt, 1 million electron-volts
MFD	Mechanical Fabrication Department
MMAD	Mass Median Aerodynamic Diameter
mR	milliroentgen
mrem	millirem
mSv	milliSievert
mV	millivolt
MW	Megawatt
NaI	Sodium Iodide
NAVSEA	Naval Sea System Command
NCRP	National Council on Radiation Protection
NIOSH	National Institute for Occupational Safety and Health
NLCTA	Next Linear Collider Test Accelerator
NTA	Nuclear Track Film Type A
ODTS	Occupational Dose Tracking System

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OIO	Office of Independent Oversight
ORAUT	Oak Ridge Associated Universities Team
ORPS	Occurrence Reporting and Processing System
OTIB	ORAUT Technical Information Bulletin
pCi	picocurie
PEP	Positron Electron Project
PIC	Pocket Ionization Chamber
PMS	Perimeter Monitoring System
PNNL	Pacific Northwest National Laboratory
POC	Probability of Causation
PPE	Personal Protective Equipment
PuBe	Plutonium Beryllium
PuLi	Plutonium Lithium
QC	Quality Control
R	Roentgen
RAMSY	Radioactive Material Storage Yard
RadCon	Radiological Control
RCA	Radiological Control Area
RCO	Radiological Control Organization
RCT	Radiological Control Technician
RDC	Radiation Detection Company
RF	Radio Frequency
RMS	Remote Monitoring System
RP	Radiation Protection
RWP	Radiological Work Permit
SC&A	S. Cohen & Associates
SEC	Special Exposure Cohort
SLAC	Stanford Linear Accelerator Center National Accelerator Laboratory
SLC	SLAC Linear Collider or Stanford Linear Collider
SPEAR	Stanford Positron-Electron Asymmetric Ring
SRDB	Site Research Database
SSRL	Stanford Synchrotron Radiation Lightsource
Sv	sievert
TA	Technical Area
TBD	Technical Basis Document
TIB	Technical Information Bulletin
TLD	Thermoluminescent dosimeter
µm	micron
yr	Year

1.0 EXECUTIVE SUMMARY

This draft report presents the results of an independent review conducted by S. Cohen and Associates (SC&A, Inc.) of ORAUT-TKBS-0051, *Site Profile for the Stanford Linear Accelerator Center* (ORAUT 2007a), which was issued by the National Institute for Occupational Safety and Health (NIOSH) as a summary site profile document. SC&A conducted this review during the period of May 2010 through August 2011.

This review was conducted in accordance with the Advisory Board's *Data Access and Interview Procedures* (ABRWH 2009a) and SC&A's Board-approved *Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). SC&A evaluated the site profile for completeness, technical accuracy, adequacy of data, compliance with regulatory objectives, and consistency with other site profiles. Review criteria and methods are described in greater detail in Section 2.0 of this report.

The Stanford Linear Accelerator Center National Accelerator Laboratory, known as SLAC, was established in 1962 at Stanford University in Menlo Park, California. SLAC is home to a 20 GeV, 2-mile linear electron accelerator that was originally established to conduct particle physics research, but has evolved to a multi-purpose laboratory for astrophysics, photon science, accelerator, and particle physics research. The 2-mile linear electron accelerator (LINAC) was constructed over a period of 4 years. The first electron beam was accelerated through the entire length of the machine on May 21, 1966. The accelerator proper is housed in a concrete tunnel 25 feet underground. Parallel to the accelerator at ground level is the klystron gallery, which contains all the components and devices for the acceleration of the subterranean electron beam. The Stanford Synchrotron Radiation Lightsource (SSRL) is a national facility for the utilization of synchrotron radiation in many fields of scientific investigation collocated at SLAC. A smaller, self-contained test band linear accelerator, the Next Linear Collider Test Accelerator (NLCTA), is used to test x-band technology, which allows for faster acceleration of particles.

A brief description of the processes that create radiation fields at a high-energy electron accelerator is presented in Attachment 1 of this report. Potential external exposures include photon and beta radiation while the accelerator is operating or when it is off, and neutron radiation while the accelerator is operating. Potential internal exposure may result from exposure to activated air or invasive work on beamline/components, experimental targets, the shielding, and the beamstops. The dominant dose contribution to workers at SLAC is external exposure.

SC&A conducted a site visit from January 24–28, 2011, comprised of a document review and unclassified site expert interviews. SLAC provided SC&A staff members with access to the intranet, where additional documents were captured. Data retrieved were made available to NIOSH via the O-drive. Interviews were conducted with 26 former and current SLAC workers, including personnel from radiological control (RadCon) and dosimetry; environmental monitoring and waste management; accelerator operations; medical; and maintenance and crafts. The purpose of these interviews was to obtain first-hand accounts about past radiological controls, personnel monitoring programs, and site operations. Attachment 2 of this report is a summary of information provided to SC&A by the SLAC site experts.

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This draft report was prepared at the request of the Advisory Board and covers ORAUT-TKBS-0051, *Site Profile for Stanford Linear Accelerator Center*, Rev. 01 (ORAUT 2007a). As part of its evaluation, SC&A also reviewed other documents that were considered relevant, including the following:

- Relevant technical information bulletins (TIBs)
- Select documents that were referenced in the SLAC Site Profile
- Documents contained in the NIOSH Site Research Database (SRDB)
- Documents retrieved from data capture at SLAC

This review found that the NIOSH site profile for SLAC fails to fully characterize some key issues that are fundamental to guiding dose reconstruction. In several sections of the technical basis document (TBD), contemporary data are applied across all years of operation, without regard to changes in accelerator power, beam modifications, and improvements in the radiological control program. Unsubstantiated basis is another concern that impacts multiple aspects of this review—NIOSH does not provide adequate documentation of data, assumptions, and methods to support their conclusions and facilitate technical review. This observation is applicable to neutron correction factors (CFs) and occupational environmental dose. The evaluation of internal hazards in the site profile is limited in scope; it is based on qualitative rather than quantitative analysis of available data, as well as incomplete analysis of internal hazards. Occupational medical dose is summarily dismissed with language that appears to exclude all x-rays from dose reconstruction. A lack of quality assurance reviews of incoming data may have led to incomplete claimant information and potential underestimate of dose.

1.1 SUMMARY OF PRIMARY FINDINGS

A summary of SC&A's primary findings for the SLAC site profile is presented below. Detailed discussions of all findings and observations are found in Section 3.0 of this report, "Vertical Issues."

Finding 1: Incomplete Basis for External Neutron Dose Adjustments

SC&A found that the CFs recommended by NIOSH for SLAC's neutron dosimeters are not adequately supported by the information presented in the site profile. The TBD contains several discussions of neutron energy spectra, as well as information and analysis concerning various neutron instruments, area monitors, and dosimetry systems. However, most of this information is not clearly connected to the few important CFs the dose reconstructor will actually use. Some recommendations in the TBD are based on a very limited evaluation of complex radiation fields and dosimetry issues. In several cases, NIOSH fails to explain how assumptions and estimates were derived from reference documents. The CFs are presented without sufficient supporting documents or details, and they are applied across all time periods for the entire accelerator complex, disregarding variations in neutron energy spectra for different times and facilities. SC&A was able to derive most of the CFs in Table 6-6, but several concerns were noted in regard to underlying data and assumptions. Although the subject of neutron radiation and its associated dosimetry at SLAC received reasonable coverage in the site profile, there are several neutron energy ranges in which reconstructed neutron doses may not adequately reflect the doses received by the workers.

Finding 2: Lack of Extremity Monitoring and Low-Energy Photon Calibration

The site profile does not adequately address extremity monitoring or low-energy photon calibrations. The characterization of common sources of exposure (Table 2-5, page 15, of the TBD) shows that contact dose rates are orders of magnitude higher than dose rates at 30 cm for most of the components tested. Handling of these activated components could present significant dosimetry geometry issues. The dose to extremities, lower sections of the body, and areas of the head (if leaning over components) could be significantly greater than the recorded dose from a monitor worn on the chest area. However, the TBD does not discuss dosimetry geometry factors, and there is no indication that extremity monitoring was needed or performed at SLAC.

In addition, dosimeters were apparently not calibrated for low-energy photon exposures before the Department of Energy Laboratory Accreditation Program (DOELAP) accreditation of the Panasonic UD-802 system in the mid-1990s. These issues were identified in the Department of Energy (DOE) Tiger Team report (DOE 1991) as deficiencies in the external dosimetry program at SLAC. Many of these deficiencies were corrected after the Tiger Team inspection, but dose reconstructions for workers exposed to these conditions before the corrections were implemented may need additional consideration and/or adjustment factors to compensate for these deficiencies.

Finding 3: Assessment of Internal Dose from Enhanced Radon and Thoron in the Tunnels

Radon and thoron (Rn-220) gases above typical building background levels may have caused internal doses that need to be accounted for when a claimant worked in the accelerator tunnel or other underground structures with low air ventilation (fresh air exchange) levels. Enhanced radon and thoron levels are considered in other site profiles where underground concrete structures exist, but no consideration is given to this potential source of internal dose in the SLAC site profile. If radon studies were conducted at SLAC, as indicated by a site expert, NIOSH should obtain the record of results and evaluate the validity and applicability of the data to account for occupational radon and thoron doses in dose reconstruction.

Finding 4: Incomplete Characterization of Internal Radiological Hazards at SLAC

The TBD fails to discuss and consider potential internal exposure from special projects historically and currently conducted at SLAC. Although the handling of radioactive materials and samples during special projects does not necessarily indicate a need for routine bioassay, it does suggest that special bioassay and air sampling efforts may have been needed to identify exposures during unusual situations or incidents. Further research should be conducted to identify source terms beyond routine accelerator operations, identify internal monitoring that may have been done, and evaluate the relative potential for internal exposures. The outcome of this analysis should be included in the TBD to inform dose reconstructors. This analysis should take into consideration the field and personnel monitoring practices of the time.

In addition, because potential internal exposure at SLAC is more likely incidental rather than chronic, the TBD should identify incidents and significant unexpected contamination events that occurred. Examples include the W-181 personnel contamination incident (SLAC 1969), residual contamination from poor machining clean-up practices (SLAC 1994a), and spread of contamination events (SLAC 1994b).

1.2 STRENGTHS

The TBD discusses the site, activities occurring at the site, and the characteristics of radiation exposure. It addresses radiation characteristics associated with electromagnetic cascades, activation products and internal dose, external fields from activation, beta dose, neutron spectra, and synchrotron radiation. Table 2-1, "Area Information," provides a well-organized and informative overview of facilities, periods of operation, access and shielding considerations, and radiation sources and fields.

Occupational external dose, acknowledged as the primary source of exposure at SLAC, was analyzed in detail, considering badging requirements, administrative practices affecting data interpretation and recording, and the responsiveness of various detectors and dosimeters to workplace radiation fields. In particular, the subject of neutron radiation and its associated personnel and environmental monitoring at SLAC were discussed at some length in the site profile. The TBD acknowledges technical challenges and limitations affecting neutron detection and presents extensive information concerning various neutron instruments, area monitors, dosimetry systems, and thermoluminescent dosimeter (TLD) readout parameters (mV/mrem, etc.). Detailed analysis is presented, particularly in Appendix A, in an effort to apply information from multiple studies and theoretical calculations to the challenges of SLAC's broad energy spectra.

1.3 OPPORTUNITIES FOR IMPROVEMENT

While the TBD provides detailed information concerning the history, developments, and facilities at SLAC, there are bases and assumptions that can be strengthened and improved. Recommendations to support bases and assumptions, as well as completeness of dose reconstruction efforts, include the following:

- Evaluation of the completeness of medical records provided by the site for dose reconstruction
- Evaluation of the availability of internal monitoring and incident reports provided by the site for dose reconstruction
- Validation of missed external dose protocols against information available in the dosimetry log
- Linkage of external dosimetry log information with claimant files
- Demonstration that neutron energy spectra used for development of neutron CFs are bounding for all exposure conditions

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- Demonstration that dose estimates derived from contemporary air sampling and contamination monitoring data are bounding for all accelerator power levels, locations, and periods of operation

In addition to the technical findings presented in this report, SC&A noted a process concern in regard to worker outreach. No worker outreach meetings were held during the development or revision of the SLAC site profile. In addition, SC&A's search of the SRDB did not produce any documentation of NIOSH site expert interviews for SLAC. An e-mail correspondence with site radiological control staff is the only source of worker input identified in the SRDB. Information obtained during SC&A site expert interviews indicates that NIOSH may have conducted limited site expert interviews with radiological control personnel at SLAC, but SC&A was unable to confirm this information. The absence of worker outreach meetings indicates a procedural noncompliance with the Oak Ridge Associated Universities Team (ORAUT) procedure ORAUT-PROC-0097 (ORAUT 2005b). The absence of worker outreach meetings and the scarcity of documented communication with SLAC personnel represent weaknesses in the completeness of data sources.

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2.0 SCOPE AND INTRODUCTION

The review of the *Site Profile for the Stanford Linear Accelerator Center* (ORAUT 2007a) was authorized by the Advisory Board at its May 19–21, 2010, meeting in Augusta, Georgia, and was conducted between May 2010 and August 2011 by SC&A's team of health physicists and technical personnel. All of the pertinent records reviewed were unclassified. This review was performed in accordance with *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, and with *Department of Energy Classification Review of Documents* (ABRWH 2009b), which provides for appropriate security clearance reviews.

SC&A understands that site profiles are living documents, which are revised, refined, and supplemented with NIOSH technical information bulletins (TIBs) as required to help dose reconstructors. Site profiles are not intended to be prescriptive or necessarily complete in terms of addressing every possible issue that may be relevant to a given dose reconstruction. However, future revisions in the SLAC site profile would serve to mitigate some of the gaps and issues raised in this report.

2.1 REVIEW SCOPE

The Advisory Board on Radiation and Worker Health (Advisory Board) is mandated to conduct an independent review of the methods and procedures used by NIOSH and its contractors for dose reconstruction. As a contractor to the Advisory Board, SC&A has been charged to support the Advisory Board in this effort by independently evaluating a select number of site profiles that correspond to specific facilities at which energy employees worked and were exposed to ionizing radiation.

This report provides a review of the TBD related to historical occupational exposures at SLAC:

- ORAUT-TKBS-0051, *Site Profile for the Stanford Linear Accelerator Center*, Rev. 01 (ORAUT 2007a).

To date, the site profile has not been supplemented by site-specific TIBs, but there are two generic TIBs that provide additional guidance to the dose reconstructor:

- ORAUT-OTIB-0006, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures*, Rev. 03-D, December 21, 2005 (ORAUT 2005a).

- ORAUT-TIB-0055, *Technical Basis for Conversion from NCRP Report 38 Neutron Quality Factors to ICRP Publication 60 Radiation Weighting Factors for Respective IREP Input Neutron Energy Ranges*, June 5, 2006 (ORAUT 2006).

SC&A also reviewed other pertinent documents, including those cited on the NIOSH SRDB. SC&A has critically reviewed the SLAC TBD, 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 SLAC site profile and supplemental documentation focuses on the quality and completeness of the data that characterized the facility and its operations, and on the use of these data in performing dose reconstruction. The review was conducted in accordance with *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004), which was approved by the Advisory Board.

The review is directed at "sampling" the site profile analyses and data for validation purposes. The review does not provide a rigorous quality control process, whereby actual analyses and calculations are duplicated or verified. The scope and depth of the review are focused on aspects or parameters of the site profile that would be particularly influential in dose reconstructions, bridging uncertainties, or correcting technical inaccuracies.

The SLAC site profile document serves as site-specific guidance to support dose reconstructions for EEOICPA claimants. 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. This report was prepared by SC&A to provide the Advisory Board with an evaluation of whether and how the TBD can support dose reconstruction decisions.

The basic principle of dose reconstruction is to characterize the radiation environments to which workers were exposed, and to determine the levels of exposure the workers received in that environment through time. The hierarchy of data used for developing dose reconstruction methodologies is dosimeter readings and bioassay data, coworker and workplace monitoring data, and process description information or source term data.

2.2 ASSESSMENT CRITERIA AND METHODS

SC&A is charged with evaluating the approach set forth in the site profiles that is used in the individual dose reconstruction process. These documents are reviewed for their completeness, technical accuracy, adequacy of data, consistency with other site profiles, and compliance with the stated objectives, as defined in *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). This review is specific to the SLAC site profile; however, items identified in this report may be applied to other facilities, especially facilities with similar source terms, exposure conditions, and mobile workforces. The review identifies a number of issues and discusses the degree to which the site profile fulfills the review objectives delineated in SC&A's site profile review procedure (SC&A 2004).

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2.2.1 Objective 1: Completeness of Data Sources

SC&A reviewed the site profile with respect to Objective 1, which requires SC&A to identify principal sources of data and information that are applicable to the development of the site profile. The three elements examined under this objective are (1) determining if the site profile made use of available data considered relevant and significant to the dose reconstruction, (2) investigating whether other relevant/significant sources are available, but were not used in the development of the site profile, and (3) determining if worker input was considered in the development of the site profile.

2.2.2 Objective 2: Technical Accuracy

Objective 2 requires SC&A to perform a critical assessment of the methods used in the site profile to develop technically defensible guidance or instructions, including evaluating field characterization data, source term data, technical reports, standards and guidance documents, and literature related to processes that occurred at SLAC. The goal of this objective is to analyze the data according to sound scientific principles, and then evaluate this information in the context of dose reconstruction.

2.2.3 Objective 3: Adequacy of Data

Objective 3 requires SC&A to determine whether the data and guidance presented in the site profile are sufficiently detailed and complete to conduct dose reconstruction, and whether a defensible approach has been developed in the absence of data. In addition, this objective requires SC&A to assess the credibility of the data used for dose reconstruction. The adequacy of the data identifies gaps in the facility data that may influence the outcome of the dose reconstruction process. For example, if a site did not monitor all workers exposed to neutrons who should have been monitored, this would be considered a gap and thus an inadequacy in the data. An important consideration in this aspect of our review of the site profile is the scientific validity and claimant favorability of the data, methods, and assumptions employed in the site profile to fill in data gaps.

2.2.4 Objective 4: Consistency among Site Profiles

Objective 4 requires SC&A to identify common elements within site profiles completed or reviewed to date, as appropriate. In order to accomplish this objective, the SLAC TBD was compared to other TBDs, particularly those referenced in the site profile and those related to frequently visited facilities. This assessment was conducted to identify areas of inconsistencies and determine the potential significance of any inconsistencies with regard to the dose reconstruction process.

2.2.5 Objective 5: Regulatory Compliance and Quality Assurance

Objective 5 requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in 42 CFR Part 82. In addition, SC&A evaluated the TBD for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions.

2.3 DOSE RECONSTRUCTION UNDER EEOICPA

[Introductory text from this section that relates to statutory and regulatory interpretations has been redacted.]

SC&A's draft report and preliminary findings will subsequently undergo a multi-step resolution process. Resolution includes a transparent review and discussion of draft findings with members of the Advisory Board Work 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 Rev. 01 of the SLAC site profile document, which is the most recently published version. Site expert interviews were conducted with former and current SLAC site workers to assist SC&A in obtaining a comprehensive understanding of the radiation protection program, site operations, and historic exposure experience.

Attachment 1 to this report contains a brief description of the processes that create radiation fields at a high-energy electron accelerator. This information provides a foundation for understanding workers' exposure potential at SLAC.

Attachment 2 to this report contains a summary of the collective interviews conducted by SC&A during the course of this review and approved by interviewees.

2.4 REPORT ORGANIZATION

In accordance with directions provided by the Advisory Board and with site profile review procedures prepared by SC&A and approved by the Advisory Board, this report is organized into the following sections:

(1) Executive Summary
(2) Scope and Introduction
(3) Vertical Issues
(4) Overall Adequacy of the Site Profile as a Basis for Dose Reconstruction

Based on the issues raised, SC&A prepared a summary list of findings, which is presented in the Executive Summary. Issues are designated as primary findings if SC&A believes they represent deficiencies that need to be corrected and pose the potential for substantial impact on at least some dose reconstructions. Issues can be designated as secondary findings if they simply raise questions, which, if addressed, would further improve the site profile and may possibly reveal deficiencies that will need to be addressed in future revisions of the site profile. Detailed analyses of the primary and secondary findings are provided in Section 3.0 of this report. Section 4.0 summarizes the evaluation of the TBD with respect to the stated objectives in *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004).

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3.0 VERTICAL ISSUES

Finding 1: Incomplete Basis for External Neutron Dose Adjustments

Despite a large volume of information and analysis presented in the site profile on the topic of neutron dosimetry, the bases, assumptions, and calculations supporting NIOSH's Correction Factor (CFs) for dose reconstruction are incomplete. There are several neutron energy ranges for which the adjusted neutron dose may not adequately reflect or bound doses received by workers.

A brief description of the process that creates the radiation fields at a high-energy electron accelerator is presented in Attachment 1 of this report. Neutrons, ranging in energy from the thermal range [0.025 electron volts (eV)] up to several hundred megaelectron volts (MeV), may be found in occupied areas of the SLAC facility during accelerator operation. As NIOSH acknowledges in the TBD, neutron dosimeters did not respond to the entire spectrum of neutrons present at SLAC. Adjustments to recorded neutron doses are needed to compensate for the dosimeters' sensitivity or lack of sensitivity to specific ranges of the energy spectrum.

The subject of neutron radiation and its associated dosimetry at SLAC received reasonable coverage in the site profile, with material in Section 2, Section 4, Section 6, and Attachment A. The TBD acknowledges technical challenges and limitations affecting neutron dosimetry and presents extensive information concerning various neutron instruments, area monitors, dosimetry systems, and readout parameters for thermoluminescent dosimeters (TLDs). Detailed analysis is presented, particularly in Appendix A of the TBD, in an effort to apply information from various studies and theoretical calculations to the challenges of monitoring SLAC's broad neutron energy spectra. However, the technical information is somewhat scattered and segmented. Rather than flowing directly from the information and analysis presented in the TBD, the CFs and their underlying assumptions are often presented as short statements without sufficient detail or supporting data. Even where references are provided, it is difficult to determine how NIOSH used the referenced information to generate the values and assumptions presented in the TBD. This complicated the technical review considerably.

To develop this finding, SC&A condensed and digested information from multiple sections of the TBD, attempted to reproduce NIOSH's derivation of neutron CFs, and evaluated the technical basis as understood by the reviewers. SC&A was able to derive most of the CFs presented in Table 6-6, but several concerns were noted in regard to underlying data and assumptions. SC&A's interpretations and concerns are presented below for each aspect of this review.

Neutron Dosimetry Systems

Table 1 summarizes the types of neutron dosimetry used at SLAC during specific time periods (from ORAUT 2007a, Table 6-6, pg. 34).

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Table 1. Neutron Dosimetry vs. Time Period

1961–6/1971	Nuclear track emulsion, Type A (NTA) film badge
7/1971–1995	Lithium fluoride (LiF) Albedo TLD
1996–3/2000	Panasonic TLD [calibrated w/unmoderated Cf-252]
4/2000–2001	Panasonic TLD [calibrated w/moderated Cf-252]
2002–2005	Landauer Columbia Resin 39 (CR-39)

Characterizing Neutron Spectra

The site profile identifies energy dependence issues associated with each neutron dosimetry system. Characterization of the radiation fields encountered by workers during these time periods is an essential step in adjusting doses to account for these issues. Multiple statements in the site profile acknowledge the significant challenges posed by the wide range of neutron energies at SLAC:

- Page 19: *Neutron spectra of concern for personnel exposure probably vary significantly.* [Emphasis added.]
- Page 57: *In the field, dose determination is more difficult because the neutron spectra extend to much higher energies than the calibration sources and most instruments.* [Emphasis added.]
- Page 57: *There are several measurements used to qualify the 5- and 6-in. moderated TLDs as a measurement tool (Liu et al. 2000). These instruments are characterized as providing information on the neutrons only below 20 MeV. Neutrons above 20 MeV are characterized as having up to as much dose in the SLAC radiation fields as the lower energy neutrons.* [Emphasis added.]
- Page 57: *For the SLAC radiation fields, the spectrum as well as the dose equivalent have not been readily available, so generating useful information for calibration has been very difficult.* [Emphasis added.]

It appears that NIOSH relied on three neutron spectra measurements from 1997 (Vylet et al. 1997) to assign the fraction of neutrons to each of the five Interactive RadioEpidemiological Program (IREP) energy bins and to derive CFs for dosimetry systems used at SLAC across several time periods. These measurements are described below.

Main Accelerator FFTB2 [Final Focus Test Beam 2] *Measured Neutron Energy Spectra*
A measurement was made at the beam dump of the main electron accelerator (Vylet et al. 1997). The parameters were as follows:

- 46.6 gigaelectron-volt (GeV) electrons
- 16^{o} downstream of beam dump
- Through 4 ft of iron plus 5 ft of concrete
- Used Bonner spheres and plastic scintillators (20-MeV threshold) detectors
- Neutron dose rate was ~20 millirem (mrem)/hour (hr)
- Resulting neutron energy spectrum shown in the TBD (Figure 2-5), presented below in Figure 1:

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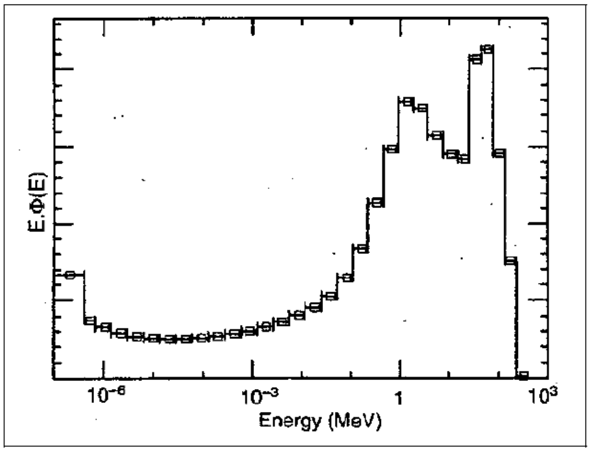


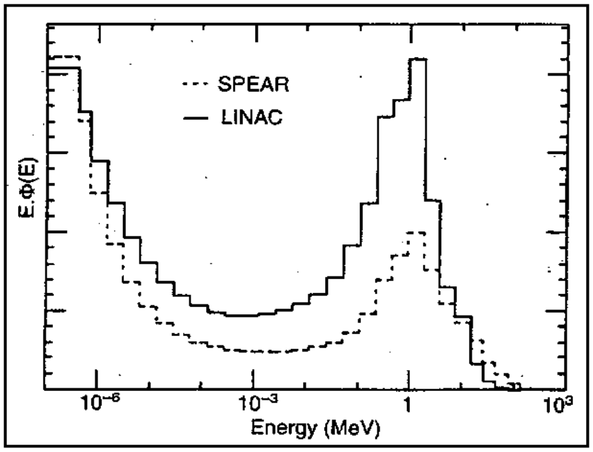
Reproduced from ORAUT 2007a, Figure 2-5, pg. 18
Source: Vylet et al. 1997

Figure 1. Neutron Spectrum from 46.6 GeV Electrons through Iron and Concrete

SSRL-LINAC and SSRL-SPEAR [Stanford Positron Electron Asymmetric Ring] *Measured Neutron Energy Spectra*

Measurements were made at SSRL accelerators with the electron beam striking a Faraday cup (Vylet et al. 1997). The parameters were as follows:

- 120-MeV electrons (LINAC); 2.3-GeV electrons (SPEAR)
- 90^o to beamline
- Through 2 ft of concrete
- Used Bonner spheres and plastic scintillators (20-MeV threshold) detectors
- Neutron dose rate was not provided
- Resulting neutron energy spectra shown in the TBD (Figure 2-6) , presented below in Figure 2:



Reproduced from ORAUT 2007a, Figure 2-6, pg. 19
Source: Vylet et al. 1997

Figure 2. Neutron Spectra at SSRL through 2 ft of Concrete

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The measurements used to derive several CFs for adjusting claimants' neutron doses were obtained in 1997 under specific operating conditions. The TBD fails to demonstrate that these measurements are representative of the moderated neutron fields at various locations and time periods at SLAC. Shielding conditions, location, beam angles, reflected radiation (such as backscatter and skyshine), and other factors could significantly change the neutron energy spectra from those present under the specific measurement conditions of the 1997 data. This could significantly alter the fraction of undetected neutron dose from low-energy and high-energy neutrons, especially as beam energies changed over time. Several site experts interviewed by SC&A reported that accelerator beam power has decreased consistently from a peak period in the early 1970s, due to improvements in beam maintenance and modifications. It is not clear how a few neutron spectra obtained in the late 1990s can adequately characterize or bound dose corrections for workers at all affected locations and times throughout the site's history.

Dose Equivalent Fractions

The spectral data from the 1997 measurements were sorted into the five IREP neutron energy bins and combined with the flux-to-dose equivalent (DE) factors in National Council on Radiation Protection (NCRP) publication NCRP 38 (NCRP 1971) to determine the fraction of the DE that falls below or above a certain neutron energy. The dose fractions for the five neutron energy bins are listed in Table 6-5 of the TBD in the column labeled "NCRP 38 Dose Fraction." This column also lists the fraction of the DE that falls below the NTA film neutron energy threshold of 0.800 MeV and the CR-39 threshold of 0.050 MeV for each of the neutron spectra (ORAUT 2007a, pg. 34).

The following table summarizes the "NCRP 38 Dose Fraction" data from TBD Table 6-5 (ORAUT-TKBS-0051, page 34) that is pertinent to specific detection limitations identified for SLAC's neutron dosimeters. Because NIOSH did not describe its calculations and assumptions or indicate which tables from NCRP 38 were used, SC&A was unable to verify the DE fractions reported in TBD Table 6-5.

Table 2. Dose Equivalent Fractions for Low-Energy and High-Energy Neutrons

Location	Electron Energy (GeV)	Dose Fraction <0.8 MeV (NTA Threshold)	Dose Fraction <0.05 MeV (CR-39 Threshold)	Dose Fraction >20 MeV (High Energy)
SSRL-LINAC	0.120	0.386	0.075	0.018
SSRL-SPEAR	2.3	0.289	0.082	0.099
FFTB2	46.6	0.120	0.016	0.463

Estimating Percentages of Undetected Low-Energy and High-Energy Neutrons

For some neutron dosimetry systems, NIOSH used the "NCRP 38 Dose Fraction" data to estimate how much of the DE was not detected due to the dosimeter's insensitivity to certain neutron energies. These data play a significant role in the derivation of CFs, particularly for NTA film, Landauer CR-39 TLDs, and the Panasonic TLDs calibrated with unmoderated neutrons (1996–March 2000). Table 3 summarizes several energy dependence issues identified by NIOSH for these neutron dosimetry systems. The fourth column presents SC&A's

understanding of how NIOSH used the 1997 neutron spectral data to derive the "Impact" values listed in Table 6-6 of the TBD (ORAUT 2007a, pg. 34).

Table 3. Impact of Detector Energy Dependence Issues

Detector System	Issue	Impact	SC&A Interpretation of NIOSH Basis (Apparent use of neutron spectral data)
NTA Film Badge	Insensitive below 800 keV	Lose 12%–40%	FFTB2 dose fraction <0.8 MeV = 12% SSRL-LINAC dose fraction <0.8 MeV = 38.6% (rounds up to 40%)
Panasonic TLD (1996–3/2000)	Not measure high-energy neutrons	Lose 2%–50%	SSRL-LINAC dose fraction >20 MeV = 1.8% (rounds up to 2%) FFTB2 dose fraction >20 MeV = 46.3% (rounds up to 50%)
Landauer CR-39	Insensitive below 50 keV	Lose 1.6%–8%	FFTB2 dose fraction <0.05 MeV = 1.6% SSRL-SPEAR dose fraction <0.05 MeV = 8.2% (rounds down to 8%)
NTA Film Badge & Landauer CR-39	Not detect heavy recoils	Lose 30%–40% of 50%–2%	SSRL-LINAC dose fraction >20 MeV = 1.8% (rounds up to 2%) FFTB2 dose fraction >20 MeV = 46.3% (rounds up to 50%) Assumption described in TBD: 30%–40% loss at energies above 10–50 MeV

NIOSH assumes 30%–40% of the high-energy dose fraction is not detected by NTA film and Landauer CR-39 TLDs. This estimate is described in the TBD as follows (ORAUT 2007a, pg. 54):

> *Above 10 to 50 MeV, carbon and oxygen recoil and spallation become important. The NTA and Neutrak* [CR-39] *systems probably do not respond to them. There are no calibration sources in this energy range, so testing cannot occur. Based on ICRU* [International Commission on Radiation Units and Measurements] *Report 63 (1999, Figure 7.19) an estimated 30% to 40% of the dose equivalent in this energy range is lost.* [Emphasis added.]

NIOSH does not explain how ICRU Report 63 (ICRU 1999) was used to estimate that 30%–40% of the dose from high-energy neutrons was lost to detection by NTA film and CR-39 TLDs. No further explanations or calculations are provided to show how this estimate was derived. Without this information, SC&A could not verify the calculated values or the assumptions used. The TBD also does not discuss the relevance of ICRU's data to the high-energy neutron fields encountered by SLAC workers throughout the years when these dosimetry systems were in use.

Derivation of Correction Factors for Neutron Dosimetry Systems

NIOSH lists the "Total Impact" for each dosimeter system and time period in Table 6-6 of the TBD (ORAUT 2007a, pg 34); these are the overall CFs applied by the dose reconstructor to adjust the recorded neutron dose. The TBD does not describe the derivation of these CFs, which

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complicated the technical review. SC&A was able to derive most of the CFs presented in Table 6-6, but several concerns were noted in regard to underlying data and assumptions. The following analysis of neutron CFs reflects SC&A's understanding of NIOSH's approach.

It appears that NIOSH used a simple average of two values to quantify the impact of each issue listed in Table 3 above. For example, the fraction of the DE in the high-energy range (>20 MeV) was determined to range from about 2% (in the SSRL-LINAC spectrum) to about 50% (in the FFTB2 spectrum). NIOSH apparently took the average of these two values (26%) to represent how much of the DE is from high-energy neutrons. Similarly, the estimated 30%–40% loss of detection for high-energy neutrons is apparently represented as the average, 35%.

The CFs that compensate for undetected low-energy and high-energy neutrons on the basis of the "NCRP 38 Dose Fractions" from the 1997 neutron spectra measurements may be obtained using the following equation:

Total Impact = 1/[1 – (threshold fraction lost + high-energy fraction lost)]

Using this approach, the following corrections would be calculated for these systems:

1. NTA Film Badge (1961–June 1971)
    a. Insensitive below 800 keV: Lose 12%–40%
       (0.12 + 0.40)/2 = 0.26
       Assume 26% of DE was not detected due to low-energy neutrons
    b. Not detect heavy recoils: Lose 30%–40% of 50%–2%
       (0.30 + 0.40)/2 = 0.35
       (0.02 + 0.50)/2 = 0.26
       0.35 * 0.26 = 0.09
       Assume 9% of DE was not detected due to high-energy neutrons
    c. SC&A calculated combined CF: 1/[1 - (0.26 + 0.09)] = **1.53**
    d. NIOSH "Total Impact:" Multiply by **1.53** +/- 0.14

2. Landauer CR-39 TLD (2002–2005)
    a. Insensitive below 50 keV: Lose 1.6%–8%
       (0.016 + 0.08)/2 = 0.048 (rounds up to 0.05)
       Assume 5% of DE was not detected due to low-energy neutrons
    b. Not detect heavy recoils: Lose 30%–40% of 50%–2%
       (0.30 + 0.40)/2 = 0.35
       (0.02 + 0.50)/2 = 0.26
       0.35 * 0.26 = 0.09
       Assume 9% of DE was not detected due to high-energy neutrons
    c. SC&A calculated combined CF: 1/[1 - (0.05 + 0.09)] = **1.16**
    d. NIOSH "Total Impact:" Multiply by **1.12** +/- 0.04
       Disagreement: SC&A's result is higher by ~4% compared to NIOSH's result.

Using simple arithmetic means of high and low values to derive CFs appears to be overly simplistic. This approach fails to account for the amount of time a worker may have spent in one accelerator field compared to the other, as well as the accelerators' respective contribution to the overall radiation field as a function of space and time.

Correction factors (CFs) for the other neutron dosimetry systems used at SLAC are not based primarily on the "NCRP 38 Dose Fractions." Each of these CFs is evaluated separately below.

3. LiF Albedo TLD (1971–1995)
   a. NIOSH "Total Impact:" Multiply by **0.56**. GSD [geometric standard deviation] of 2.5.
   b. SC&A interpretation: 1/1.8 = **0.56**

   The CF of 1.8 is mentioned in the TBD (ORAUT 2007a, pg 63):

   > *The neutron dose equivalent for the SLAC LiF system used from 1971 should be reduced by a factor of 1.8 with a GSD of 2.5 [14].*[1] *The large uncertainty is likely due to different albedo neutron responses to different spectra at SLAC; there was no attempt to evaluate the different spectra to which individuals were exposed. To attempt such an evaluation would have been a time-consuming task that would likely have been unsuccessful. The correction is due to the fact that SLAC conservatively erred on the side of over-reporting the neutron dose equivalent.*

   The basis for this CF is not expressly identified in the TBD. If it is based on NIOSH's detailed analysis of response characteristics of albedo TLD systems (ORAUT 2007a, pp. 59–62), the derivation is not clear. A factor of 1.8 is listed in Table A-1 (ORAUT 2007a, pg. 58) in Column 6, Row 12; this value is associated with TLDs in a 6-in water moderator exposed to CERN (European Organization for Nuclear Research) neutron fields with concrete shielding. It is not readily apparent why TLDs exposed in a 6-in water moderator to CERN concrete-shielded neutrons are representative of the neutron fields workers were exposed to at all locations at SLAC throughout this time period.

4. Panasonic TLD (1996–March 2000)
   a. Use unmoderated rather than moderated Cf for dose evaluation:
      Divide by 7. GSD of 2.5.
      Assume the dose of record was overestimated by a factor of 7.
   b. Not measure high-energy neutrons: Lose 2%–50%
      [SC&A incorporated the 30%–40% assumption for high-energy neutron detection. The TBD does not indicate if this factor applies to the Panasonic TLD.]
      (0.02 + 0.50)/2 = 0.26
      0.35 * 0.26 = 0.09
      Assume 9% of DE was not detected due to high-energy neutrons.
   c. SC&A calculated combined CF: 1/[1 - 0.09] × 1/7 = **0.16**
   d. NIOSH "Total Impact:" Multiply by **0.14**. GSD of 2.5.
      Disagreement: SC&A's result is higher by ~14% compared to NIOSH's result.

[1] [Annotation provided in TBD]. Rohrig, Norman D. ORAU Team. Health Physicist. April, 2006.

NIOSH did not incorporate a correction for undetected high-energy neutron dose into the combined CF—the combined CF ("Multiply by 0.14") is equivalent to the first issue impact ("Divide by 7"). This accounts for the discrepancy between SC&A's calculation and the CF listed in Table 6-6. The TBD does not indicate if the 30%–40% estimate for the percentage of high-energy neutrons lost to detection, described above for NTA film and CR-39 TLDs, is applicable to the Panasonic TLD.

Some contradictions were noted in different sections of the TBD regarding calibration of the Panasonic TLD during this time period. It appears that the TLDs were calibrated using unmoderated (i.e., higher-energy) neutrons, but NIOSH assumes workers were exposed primarily to lower-energy moderated neutrons. Multiplying the dose of record by 1/7 (0.14) reduces the assigned dose to compensate for the TLD's higher sensitivity to lower-energy neutrons. The final sentence in Attachment A describes this position (ORAUT 2007a, page 63):

> *We understand that the reported neutron doses for the Panasonic system until March 2000 were based on the unmoderated ^{252}Cf spectrum, resulting in reported doses being about a factor of 7 too large (Flood* [1995]*).* [Emphasis added.]

If the statement quoted above correctly represents NIOSH's position, the following statements should be revised to improve clarity and consistency.

- Table 6-6, Column 3, Row 4 (ORAUT 2007a, pg. 34):
  - Current wording: *Use unmoderated rather than moderated Cf for dose evaluation.* [Emphasis added.]
  - Suggested wording: *Unmoderated rather than moderated Cf was used for dose evaluation.* [Emphasis added.]

- Section 6.3.3.2, second paragraph, second sentence (ORAUT 2007a, pg. 32):
  - Current wording: *…between 1996 and March 2000, the Panasonic system used the dose response for a moderated ^{252}Cf neutron source...* [Emphasis added.]
  - Suggested wording: *…between 1996 and March 2000, the Panasonic system used the dose response for an unmoderated ^{252}Cf neutron source…* [Emphasis added.]

There still remains the important issue of how the correction factor of 1/7 was derived and how it was determined that workers were exposed mainly to lower-energy moderated neutrons. It is important for NIOSH to clarify this analysis, as it supports a decision to reduce a worker's neutron dose by a factor of 7 for a period of 4 years. SC&A reviewed the cited reference (Flood 1995) to determine the source and rationale of the 1/7 CF. The following figure, excerpted from this document (Flood 1995, pg. 4), appears to be relevant:

	Dose Conversion Factors Element 1 mR*/mrem
Unmoderated (High Energy) Cf-252 Neutrons	0.222
Moderated (Low Energy) Cf-252 Neutrons	1.546

Figure 3. Neutron Dose Conversion Factors (Flood 1995)

NIOSH's CF appears to be a ratio of Flood's dose conversion factors for unmoderated and moderated Cf-252 neutrons.

CF = Unmod response/Mod response = 0.222/1.546 = 1/7 = 0.14

The CF should incorporate all of the energy dependence issues identified in the TBD, and inconsistencies in wording should be corrected. Considering the significance of a decision to reduce a worker's reported neutron dose by a factor of 7, the TBD does not adequately explain NIOSH's derivation of this CF, nor does it support the underlying assumption that workers were mainly exposed to lower-energy moderated neutrons (similar to moderated Cf-252 neutrons).

5. Panasonic TLD (April 2000–2001)
   a. May overcompensate for high-energy neutrons
   b. NIOSH "Total Impact:" **None.** GSD of 2.5.

According to the TBD, moderated Cf-252 neutrons were used to calibrate the Panasonic TLDs during this period (ORAUT 2007a, pg 32):

> *Dose using the Panasonic system was defined from the response to the <u>moderated</u> ^{252}Cf source. Beginning in March 2000 (Flood* [2000]*), in consideration of the high-energy neutron peak at 80 to 100 MeV, the dose conversion factors were divided by 2, which effectively doubled the reported neutron dose equivalent.* [Emphasis added.]

In Table 6-6, NIOSH recommends no further adjustments [other than those recommended by the International Commission on Radiological Protection (ICRP)] to the neutron dose of record, because the recorded dose may already overcompensate for high-energy neutrons. The TBD provides no further details concerning the rationale for dividing dose conversion factors by 2, or if that adjustment correctly compensated or overcompensated for undetected high-energy neutrons. While the Flood document (Flood 2000, pg. 43) provides some additional details, the rationale appears to be based on the assumption that approximately 50% of the DE is from high-energy neutrons. SC&A's concern about

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oversimplified assumptions in regard to complex and varied neutron spectra have been discussed in earlier segments of this finding.

In summary, despite a large volume of information and analysis presented in the TBD on the topic of neutron dosimetry, the CFs that are actually used to adjust recorded neutron dose are not adequately supported. The TBD recommendations are based on a very limited treatment of complex radiation fields and dosimetry issues. Several components of the recommended CFs are based on simple averages of upper and lower values that may not represent the radiation fields to which workers were exposed. The 1997 neutron spectral measurements are based on limited parameters, and the TBD fails to demonstrate that these measurements are representative of the moderated neutron fields at various locations and time periods at SLAC, especially as beam power changed over time. Dose fraction values in Table 6-5 could not be verified without additional information on NIOSH's use of NCRP 38 (NCRP 1971). Similarly, the reference to ICRU Report 63 (1999, Figure 7.19) was not sufficiently detailed to support an assumption that 30%–40% of the DE from high-energy neutrons was not detected by NTA film or CR-39 TLDs. Several other assumptions and CFs appear in the TBD without sufficient explanations or supporting data. Without sufficient support for NIOSH's "Total Impact" CFs, SC&A cannot conclude that neutron dose reconstruction adequately reflects or bounds the doses received by workers.

Finding 2: Lack of Extremity Monitoring and Low-Energy Photon Calibration

The site profile does not adequately address the need for, or the lack of, extremity monitoring at SLAC. In addition, significant monitoring and calibration for beta and low-energy photon exposures do not appear to have occurred before approximately 1996. These issues require further investigation and should be addressed in the TBD.

As described in Attachment 1 of this report, the energy spectra of the photons created at SLAC can range from several keV up to near the maximum energy of the electron beam. The photon energies of most concern from a health protection aspect (outside the shielding) range from approximately 30 keV to several MeV at SLAC. When the accelerator is not operating, exposure comes from activated materials (e.g., targets, beamline components, structural materials, and air). Adequate beta/photon monitoring would include dosimetry that is responsive and appropriately calibrated for field exposure conditions:

- Photons: 30 keV to 3 MeV, both while the accelerator is operating and when it is off.
- Betas: keV and MeV range, both while the accelerator is operating and when it is off.

The following table summarizes the types of photon and beta dosimetry used at SLAC as a function of time:

Table 4. Photon and Beta Dosimetry at SLAC

	Photon	Beta
1961–1971	Type 2 film	Type 2 film
1972–1995	TLD	None
1996–2001	TLD	TLD
2002–2005	TLD	TLD

SLAC's photon/beta dosimetry system throughout its operating history appears to be similar to the standard photon/beta dosimetry used at most institutions during these periods. This dosimetry accounts for prompt photons outside the shielding during accelerator operations and photons from activated materials. It would detect the photons emitted from the klystrons (300–400 keV) and synchrotron radiation (in the 30-keV energy range).

It is not apparent from the TBD if dosimetry geometry issues were considered for SLAC. Handling of activated components could present significant dosimetry geometry issues, including extremity exposures that could be much higher than the whole-body recorded doses. There is no indication that extremity monitoring was needed or performed. However, the characterization of common sources of exposure (Table 2-5, page 15 of the TBD) shows that contact dose rates are orders of magnitude higher than dose rates at 30 cm for most of the components tested. The dose to extremities, lower sections of the body, and areas of the head (if leaning over components) could be significantly greater than the recorded dose from a monitor worn on the chest area. This issue is applicable to the calibration facilities as well as the accelerators and experimental areas.

Beta and low-energy gamma exposure are important to the reconstruction of dose for skin cancers. The TBD acknowledges that synchrotron radiation includes x-rays below 30 keV. Furthermore, the site profile indicates beta radiation is 10% to 30% of the gamma dose. Before approximately 1996, there does not appear to have been significant monitoring and/or calibration for beta or low-energy gamma exposures (see Table 6-2, pg. 31, for a summary of recorded dose practices). In Section 6.3.1, "Site Dosimetry Technology," calibration of dosimetry for low-energy photon exposures is not mentioned before the DOELAP accreditation of the Panasonic UD-802 system in the mid-1990s (ORAUT 2007a, pg. 30).

These issues were identified in the DOE Tiger Team report (DOE 1991) as deficiencies in the external dosimetry program at SLAC. Many of these deficiencies were corrected after the Tiger Team inspection; however, dose reconstructions for workers exposed to these conditions before the corrections were implemented may need additional consideration and/or adjustment factors to compensate for these deficiencies.

Finding 3: Assessment of Internal Dose from Enhanced Radon and Thoron in the Tunnels

Radon and thoron gases above typical building background levels may have caused internal doses that need to be accounted for when a claimant worked in the accelerator tunnel or other underground structures with low air ventilation (fresh air exchange) levels. Enhanced radon and thoron levels are considered in other site profiles where underground concrete structures exist, but no consideration is given to this potential source of internal dose in the SLAC site profile.

According to the introduction section for ICRP Publication 65 (ICRP 1993):

> *The naturally radioactive noble gas radon (^{222}Rn) is present in the air outdoors and in all buildings, including workplaces. It is thus an inescapable source of radiation exposure both at home and at work. High radon levels in air can occur in buildings, including workplaces, in some geographical locations. This applies particularly in workplaces such as underground mines, natural caves, tunnels,*

> *medical treatment areas in spas, and water supply facilities where ground water with a high radon concentration is treated or stored.*

The SLAC site profile states that radiation from naturally occurring radon present in conventional structures is not considered occupational exposure. SC&A maintains that an accelerator tunnel, intentionally placed underground due to the very high radiation fields and immense shielding requirements associated with accelerator operations, is not a conventional structure. It is assumed that higher levels of radon and thoron exist in the tunnel than in a conventional structure. The tunnel walls are under soil, and the gas in the soil contains a higher level of radon and thoron than is present in the ambient air above ground. Gas from the soil enters through walls and floors into the tunnel, where penetrations and building materials allow diffusion from the soil into the tunnel's air.

The importance of this potential exposure is reinforced by a study (Oki et al. 1999), which measured radon concentrations in accelerator tunnel air several times higher than the concentration in a nearby building basement (280 Bq/m^3 versus 50 Bq/m^3 for Rn-222). The particle size measured for Po-218 in the study was several times smaller in the tunnel than in the building basement (0.03 µm vs. 0.2 µm), which would increase the comparative lung dose from this radon decay product.

If radon and thoron enter the tunnel air via soil gas penetration, and if fresh air exchange is not adequate, there may be potential for elevated concentrations higher than typical buildings onsite that are above ground. Discussions during SC&A's site expert interviews seem to indicate that the level of fresh air ventilation in accelerator tunnels at SLAC varies and can be low at times.

The TBD mentions radon as a consideration affecting job-specific air sampling, but it does not discuss radon dose assignment for work in the tunnels:

> *Air-sampling results on job activities have resulted in a negligible signal above a contemporary radon background measurement (Gooch 2005). Air samples are taken near but outside the work area prior to work to get radon background results. Air sample results are then compared to these results until the radon has been allowed to decay, after which they are compared to instrument background.* (ORAUT 2007a, pp. 26–27)

According to a site expert, a radon study was completed in the tunnel at SLAC during the late 1980s using track etch detectors provided and analyzed by a vendor laboratory. This is a well-established measurement method. At times in the past, a national certification process was in place for vendors to demonstrate the quality of their analyses.

In summary, radon and thoron gases above typical building background levels may have caused internal doses that need to be accounted for when a claimant worked in the accelerator tunnel or other underground structures with low air ventilation (fresh air exchange) levels. NIOSH should locate the records of radon studies conducted at SLAC and evaluate the validity and applicability of the data to account for occupational radon and thoron exposures in dose reconstruction.

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3.1 SECONDARY FINDINGS

Finding 4: Incomplete Consideration of Internal Exposure Potential from Routine Operations

Section 5.0 of the TBD accepts the analysis from the SLAC internal dosimetry TBD (Kase et al. 1993; Tran 2005), indicating that a conventional internal bioassay program was unnecessary, because workers were unlikely to receive a committed effective dose equivalent (CEDE) of 100 mrem/yr. These determinations were made based on the regulatory requirements for operational internal dosimetry programs. While SLAC's determination is suitable in this context, it is not an appropriate basis for NIOSH to disregard internal dose contributions under the compensation program. The SLAC site profile does not provide a thorough quantitative analysis of organ dose demonstrating that internal dose potential is negligible in the context of the compensation program. SC&A recommends additional consideration of issues affecting internal exposure potential, including the source term, modeling assumptions, contamination surveillance and air sampling data, and the completeness of bioassay records available for dose reconstruction.

Section 5.0, "Occupational Internal Dose," describes NIOSH's rationale for excluding internal dose assignment in dose reconstruction. The TBD states that internal dose was not a routine or typical exposure occurrence at the site (i.e., any significant internal dose would be unusual and likely from a major incident). The only time a dose reconstructor should assign internal doses for a claimant is when internal monitoring is identified in the claimant's file provided by SLAC. According to the TBD (ORAUT 2007a, pg. 27):

> *Based on these considerations, no internal dose should be assigned for all SLAC employees unless an intake is identified in the worker files.*

The TBD mentions as its basis:

- Absence of significant removable radioactivity
- Insignificance of internal dose potential compared to external dose
- Active air-sampling and contamination control programs demonstrating minimal hazard
- Lack of internal dose measurements in claimant files

Published studies from accelerator facilities (nationally and internationally) show some level of concern about internal monitoring and characterizing exposures, from earlier years through the last decade of high-energy accelerator work (Patterson et al. 1969, Patterson and Thomas 1973, Lucci et al. 1973). A CERN study, for example, warns about neglecting potential hazards of internal exposure (Charalambus and Rindi 1967):

> *In spite of the fact that internal contamination has not been found so far in persons and that smear tests or air measurements do not normally show high contamination level, a potential hazard exists in the machine and it is possible to find highly activated machine parts. Consequently, the hazard for internal contamination should be followed up in parallel with the danger from external radiation.*

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While the internal dose may be neglected for regulatory purposes, NIOSH should consider the potential internal dose in the context of the compensation program and organ dose.

The following radionuclides have been associated with activated components of accelerator hardware at SLAC: Na-22, Na-24, Ca-45, Sc-46, V-48, Cr-51, Mn-52, Mn-54, Fe-55, Fe-59, Co-56, Co-57, Co-58, Co-60, Zn-65, and Cu-64 (Busick and Warren 1969, Donahue 1991, SLAC 1994a). Several other radionuclides can be produced in metal components, varying by material composition and the types of reactions likely to occur. The lists of radionuclides in Section 2 of the TBD appear incomplete in comparison to applicable studies and modeling of induced activities at other sites (Patterson and Thomas 1973, Tesch 1991, Oki et al. 1994, Numajiri et al. 1994, Endo et al. 2004, Oishi et al. 2005). Activated cooling water contains tritium; other liquids, such as pump oils, are known to contain tritium as well. Other radioactive materials include Be-7 and C-11 from air activation. Induction of radionuclides in concrete can occur, although this is not specifically addressed in the TBD. Endo et al. (2004) measured H-3 and C-14 in one study. Oishi et al. (2005) detected Na-24, Sc-47, Ca-47, and Mn-54, along with other radionuclides in another study. NIOSH's analysis should include thorough consideration of the source term to support bounding assumptions.

The TBD indicates that an electron accelerator does not generate significant removable radioactivity; most of the activity induced by the accelerator is within the structure of materials exposed to the beam. The principal risk for internal exposure identified in the SLAC site profile is the generation of respirable radioactive aerosols during occasional machining activities, such as sawing, drilling, grinding (used rarely), and welding. The bulk of SLAC's machining experience has been with copper and stainless steel. The TBD cites the following references as demonstrating that the CEDE from machining activated materials would be trivial in comparison to the external exposure received (Busick and Warren 1969, Donahue 1989, and Donahue 1991).

The focus of Busick and Warren (1969) was to establish operational guidelines for machining of activated hardware in machine shops and other environments. The paper mentions personal air sampling use during machining operations "with negative results;" neither Busick and Warren (1969) nor the TBD provides details on this air sampling. The authors go on to say the specific activity in irradiated copper, stainless steel, or aluminum would have to reach proportions that would create external whole-body radiation protection problems before measureable airborne exposure becomes significant. SC&A's site expert interviews indicate that external exposure rates did result in High Radiation Areas in some situations. Busick and Warren caution that their analysis does not consider long-term buildup of radioactive contamination on machines and machine shop areas. SC&A notes that resuspension of loose contamination from buildup of dust and debris may have led to skin, ingestion, and inhalation exposures if precautions were not adequate.

SLAC has used modeling of possible inhalation exposures from the induced radionuclides that could occur in high-energy accelerators (Donahue 1989, 1991), along with some air sampling studies, as a basis to assume radionuclide intakes under routine conditions are insignificant. It should be noted that SLAC's basic position on internal dose from normal operations has continued through current operations, supported by more recent reviews and revisions to SLAC's dosimetry technical documents (e.g., Tran 2005, Sit 2000).

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Section 2.0 of the TBD includes the following statement (ORAUT 2007a, pg. 13), which is also echoed in Section 5.0:

> *Donahue (1989[2], 1991, p. 10) compared the possible internal dose to the external dose for a machining process and showed that the internal dose by this pathway is about 10^{-6} of the external dose (see the next to the last column of Table 2-2). Because the external dose would be received during the setup of the machining process, the relative contribution from internal dose would be much smaller. These ratios depend on the assumed exposure and decay times, material mass being machined, and detailed machining practices; however, the conclusion that internal exposure is trivially small in comparison to the external dose remains true.*
>
> [2] *The 1989 reference contains an error (cm vs m) that results in erroneous concentrations a factor of 10,000 large*r.

As cited in the TBD, Donahue (1991) calculated estimates of the internal radiation exposure relative to the external exposures from machine shop operations during cutting, grinding, and welding operations performed on activated beamline components. Donahue (1989, 1991) concluded internal doses from these activities were such small fractions of the external dose that there was no need to account for the internal dose. However, the Donahue (1989, 1991) modeling of intakes and doses calculated were challenged by a study from Germany (Tesch 1991). The conclusion of the opposing study directly points out their disagreement with SLAC's conclusion (Tesch 1991):

> *Our conclusions do not agree with the work of Donahue* [Donahue (1989, 1991)], *who came to the conclusions that internal dose can be neglected compared with the external dose. The three main reasons for this difference are: The activities for iron given in Table 3 of Reference 3* [Donahue, 1991] *are too low. They produce a dose rate of 0.14 mSv.h*$^{-1}$ *instead of 1 mSvh*$^{-1}$ *at a distance of 30 cm. The ventilation rate of 8.5 m*^{3}*.min*$^{-1}$ *of the test set-up in Reference 2* [Donahue, 1989] *was used, whereas a rate of 1 m*^{3}*.min*$^{-1}$ *appears to us to be more realistic. A detailed discussion of the lung dose equivalent is absent. Furthermore, the nuclide distribution we obtained experimentally deviates from Swanson's theoretical values, especially in the case of copper.*

In their modeling, both Donahue and Tesch determined dose estimates by comparing modeled air concentrations that could have been inhaled to the specific Derived Air Concentration (DAC) regulatory limit for each radionuclide. The DAC limits at that time were based on the old standard default particle size of 1 µm AMAD (Activity Median Aerodynamic Diameter); current health physics practice uses a default assumption of 5 µm AMAD. Table 4 of Donahue (1991) shows various maintenance activities with metal components, such as pipe cutting, sawing, and torch cutting with different tools, could generate a wide range of particle sizes [0.1–10.3 µm Mass Median Aerodynamic Diameter (MMAD), which equates to AMAD assuming uniform radionuclide distribution within the particles]. It should be noted that the data in Table 4 is based on empirical airborne particle size data from another research facility (Newton et al. 1987), which was assumed to be applicable for this modeling. By including a wide range of particle sizes in Table 4, Donahue (1991) appears to accept that some types of machining may have led to possible sub-micron particle size exposures, depending on the specific materials and methods involved. For example, torch cutting and welding can produce very small particle aerosols in more insoluble forms, due to oxidation enhancement by the heat. When creating aerosols of unusually small particle sizes far into the sub-micron (<1 µm) range, deposition in the alveolar or pulmonary region of the lung increases by factors even greater than 2 (ICRP 1994a). Increases in lung doses for insoluble particles produced by extremely hot processes can be expected.

In addition to the Newton et al. (1987) study referenced by Donahue (1991), several studies in international literature have shown the airborne radionuclide particle size distributions at those accelerator locations characterized are different than the default AMAD assumption of 5 µm, which is typically used in absence of site-specific particle size data (Yokoyama et al. 2007, Endo et al. 2001, Kondo et al. 1984, Muramatsu et al. 1988, Oki et al. 1994, Oki et al. 1999).

The TBD discusses doses from induced radionuclides. However, consideration of other studies indicates that NIOSH's estimates may be significantly low. For example, Be-7, S-38 and Na-24 aerosols were determined to have very small particle sizes, with mean radii of approximately 0.03 µm (Kondo et al. 1984, Muramatsu et al. 1988), which could increase lung dose from these airborne contaminants found in accelerator tunnels.

Another issue that complicates accurate modeling of airborne contamination releases from heat cutting of activated metals is the fuming rate of radionuclides. This issue has also been studied closely (Oki et al. 1994). In this study, it is apparent that different radionuclides fume (i.e., vaporize and condense to form airborne particulates) at different rates from the metals. The different rates are apparently related to the thermal properties of the radioactive and matrix elements. The composition of the fumes to which the worker is exposed may not be directly proportional to that of the solid material being handled. Therefore, it appears improper to assume that the radionuclides come out of the heated material at uniform rates in mass and activity ratios that are the same as the material's induced activity concentration (Bq/gram) ratios.

In regard to the relative exposure risk from internal versus external radiation, NIOSH should consider published studies on airborne radionuclide hazards that SC&A has cited here from Japanese high energy accelerators. These studies indicate that the ratio of internal dose to external dose will increase significantly depending on the length of time that elapses between the material's exposure to inducing reactions and the work activities that generate airborne particles (welding, sawing, etc.). Researchers have pointed out that in some situations, for materials that have been allowed to sit unexposed to inducing reactions for periods of time, the external radiation can diminish significantly due to the decay of shorter-lived gamma-emitting radionuclides. The two longest-lived radionuclides induced, Fe-55 and Ni-63, stay at significant levels, but they are not detected proportionally by external dose rate measurements, because they do not emit easily detected penetrating radiations (Oki et al. 1992, Numajiri 1994). Given sufficient time post-irradiation, Fe-55 and Ni-63 could become the dominant radionuclides, increasing the relative significance of these nuclides in the internal exposure and dose potential from machining activities. Assumptions about the relative significance of internal and external dose from activated metals may not be applicable to all relevant situations.

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Carbon-11, which is typically assumed to be only an external dosimetry issue, was studied thoroughly for possible internal dose consequence and in some tunnel work exposure scenarios. It was found to have an internal dose contribution up to 29% of the total dose from C-11 (Endo et al. 2001). Thus, if this scenario occurs, almost one-third of the total dose from the C-11 exposure may not be accounted for by doing external dosimetry alone. Researchers have also gone further with characterizing the airborne radionuclide hazards of induced radioactivity of air (Cl-38, Cl-39, S-38, and Br-82), which may affect internal dose estimates from tunnel work (Yokoyama et al. 2007, Kanda and Yoshioka 2007).

Regarding the full spectrum of possible inhaled radionuclides at accelerators, the assumption that internal dose potential is negligible has not been demonstrated in the context of the compensation program. Additional quantitative analysis is warranted.

Air Sampling and Contamination Control

The DOE Tiger Team came to SLAC in the early 1990s. Among its observations, the Tiger Team identified weaknesses in radiation safety training for staff, documentation of surveys, and radiological records. As a result of this evaluation, major improvements to the radiation protection program were initiated. Rigorous procedures and policies based on Navy procedures were implemented. The documentation became more frequent, structured and formalized. Improvements in the radiological surveillances included a strong emphasis on continuous job coverage during radiological work. SLAC procured more sensitive instrumentation and implemented self-frisking practices.

The DOE Tiger Team inspections identified weaknesses in the air sampling program to the point that the program was not sufficient to demonstrate compliance with DOE Order 5480.11. The report raises the following concern (DOE 1991):

> *The SLAC 5480.11 implementation plan indicates air monitoring requirements do not apply to SLAC. Two samples, taken in 1972, augmented by a tutorial paper serve as a basis for obviating the need for air sampling during cutting operations at the open storage area. This information does not support the conclusion that air monitoring is unnecessary during cutting and welding operations.*

While the air sampling and contamination control programs are active now, the statement above implies that workplace air sampling was not consistently performed throughout the operation of the site. If air sampling was not consistently performed during earlier periods, greater emphasis is placed on effectiveness of any engineering (ventilation) controls, and proper performance of surface and personal contamination monitoring by workers and radiological control staff. Lack of air sampling data complicates the bounding of past potential exposures in the absence of routine bioassay. The TBD presents data for historical airborne and contamination levels from work areas to justify the position that intakes did not occur at SLAC. These data are limited primarily, although not exclusively, to the 1990s and 2000s.

It is likely that the relative hazard at SLAC has changed over time. The site has undergone major improvements in beam control and maintenance, mostly performed from the mid-1970s through the 1980s. Site experts indicated the contamination detected at SLAC came about from past high-energy operations of the LINAC, the Beam Switch Yard (BSY), and the end stations starting in the 1960s and ending in the mid-1970s. As the energy and average power of the accelerator has dropped, reductions in external dose and contamination levels have resulted, lowering the internal exposure potential over time. The TBD should demonstrate that airborne radioactivity and contamination level data are representative of all periods of operations, particularly when accelerator power was at its maximum.

Organ Dose

According to Tesch (1991), Donahue (1991) lacks a detailed discussion of the lung DE and focuses only on the effective dose in assessing the relative contribution of internal dose. The potential committed dose to an individual organ/tissue concentrating the radionuclide (and to nearby organs for penetrating radiations) can be many times higher than the resulting effective dose. Section 5.0 of the TBD acknowledges this (ORAUT 2007a, pg. 26):

> *For the principal isotopes generated at SLAC, (H-3, Na-24, Sc-46, Mn-54, Fe-55, and Co-60) the highest organ dose is 1 to 10 times the effective dose equivalent and most of it is delivered in the first year after the intake.*

The TBD does not provide sufficient information for SC&A to evaluate this statement. The source of this statement is not identified in the TBD, and the relative organ dose from the radionuclides is not specified as a point of comparison to external dose. The statement above emphasizes that organ doses received from potential intakes can exceed effective dose determined in cited dose estimates. Dose reconstructors are concerned with organ doses, which contribute to POC calculations used in determining compensation. Organ dose must be kept in mind when reviewing determinations of the significance of possible internal doses, whether estimated from modeling or any other methods of assessment. Contribution of internal dose relative to external dose, as presented in the Donahue (1989, 1991) studies, is irrelevant for dose reconstruction and compensation decisions. In order to exclude the dose contribution from internal dose, the TBD must demonstrate that internal dose to all organs is negligible.

Lack of Internal Dose Measurements in Claimant Files

The lack of internal dose measurements in claimant files is not sufficient justification for neglecting internal dose, unless there is reasonable confidence that the files provided by the site are complete. Potential sources of internal monitoring data include dosimetry files, medical files, incident reports, and other relevant sources in the historical archive. The SC&A onsite review yielded a series of in-vivo counts unknown to personnel supplying information for claimant files. An additional report on a W-181 personnel contamination incident was identified in a medical file (SLAC 1969).

Given the episodic nature of potential internal exposures, knowledge of radiological incidents becomes imperative. Radiological Control (RadCon) staff interviewed by SC&A indicated there is no incident database. According to some RadCon staff, occurrences such as personal contamination events are documented on survey forms and include laboratory analysis to identify the radionuclide. These records are not likely captured in the dosimetry file.

It would be prudent for NIOSH to confirm the completeness of internal monitoring data provided for claimants before assuming that the absence of data substantiates the absence of internal dose potential.

Summary

The site profile does not provide sufficient justification for neglecting internal dose for routine invasive operations, such as machining of activated components, and from existing area contamination. Theoretical models used to demonstrate minimal potential for internal dose contained questionable assumptions. Donahue (1989) presents a theoretical calculation of internal dose in comparison with external dose. Tesch (1991) challenges Donahue's conclusion that internal dose can be neglected on the basis of assumed ventilation rate, absence of a detailed discussion of lung DE and organ dose consideration, and assumed radionuclide distribution. Oki et al. (1994) also concludes that different radionuclides fume at different rates from the metals, due to the thermal properties of the radioactive and matrix elements. Publications from other accelerators conclude internal doses can be a significant fraction of external dose when using organ dose.

While air sampling and contamination surveys are discussed in the TBD, the data are limited and detailed analyses are not presented. Insufficient data prevent SC&A from fully evaluating NIOSH's conclusions. The TBD makes use of mostly contemporary data, which may not be reflective of periods of maximum accelerator power. The TBD should quantitatively demonstrate these data are bounding for all accelerator power levels, locations, and periods of operation. A thorough analysis would consider changes in engineering and administrative controls, use of personal protective equipment, radiological surveillance policies, and instrument capabilities.

Contribution of internal dose should be considered in the context of the compensation program, rather than an operational health physics program (i.e., allowing no monitoring at 100 mrem per year CEDE), with the TBD quantitatively demonstrating that organ dose is negligible. Furthermore, there is an indication that the absence of internal monitoring records in claimant files is partially an artifact of the availability of these data to SLAC staff. Additional investigation of data completeness is needed before a lack of monitoring records can be interpreted as a lack of internal exposure potential.

Finding 5: Incomplete Claimant Medical Records for Historical Workers

Section 3.0 of the TBD summarizes the methodology used to assign dose from medical x-rays required as a condition of employment. The TBD states (ORAUT 2007a, pg. 20):

> *Medical examinations for most DOE contractors usually involved chest X-rays. Such routine X-rays contribute dose that is included in the Interactive RadioEpidemiological Program (IREP) POC calculations. The SLAC medical*

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department reports that it never gave such routine X-rays. Current medical documents do not identify chest X-rays as part of the examination process (Gherman 2006).

The TBD indicates 20 out of 27 individuals submitting claims contained no medical information. Based on the lack of medical x-rays in the files and statements provided by the SLAC medical department, the TBD concludes the following (ORAUT 2007a, pg. 20):

Based on this information, this analysis concludes that SLAC gave no X-ray examinations that EEOICPA dose calculations need to include.

While the TBD acknowledges x-rays were given to beryllium workers at SLAC, it does not consider assignment of dose for beryllium-related x-rays. This is in contrast to other site profiles, such as Rocky Flats (ORAUT 2007b), where annual x-rays provided to beryllium workers are acknowledged and included in EEOICPA dose calculations. Although a recommendation for semi-annual x-rays for beryllium workers was apparently not implemented at Brookhaven National Laboratory (BNL), the site profile gives no indication that x-rays provided to a claimant for this purpose would be excluded from dose calculations. Rather, the BNL site profile states, "Dose reconstructors should assign dose according to the number of photofluorograhy and 14-in × 17-in posterior-anterior chest x-rays in the claim file records if they are provided" (ORAUT 2010, pg. 48). A review of the reference cited by NIOSH (Pindar 1965) indicates that chest x-rays were provided as early as 1964–1965 for "beryllium work." Because x-rays for "beryllium work" were provided under a different contract than the routine "radiation medical exams" described in Pindar (1965), SC&A is unable to determine the frequency or technique factors of x-rays provided to beryllium workers at SLAC.

Interviews and reviews of medical records during SC&A's site visit revealed two important issues. First, medical records are stored onsite for active employees only. Remaining medical records are maintained at the nearby Federal Records Center (FRC). According to records staff, if the Medical Department is unable to provide an accession number to pull records from the FRC, claimants' medical records are not obtained and provided to NIOSH or the Department of Labor. The Medical Department has accession numbers available to retrieve records only for employees whose employment ended after 1990. While there is an electronic list of recent records sent to the FRC, historical records require a hand search of disposition schedules to obtain accession numbers. For those claimants terminating prior to 1990, medical staff currently does not have accession numbers and is not able to retrieve medical records. As a result, historical medical records are most likely incomplete.

Medical staff interviewed by SC&A stated there was never an x-ray machine onsite at SLAC; x-rays were done offsite if indicated. A limited number of SLAC employees have been screened for beryllium sensitization; a screening chest x-ray was offered to these individuals and performed offsite if the employee consented to the x-ray. These x-rays were mostly performed at Alliance Occupational Health Center or Work Force Medical. As far as Medical can see, only one-time chest x-rays were performed on those who consented (with no follow-up screening).

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As a part of the onsite review, SC&A identified and reviewed a set of historic medical records located at the FRC. While it appears that routine chest x-rays were not received by all employees, SC&A found a subset of employees was sent offsite for chest x-rays. Chest x-ray reports received from an offsite vendor indicated both posterior-anterior and lateral chest x-rays were performed. Most of the x-rays found in the historical medical records were associated with pre-employment assessments. These observations suggest the TBD is incorrect in assuming employment-related x-rays were limited to beryllium workers. In the limited sample of records reviewed, SC&A was unable to identify commonality among the workers who received x-rays as compared to those who did not. Further review of historical medical practices and records is recommended.

SC&A also performed a review of 28 claimant files. SC&A noted one case in which the Energy Employee's medical records listed two chest x-ray exams (1976 and 1980); NIOSH assigned annual x-ray examination doses in the dose reconstruction report for this claimant, which was an over-estimate dose reconstruction. This dose assignment contradicts the conclusion of TBD Section 3: "SLAC gave no x-ray examinations that EEOICPA dose calculations need to include." If situations exist in which assignment of dose is warranted based on information in the claimant medical file, the TBD should provide sufficient guidance to assure consistency of practice among dose reconstructors.

In summary, a more comprehensive onsite review of medical records should be conducted to ascertain whether medical records for all claimants are captured from the historical archives. The TBD should provide more detail regarding x-rays provided to beryllium workers, including a basis for assigning or not assigning occupational medical dose. Historical medical records and/or medical practices should be reviewed to determine other factors for which x-rays may have been indicated for occupational purposes. The TBD should also provide clear direction to dose reconstructors in regard to assignment of dose from x-rays based on information in the claimant medical file. Given that no medical records were provided to NIOSH for 20 of 27 claimants, and significant obstacles to records retrieval have been communicated by site experts, it is not claimant favorable to assume no occupational medical dose without further evaluation.

3.1.1 Finding 6: Incomplete Basis for Environmental External Dose from Neutron Skyshine

SC&A did not have sufficient information to evaluate the annual neutron dose values reported in Table 4-6 of the TBD (ORAUT 2007a, pp. 25–26), particularly for years when the TBD indicates that environmental neutron monitoring data are not available or are not useful. The site profile does not provide adequate detail to support technical review of the calculated or extrapolated dose estimates.

NIOSH assumes that the only measurable neutron dose to unmonitored workers was from neutrons resulting from skyshine. This is a reasonable assumption for an electron accelerator with controlled access, such as SLAC. NIOSH used the data from environmental Perimeter Monitoring Station (PMS) neutron detectors to estimate annual environmental neutron doses to personnel. These are Boron Trifluoride (BF_3) detectors surrounded by a moderator with a cadmium cover and are calibrated to read out in mrem of neutron dose.

Some neutron PMS data are listed in the TBD [see Table 4-3 (1972–1979) and Table 4-4 (1980–1989)]. NIOSH applied corrections to generate estimates of environmental neutron doses from the PMS measurements. Despite some confusion in the wording of Section 4.3.3 ("Two corrections" in the first sentence vs. "three corrections" in the last sentence), SC&A is fairly confident that NIOSH utilized the following corrections:

- A CF of 1.51 +/- 0.53 compensates for the difference in neutron energy spectra used for calibration compared to skyshine neutrons. The derivation of this factor is discussed on page 59 of the TBD (Attachment A).
- Equation 4-1 (TBD page 25) compensates for the different distances that the PMS detectors and buildings were located from the source of the skyshine neutrons.
- A correction is made for annual work hours (occupational exposure time) as compared to the continuous exposure of the detector: 2,000 hrs/8,766 hrs = 0.228.

NIOSH used the above data and CFs to generate a "Neutron skyshine annual dose" for each year at various buildings onsite. These values are listed in Table 4-6 of the TBD and are used by the dose reconstructor to assign neutron dose to unmonitored workers. SC&A did not have access to details such as the distances, measured doses, and calculations used by NIOSH to derive the net neutron dose from the "PMS detector accelerator neutrons" and "Neutron background" data provided in Tables 4-3 and 4-4. Without this information, SC&A could not replicate and/or verify the annual doses listed in Table 4-6.

According to the text on pages 22–25 of the TBD (ORAUT 2007a), the only useful PMS environmental data available were for 1972–1979 (as shown in Table 4-3) and 1980–1989 (as shown in Table 4-4). However, Table 4-6 lists annual doses for every year from 1966–2005. According to the TBD, "Estimates for the early years were generated by extrapolation from the 1972 values. Estimates for later years when TLDs were used were based on the latest years of monitor operation" (ORAUT 2007a, pg. 25). The values in Table 4-6 for 1966–1971 do not match those for 1972, and the values for 1990–2005 do not match those for 1989. Since the site profile states that data from these years are not available or are not useful for various reasons, it should demonstrate how the maximum dose values for these years were generated. If the data from some other years were used and/or dosimeter lower limits of detection (LLD) values were used, the approach should be described. Additionally, Table 4-6 should clarify if the "annual dose" values represent 8,766 hours per year or 2,000 hours per year exposure.

SLAC's semi-annual radiation reports to the Atomic Energy Commission (AEC) would be an appropriate source of data for validating the maximum dose values listed in Table 4-6. The PMS was set up and running at least as early as 1965. Each current PMS system includes a pair of BF_3 detectors and Geiger-Mueller (GM) detectors to measure skyshine neutrons and photons, respectively. The neutron and gamma dose data were collected and recorded in the same manner as that from 1972–1979. These data were reported to the AEC in semi-annual radiation reports. Recovery and review of these data would serve to validate maximum dose values listed in Table 4-6.

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3.1.2 Finding 7: Back Extrapolation of Occupational Environmental Photon Doses

SC&A did not have sufficient information to evaluate the data and methodology used by NIOSH to estimate annual dose from ambient environmental photons. Applying relatively recent environmental photon dose data to the 1966–1994 time period does not appear to be technically sound, especially since the accelerator operated at its highest power in the early 1970s. When applying contemporary data to earlier periods, NIOSH should demonstrate technical equivalency or account for differences in operational parameters, monitoring locations, and monitoring results.

According to Section 4.3 of the TBD, a program was in place from the start of accelerator operations using eight PMSs to measure ambient gamma and neutron fields near the site boundaries. The monitoring stations originally used GM counters for photon detection and BF_3 detectors for neutrons. The TBD indicates that the gamma monitor readings were the same regardless of whether the accelerator was on or off, presumably throughout the period when GM counters were used. After 1990, the ambient photon radiation levels were measured with high-sensitivity TLDs. Table 5 lists the environmental photon detection methods and data availability for the years of operation, as gleaned from TBD Section 4.3.2 and related data tables (ORAUT 2007a, pp. 22–25).

Table 5. Environmental Photon Monitoring and Data

Time Period	Detector Type	Data Status
1966–1970	GM	Not found
1971	GM	Combined gamma and neutron data are not useful for dose reconstruction.
1972–1979	GM	Photon data are not reported in TBD – characterized as indistinguishable from natural background.
1980–1990	GM	PMS locations changed in 1980 (text, page 23) or 1983 (Figure 4-1 caption). Photon data are not reported in TBD. Several PMSs were out of service each year from 1983–1990 (Table 4-4). Apparently, all stations were out of service in 1988 (Table 4-4) and from 1990 to the third quarter of 1991 (text, page 23).
1991–1992	TLD	TLD program was initiated near end of 3rd quarter 1991. All neutron & gamma results were <1 mrem both years.
1993–2001	TLD	Net annual TLD photon doses for 7 PMS stations are reported in TBD Table 4-5.
2002	TLD	Results were compromised by inadequate attention to storage times.
2003–2004	TLD	Results "were not reported." TBD does not explain why.

NIOSH used TLD measurements obtained from 1995–2001 at the PMS with the highest 7-year total dose to calculate an average environmental photon dose. This environmental dose is assigned only to unmonitored workers. The approach is described in the TBD (ORAUT 2007a):

Page 23:

> *The largest total dose for the 7 yr from 1995 to 2001 was 82.5 mrem at PMS6. This location is near LINAC Sector 20 (radiation from klystrons) far away from the site buildings. Dose reconstructors should assign a 3-mrem/yr photon dose*

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based on the exposure for 2,000 (40 hr/wk for 50 weeks) of 8,766 hours that the TLDs were exposed (82.5 ÷ 7 × 2,000 ÷ 8,766).

Page 25:

Assignment of an annual photon dose of 3 mrem as discussed above in Table 4.5 [4-5] *is recommended. This value should be assumed to encompass the critical uncertainty range. Dose reconstructors should not add these doses if the energy employee was monitored.*

SC&A has several concerns regarding the use of contemporary data for back extrapolation. The dose value of 3 mrem/year for environmental photons is based on data from 1995–2001, when the accelerator was not operating at the same power as it had in previous years. During SC&A's site interviews, several current and retired staff members indicated that accelerator beam power has decreased consistently and significantly over the period from the early 1970s to the 1990s due to improvement in beam maintenance, engineering, and control. These changes have lowered the external radiation levels, particularly adjacent to the operating area, as a result of the direct correlation between accelerator power and ambient radiation levels.

Other factors affecting technical equivalency are difficult to evaluate. The TBD does not provide PMS GM counter data and does not discuss detection levels or adjustment factors used to derive photon dose from GM counters. This makes it difficult to ascertain the equivalency of dose values obtained prior to and after the implementation of TLDs. The TBD mentions one change in PMS locations; it seems to imply that PMS locations were otherwise stable over time, but this is not directly stated. The document is not internally consistent regarding when the PMS locations were changed (1980 or 1983). While the TBD mentions the use of area monitors around the research yard, these results are not taken into consideration when bounding the photon dose potentially received by unmonitored workers. These readings may be more representative of dose received by onsite workers in some cases.

It is not clear why the PMS results from 1993 and 1994 were excluded from the dose estimate calculation, but this decision has no significant impact on the dose estimate. Performing the calculation using all available photon dose data from Table 4-5 (1993–2001 instead of 1995–2001) produced essentially the same results for average annual photon dose at the site boundary.

In summary, the TBD fails to demonstrate that 3 mrem/year is an appropriate estimate of environmental photon dose for unmonitored workers at SLAC as a function of location and time. There is insufficient evidence to demonstrate technical equivalency in operational parameters, monitoring station location, and monitoring results over time. Changes in accelerator power and detection limits, in particular, bring into question the use of back extrapolation to assign ambient environmental photon doses.

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3.1.3 Finding 8: Unsupported Assumptions for Calculation of Environmental Internal Dose from Onsite Releases to Air

Section 4.2.1 of the TBD concludes that environmental internal doses from onsite releases to air are negligible, but the discussion and data provided in the TBD to support this assessment is limited. NIOSH obtained estimates of air activity releases from SLAC annual environmental reports; these estimates were calculated based on beam power, the air distance traversed, and access made to the beam areas (ORAUT 2007a, Page 21).

The bases supporting the decision to exclude ambient internal dose from dose reconstruction are incomplete and inadequately supported. The quantitative discussion is limited to Cl-38 and Cl-39. The calculated dose is estimated from calculated chlorine emissions in 1993, which does not represent the period of maximum beam power at SLAC.

Table 4-1 of the TBD shows a history of reported total activity released by year (primarily Ar-41). Table 4-1 is based on measured values, in contrast to Table 4-2, which is based on calculated values. Table 4-1 indicates the highest measured environmental releases occurred in 1972 and 1975, and releases diminished significantly after 1975. This information is consistent with the time period of peak operating power levels at SLAC as described by site experts. The data confirm that emissions in the earlier years are much greater than in more recent years.

According to site expert interviews, the current environmental monitoring utilizes confirmatory measurements with the Air Monitoring Systems (AMSs). Air is pumped from the vent in an accelerator housing into a pressurized and low-background tank where a GM detector is used to measure the short-lived airborne radionuclides produced inside the housing (Attachment 2). McCall and Jenkins (1966) identify N-13, O-15, H-3, C-11, Ar- 41, Be-7, Cl-38, and Cl-39 as radioactive air emissions, in decreasing order of saturation activity. A 2-hour waiting period allows for decay of short-lived radionuclides. Beryllium-7 and other radionuclides typically assumed to only be in a gaseous state have been found to exist in particulate forms in accelerators (Endo et al. 1995, Endo et al. 2001, Muramatsu et al. 1988). Radioactive effluents include H-3, C-11, N-13, and Ar-41. Assuming NIOSH is taking this position, the TBD should state no particulate emission occurred and discuss the rationale for this assumption, such as HEPA filtration of all applicable exhaust or other methods used to prevent release of particulates to the environment. Dose calculations within later environmental reports principally base the ambient internal dose calculations on N-13, O-15, C-11 and Ar-41. The only radionuclides NIOSH considers as contributors to occupational environmental internal dose are Cl-38 and Cl-39. The rationale for exclusively selecting Cl-38 and Cl-39 is unclear. Further quantitative justification demonstrating that other air emissions contribute negligible dose should be included in the site profile.

Dose coefficients for radionuclides released to the environment and potentially giving environmental internal dose were based on an assumed 5 µm AMAD and Type M absorption class. Per the ICRP guidance (ICRP 1995, ICRP 1996), the default particle size for estimating environmental exposures is 1 µm AMAD. Although Energy Employees covered under the EEOICPA are occupational workers and not members of the public, the modeling for environmental scenarios is applicable for environmental dose, rather than normal occupational exposure scenarios. In other words, the individuals are like members of the public who are closer to the release point, and the airborne contamination they may be exposed to likely has properties similar to public exposure scenarios.

The calculated environment airborne release quantity in 1993 for chlorine (Cl-38 and Cl-39) is 0.36 Ci. Using a dispersion factor of 4.5×10^{-4} s/m^3, NIOSH calculated an airways dose of about 0.053 mrem/year for an individual located at the site boundary. Although the TBD recognizes that "site buildings are somewhat closer resulting in slightly larger doses," it does not attempt to quantitatively adjust the boundary dose (i.e., member of the public) to a dose representative of workers within the site boundary. The TBD should attempt to estimate the actual dose to the highest exposure locations onsite, to determine the potential impact of distance ratios and short distance site-specific dispersion modeling (building wake effects, etc.).

The total calculated chlorine release for 1993 is assumed for all years, but no rationale or defense is provided in the TBD. NIOSH may have selected 1993 as the year of highest estimated release activity to maximize estimates of particulate radionuclide dose contribution, but the TBD does not state this rationale or provide data to demonstrate it. The assumed release activity for chlorine appears to come from the addition of Cl-38 and Cl-39 from Table 4-2, "Airborne Release Quantities (Ci)," which are based on calculated values. Table 4-1, "Reported Total Activity (Ci) Released by Year, Primarily ^{41}Ar," indicates the highest measured environmental releases occurred in 1972 and 1975, which corresponds to the time period of peak operating power levels mentioned by site experts. The relative contributions of other airborne emissions would similarly increase with power levels. The TBD should demonstrate that the combined airborne release quantity of Cl-38 and Cl-39 would bound the total release quantities for years of peak power.

In summary, NIOSH should quantitatively demonstrate that annual environmental internal doses total less than 1 mrem based on clearly defined and justified assumptions. The completeness of the source term, the particle size, and quantitative adjustments for onsite versus boundary dose should be taken into consideration. The TBD does not adequately validate the assumption that Cl-38 and Cl-39 emission data from 1993 are representative or bounding for all years of operation and periods of maximum accelerator power.

Finding 9: Lack of Adequate and Accurate Dose Records Prior to 1974

SC&A's review of 28 claimant files indicates that most workers' exposures to photon and neutron radiation were generally not excessive and were fairly low in magnitude compared to most DOE facilities. This would be expected for an electron accelerator. However, neutrons were a measurable part of the total external dose. From 1974 to present, workers' dose records include badge cycle results that distinguish between photon deep dose and neutron dose. Prior to 1974, claimant files contain annual summaries of external monitoring results that are not broken into dose components (i.e., photon and neutron). SC&A questions the validity of the assumptions used by NIOSH to estimate neutron and photon dose components. NIOSH has not validated that these assumptions are claimant favorable based upon available data. They failed to capture the methodology in the TBD.

From the 28 claimant files reviewed by SC&A, it appears that the DOE files provided to NIOSH for dose reconstruction purposes contain detailed dose data for 1974 to present. However, detailed dose data are rarely provided to NIOSH for employment periods from the beginning of SLAC operations through 1973. This observation appears to reflect a transition to an electronic database for dosimetry data in 1974. Claimant files for earlier employment periods typically include a letter from SLAC's Environmental Safety and Health (ES&H) Division containing a statement similar to the following:

> *Please note that the reported lifetime dose before 1974 (about* [xxx] *mrem) were obtained from the archived records of the personal dose reports. Dose records after 1974 are currently maintained electronically in our Occupational Dose Tracking System (ODTS) computer data base.*

In almost all cases reviewed, the DOE files do not include details of the dose or copies of original forms. It does not appear that pre-1974 badge cycle dosimetry data have been provided to NIOSH for any of the claims analyzed to date. In some cases, as in the following example, a summary table is provided in the claimant file:

Table 6. Lifetime Dose Summary for [EE]

(From archived paper records)

Year	CEDE [mrem]
1966	45
1967	0
1968	0
1969	84
1970	0
1971	660
1972	33
1973	0
Total:	**822**

Occasionally, a handwritten note (see Figure 4 below) is found in the margin of the DOE file listing the years and associated doses.

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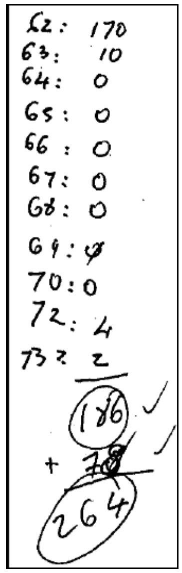

Figure 4. Handwritten Note of Early Doses

SC&A reviewed some of the dose reconstruction reports for these claims and found that NIOSH divides the pre-1974 doses into half photon and half neutron exposures when assigning doses. NIOSH also assigns missed dose, based on the LLD of the dosimetry system, for each potential exchange cycle from the start of employment through 1973. No data validation is discussed in the TBD to support the practice of estimating half photon and half neutron dose for doses recorded prior to 1974. If the dose record is correct and complete, this approach may result in an overestimate of dose, most likely an extreme overestimate for non-radiation workers, such as administrative personnel. However, it could result in an underestimate of dose for radiation workers if the summarized data tables or notes are not based on verified dose records. Additionally, it is questionable if the present method used by NIOSH would be considered plausible and reasonably accurate.

SC&A interviews with SLAC dosimetry personnel indicate that external dosimetry data from 1961 through 1973 are available as printouts from Radiation Detection Company (RDC) by cycle. SC&A located copies of RDC dosimetry reports during the site visit and found that they include penetrating x-ray, gamma, and neutron dose. While many of these dosimetry reports are available on the SRDB, the results have not been linked to claimant files. There is no indication in the SLAC TBD that dose data received in summary tables or handwritten notes are verified against these original dosimetry reports. Since data for photon and neutron dose are available in dosimetry logs for exposures prior to 1974, these data could be used for dose reconstruction, eliminating the need for estimates and assumptions about the dose component fractions. At a minimum, the available RDC reports should be used to validate that NIOSH's assumptions about dose components are claimant favorable; the methodology and validation should be documented in the TBD.

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4.0 OVERALL ADEQUACY OF THE SITE PROFILE AS A BASIS FOR DOSE RECONSTRUCTION

The SC&A procedures call for both a "vertical" assessment of a site profile, for evaluating specific issues of adequacy and completeness, and a "horizontal" assessment, considering how effectively the profile satisfies its intended purpose and scope. This section addresses the latter objective in a summary manner by assessing:

(1) How, and to what extent, does the site profile satisfy the five objectives defined by the Advisory Board?

(2) How usable is the site profile as a generalized technical resource for the dose reconstructor when individual dose records are unavailable?

(3) Have generic technical or policy issues been identified that transcend any single site profile and need to be addressed by the Advisory Board and NIOSH?

4.1 OBJECTIVE 1: COMPLETENESS OF DATA SOURCES

The TBD discusses the site, activities occurring at the site, and the characteristics of radiation exposure. The primary focus is on accelerator operation, with some consideration given to invasive work with beamline/components. The TBD fails to discuss and consider potential exposure from special projects conducted at SLAC.

Consideration of the radionuclides that may be found in sufficient quantities to impact internal dose potential is incomplete. The TBD may not be considering the full spectrum of induced radionuclides, including those discovered at other accelerators that should be used in modeling and estimating potential internal doses at SLAC. Further research should be conducted to characterize significant source terms and to evaluate the relative potential for internal exposure. The outcome of this analysis should be included in the TBD to inform the dose reconstructors.

Radon and thoron (Rn-220) gases above typical building background levels may have caused internal doses that need to be accounted for when a claimant worked in the accelerator tunnel or other underground structures with low air ventilation (fresh air exchange) levels. No consideration is given to this potential source of internal dose in the SLAC site profile. According to a site expert, a radon study was completed in the tunnel at SLAC during the late 1980s, using track etch detectors provided and analyzed by a vendor laboratory. NIOSH should obtain the record of results and evaluate the validity and applicability of the data for assignment of occupational internal dose.

A review of internal monitoring data sources should be conducted to ascertain whether complete records for all claimants are captured from dosimetry files, medical files, and other relevant sources, including historical archives. The SC&A onsite review yielded a series of in-vivo counts unknown to personnel who retrieve information for claimant files. The TBD should also identify incidents and significant unexpected contamination events, such as the W-181 personnel contamination incident identified in a medical file (SLAC 1969). This analysis should consider the field and personnel monitoring practices of the time, including documentation of incidents in field monitoring records, rather than personal dosimetry files.

Although it was determined during interviews that SLAC has performed a significant amount of occupational radiological air sampling during higher exposure risk situations, these data were not shown or discussed adequately in the site profile. Further discussion of air concentrations detected in worker breathing zones and general work areas should be included in the site profile to validate the assumption there was no missed internal dose.

SC&A interviews with SLAC dosimetry personnel indicate that external dosimetry data from 1961 through 1973 are available as printouts from RDC by cycle; however, claimant files typically contain summary doses without copies of original RDC monitoring data. SC&A located a copy of all RDC dosimetry reports during the site visit. Furthermore, many of these logs are available on the SRDB; however, the data are not linked to individual claimant files. The RDC data provides sufficient detail to differentiate between photon and neutron dose, whereas summary data requires assumptions be made.

A more comprehensive onsite review of medical records should be conducted to ascertain whether medical records for all claimants are captured from the historical archives. Indication from site expert interviews is that medical records are not pursued for individuals terminating prior to 1990. The TBD should include a provision for assigning dose from x-rays based on information in the claimant medical file, as opposed to assignment of no occupational medical dose (as mentioned in the TBD), or assignment of annual occupational medical dose (as observed in a dose reconstruction report). A review of the reference cited by NIOSH (Pindar 1965) indicates that chest x-rays were provided as early as 1964–1965 for "beryllium work." The contract number under which x-rays were provided for beryllium workers is noted in Pindar (1965). This contract may provide additional information regarding the frequency and/or technique factors of x-rays provided to beryllium workers at SLAC. It seems likely that contracts and invoices from offsite medical providers, similar to Pindar (1965), can be located for other time periods, shedding light on the uncharacterized subset of workers who received occupationally related x-rays at SLAC.

Site boundary PMSs measure potential real-time external dose, which includes skyshine or direct radiation doses that the public may receive. These systems were set up and running at least as early as 1965. Each current PMS system includes a pair of BF_3 detectors and GM detectors to measure skyshine neutrons and photons, respectively. The neutron and gamma dose data were collected and recorded in the same manner as that from 1972–1979. These data were reported to the AEC in semi-annual radiation reports. Recovery and review of these data would serve to validate maximum dose values listed in Table 4-6. Site experts have confirmed that environmental monitoring reports were prepared prior to 1971.

The solicitation and consideration of input from site experts and other workers is important to ensuring the adequacy and completeness of the site profile and the subsequent dose reconstruction. NIOSH appears to have neglected or underutilized this invaluable resource. No worker outreach meetings were conducted during the development of the SLAC site profile. In addition, SC&A's search of the SRDB did not produce any documentation of NIOSH site expert

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interviews for SLAC. An e-mail correspondence with site radiological control staff is the only source of worker input identified in the SRDB. Information obtained during SC&A site expert interviews indicates that NIOSH may have conducted limited site expert interviews with radiological control personnel at SLAC, but documentation of these interviews is not available on the SRDB. SC&A interviews also indicate that radiological control personnel were afforded the opportunity to review the site profile, but no documentation was found to support this information. Because worker outreach meetings and site expert interviews provide valuable opportunities for NIOSH to obtain information and insights into site operations and safety programs, this omission represents a weakness in the completeness of data sources.

4.2 OBJECTIVE 2: TECHNICAL ACCURACY

Table 2-5 of the TBD (ORAUT 2007a, pg. 15) shows that the contact dose can be orders of magnitude greater than the dose at 30 cm for most components tested. Therefore, the dose to extremities, lower sections of the body, and areas of the head (if leaning over components) could be significantly greater than the recorded dose from a monitor worn on the chest area. This issue is also applicable to the calibration facilities. However, the TBD does not discuss dosimetry geometry factors, and there is no indication that extremity monitoring was needed or performed at SLAC.

Additionally, before approximately 1996, there does not appear to have been significant monitoring and/or calibration for beta or low-energy gamma exposures (see Table 6-2, pg. 31, for a summary of recorded dose practices). As indicated in the TBD, there was no apparent calibration of dosimetry for low-energy photon exposures before DOELAP accreditation in the mid-1990s (ORAUT 2007a, pg. 30). This is an area that needs further investigation and should be addressed in the TBD for SLAC.

Despite a large volume of information and analysis presented in the TBD on the topic of neutron dosimetry, the CFs that are actually used to adjust recorded neutron dose are not adequately supported. Several components of the recommended CFs are based on simple averages of upper and lower values that may not represent the radiation fields to which workers were exposed. The 1997 neutron spectral measurements are based on limited parameters, and the TBD fails to demonstrate that these measurements are representative of the moderated neutron fields at various locations and time periods at SLAC, especially as beam power changed over time. Dose fraction values in Table 6-5 could not be verified without additional information on NIOSH's use of NCRP 38 (NCRP 1971). Similarly, the reference to ICRU Report 63 (1999, Figure 7.19) was not sufficiently detailed to support an assumption that 30%–40% of the DE from high-energy neutrons were not detected by NTA film or CR-39 TLDs. Several other assumptions and CFs appear in the TBD without sufficient explanations or supporting data. Without sufficient support for NIOSH's "Total Impact" CFs, SC&A cannot conclude that neutron dose reconstruction adequately reflects or bounds the doses received by workers.

Section 4.2.1 of the TBD concludes that environmental internal doses from onsite releases to air are negligible, but the discussion and data provided in the TBD to support this assessment are limited. The TBD states that the only radionuclides contributing to occupational environmental internal dose are Cl-38 and Cl-39. It assumes that calculated estimates of chlorine releases from

1993 are representative of bounding doses for all years of operation at SLAC. This assumption is questionable, because both prompt and residual radiation fields have declined significantly from periods of maximum power in the early 1970s. The estimate of dose to workers also uses an inappropriate particle size, assuming 5 µm AMAD for worker exposure rather than 1 µm used in the calculation of environmental exposures. The TBD acknowledges that site buildings are closer to the releases than the site boundary, but it does not attempt to estimate the actual dose to the highest exposure locations onsite. The assumptions used in the calculation of onsite internal dose from airborne releases should be further validated. The completeness of the source term, the particle size, and lack of quantitative adjustment for onsite versus boundary dose should be addressed.

According to the text on pages 22–25 of the TBD, the only useful PMS environmental data available were for 1972–1979 (as shown in Table 4-3) and 1980–1989 (as shown in Table 4-4). Data were not available for 1966–1971; data from 1991–2005 were monitored with TLDs, which precluded differentiation between accelerator-produced radiation and background. However, Table 4-6 lists data for every year from 1966–2005. The TBD on page 25 states, "Estimates for the early years were generated by extrapolation from the 1972 values. Estimates for the later years when TLDs were used were based on the latest years of monitor operation." The TBD should demonstrate how the maximum dose values were calculated for years when useful environmental data were not available. Additionally, it is not stated if the values in Table 4-6 assume 8,766 hours per year or 2,000 hours per year exposure.

4.3 OBJECTIVE 3: ADEQUACY OF DATA

During the site interviews, several current and retired staff reported accelerator beam power has decreased consistently since the peak period in early 1970s, due to improvement in beam maintenance and modifications. As a result, external radiation levels have decreased. Applying relatively recent (1995–2001) environmental photon dose data to the 1966–1994 time period, especially when the accelerator was operating at peak power in the early 1970s, is not a technically sound method to use for dose reconstruction.

SC&A questions the basis and appropriateness of data supporting the decision to neglect internal dose in the absence of internal monitoring data. The basis for assignment of no internal dose includes the absence of internal monitoring data in claimant files, the ratio of the internal dose to the external dose, the analysis of contamination survey and air monitoring data, dose estimates based on exposure to activated water, and on exposure caused by torching of activated materials. Donahue (1991), Busick and Warren (1969), and the SLAC internal dosimetry TBD (Kase et al. 1993; Tran 2005) are cited in support of NIOSH's conclusion that no internal dose should be assigned. Tesch (1991) challenges Donahue's (Donahue 1989) conclusion that internal dose can be neglected when compared with external dose on the basis of radionuclide dose rate produced, ventilation rate assumed, and absence of organ dose consideration. Publications from other accelerator facilities conclude that internal doses can be at significant fractions of the external doses to the worker, especially when looking at the organ dose (e.g., lungs).

Studies reviewed by SC&A provide valuable information on particle size during typical maintenance activities at accelerator facilities. Several studies have shown the airborne

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radionuclide particle size distributions at those accelerator locations characterized are different than the default AMAD assumption of 5 µm typically used in the absence of site-specific particle size data (Yokoyama et al. 2007, Endo et al. 2001, Kondo et al. 1984, Muramatsu et al. 1988, Oki et al. 1994, Oki et al. 1999). Table 4 of Donahue (1991) shows that particle sizes could have a wide range (0.1–10.3 µm MMAD, which equates to AMAD assuming uniform radionuclide distribution within the particles) in performing various maintenance work on metal components such as pipe cutting, and sawing and torch cutting with different tools. It should be noted that the data in Table 4 are based on empirical airborne particle size data from another research facility (Newton et al. 1987), which was assumed to be applicable for this modeling.

A quantitative analysis demonstrating insignificant internal organ dose should be included in subsequent revisions of the TBD. NIOSH should review particle size studies from other accelerator sites to determine the appropriateness of using the default 5 µm AMAD particle size for internal dose calculations and for calculations justifying the decision that internal dose does not need to be considered. Furthermore, a validation should be completed to demonstrate that the mostly contemporary air sampling data used to justify the assignment of no internal dose are bounding. This validation should consider changes in accelerator power levels, and thus potential internal exposure, through time.

The dose reconstruction method of assigning half photon and half neutron dose for doses recorded prior to 1974, and assigning missed photon and neutron doses for each badge exchange cycle prior to 1974, results in an overestimate in some cases; most likely an extreme over-estimate for non-radiation workers, such as administration personnel, if the dose of record is correct. However, it could result in an underestimate of dose for radiation workers if the data provided in the summary statement (or tables or notes) are not based on verified dose records. Additionally, it is questionable if the present method used by NIOSH would be considered plausible and reasonably accurate. While dosimetry logs including penetrating x and gamma and neutron dose are available, no data validation supporting assigning half photon and half neutron dose for records doses prior to 1974 was presented in the TBD.

4.4 OBJECTIVE 4: CONSISTENCY AMONG SITE PROFILES AND OTHER NIOSH DOCUMENTS

SC&A has conducted reviews of methodologies applied for accelerator facilities at Argonne National Laboratory-East (ANL-E), Brookhaven National Laboratory (BNL), Lawrence Berkeley National Laboratory (LBNL), and Los Alamos National Laboratory (LANL), which are similar to that at SLAC. Site profiles from SLAC, ANL-E, BNL, LBNL, and LANL focus much of the analysis on occupational and environmental external dose. SLAC is unique from other DOE facilities reviewed to date in that its mission was focused exclusively on high-energy physics research, with no mission to produce radioactive material. The SLAC site profile speaks directly to dose associated with high-energy accelerator operations, as opposed to potential dose from target material. The activation products listed in the SLAC site profile are similar to those listed in other site profiles; however, consideration of these radionuclides in contribution to occupational and environmental internal dose is not always consistent. One possible reason for this is the availability of in-vivo and in-vitro bioassay at ANL-E, BNL, LBNL and LANL for a limited number of these radionuclides.

The SLAC site profile gives no consideration to the assignment of internal dose from enhanced radon and thoron in the accelerator tunnel. The lack of consideration of dose from enhanced radon and thoron levels is inconsistent with other site profiles where underground concrete structures exist. An underground accelerator tunnel is assumed to have higher levels of radon and thoron concentrations than exist in conventional structures. If radon and thoron enter the tunnel air via soil gas penetration, and if fresh air exchange is not adequate, there may be potential for elevated concentrations higher than typical buildings onsite that are above ground. This general assumption is supported by a study conducted by Oki et al. (1999), which showed radon concentrations measured in accelerator tunnel air were several times higher than in a nearby building basement (280 Bq/m^3 versus 50 Bq/m^3 for Rn-222). Discussions during SC&A's site expert interviews seem to indicate that the level of fresh air ventilation in accelerator tunnels at SLAC varies and can be low at times. According to a site expert, a radon study was completed in the tunnel during the late 1980s, using track etch detectors provided and analyzed by a vendor laboratory. The TBD does not discuss any radon/thoron monitoring information for the site, nor does it consider internal dose from exposure to enhanced radon and thoron levels in the tunnel.

One noted discrepancy between site profiles for facilities with accelerators is the selection of photon radiation energy and percentages for use in dose reconstruction. In the case of ANL-E and LBNL, all types of accelerators are grouped into a single category with an assumed photon distribution of 90% >250 keV photons and 10% 30–250 keV photons. These photon distributions are assigned for the high-energy physics area at SLAC, with different assumptions applied to the SSRL. The SLAC site profile recommends the dose reconstruction assume 100% 30–250 keV photons for the SSRL, which is identical to that recommended for the National Synchrotron Light Source at BNL. The optimal method for presenting beta, photon, and neutron energies and percentages is by using available characterization data. In the absence of this, the method applied in the SLAC site profile, distinguishing between different accelerators and supporting facilities, is preferable to grouping all accelerator types.

Some confusion exists in regard to assignment of Occupational Medical Dose. Section 3.0 of the site profile concludes that SLAC gave no x-ray examinations that EEOICPA dose calculations need to include (ORAUT 2007a, pg. 20). However, SC&A notes that some employees have been sent offsite for x-rays, including, but not necessarily limited to, pre-employment assessment and beryllium sensitivity screening. While the TBD acknowledges x-rays were given to beryllium workers at SLAC, it does not consider assignment of dose for beryllium and pre-employment x-rays. This is in contrast to other site profiles, such as Rocky Flats (ORAUT 2007b), where annual x-rays provided to beryllium and other workers are acknowledged and included in EEOICPA dose calculations.

SC&A also notes one case in which a claimant was assigned annual dose for x-rays associated with employment at SLAC, which appears to contradict instruction provided in the site profile. The dose reconstructor is directed to assign dose according to the number of x-rays reported in the claimant files in the absence of default occupational medical dose assumptions.

4.5 OBJECTIVE 5: REGULATORY COMPLIANCE AND QUALITY ASSURANCE

SC&A reviewed the site profile with respect to Objective 5, which requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in 42 CFR 82. In addition, SC&A evaluated the site profile for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions.

The SLAC site profile was developed and revised in the absence of the worker outreach efforts. *Conduct of the Worker Outreach Program*, ORAUT-PROC-0097 (ORAUT 2005b), which was in place at the time of the site profile development, specified worker outreach activities be performed during the development of site profiles. No technical issues were found in this regard that required attention, but SC&A has previously raised concerns regarding compliance with the requirements of ORAUT-PROC-0097. The solicitation and consideration of input from site experts and other workers is important to ensuring the adequacy and completeness of the site profile and the subsequent dose reconstruction.

Since ORAUT-PROC-0097 has been replaced by OCAS-PROC-012, *Worker Outreach Program* (OCAS 2009), there is no longer a procedural requirement for NIOSH to conduct worker outreach in conjunction with site profile development. However, the objectives of worker outreach remain (OCAS 2009, pg. 2):

> *This program provides current and former Department of Energy (DOE) and Atomic Weapons Employer (AWE) employees with the opportunity to obtain information about the Special Exposure Cohort (SEC) program and site profiles and to provide information for consideration and possible use in dose reconstructions, site profiles, and SEC petition evaluations.*

During SC&A interviews, it was evident that individuals at SLAC were not familiar with the EEOICPA program. By failing to conduct worker outreach meetings, NIOSH denied current and former workers the opportunity to receive information about EEOICPA, and to provide input to the site profile and the dose reconstruction process. SLAC workers also had minimal opportunity to contribute to site profile development through site expert interviews. Additional interviews and/or worker outreach activities, in accordance with OCAS-PR-012, *Worker Outreach Program* (OCAS 2009), should be considered in subsequent revisions of the site profile. Worker outreach efforts would benefit the site profile and may also improve awareness of EEOICPA at this facility.

4.6 INCONSISTENCIES AND EDITORIAL ERRORS IN THE SITE PROFILE

Inconsistencies and editorial errors were identified in the site profile and are detailed below.

- Pages 7 and 12: The acronym, SSRL, is defined as Stanford Synchrotron Radiation Laboratory. Site experts and the SLAC website indicate the last term in this facility's acronym is "Lightsource" rather than "Laboratory."

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- Pages 15 and 16, Table 2-5: The headings of the third and fourth columns should contain the units of **m**rem/hr, not **M**rem/hr (a factor of 10^9 difference).

- Page 16, Section 2.3.5: The meaning of the next to the last full sentence on this page is not clear; it states, "At 50 to 200 MeV, the high-energy neutrons are generated by the photopion process." However, according to the contents of this section and Patterson and Thomas (1973), it would be more appropriate to state, "High-energy neutrons, in the range of 50 to 200 MeV, are generated by the photopion process." The current text does not state if it is the photons or the resulting neutrons that are in the 50–200 MeV energy range.

- Page 17, Section 2.3.5: The terms FFTB and FFTB2 appear multiple times (Sections 2, 6, 7, and Attachment A). They are not defined.

- Page 22, Section 4.3.2: The second sentence, since it follows a description of the earliest monitoring systems, seems to imply that the GM and BF_3 detector results from "when SLAC began operating" are provided in the report. This does not appear to be the case: Table 4-3 (page 23) contains neutron data from 1972 to 1979; Table 4-4 (page 24) contains neutron data from 1980 to 1989; and Table 4-5 (page 25) contains photon data from 1993 to 2001. Perhaps the second sentence would make more sense following the introduction of the first data table (Table 4-3) in the second paragraph of this section.

- Pages 24 and 25, Section 4.3.3: The first sentence of the section states, "Two corrections must be made for the environmental neutron dose," referring to corrections for energy dependence of the dosimeter and distance dependence of the skyshine field. The final sentence of the section begins, "Combining all three corrections…" The additional correction appears to be a factor accounting for 8,766 hours of exposure for the PMS versus 2,000 hours of exposure for a worker. The discrepancy is confusing to the reader, who is left to search and/or guess which corrections are being referenced.

- Page 25, Table 4-5: Since NIOSH selected the PMS location with the highest 7-year total dose as a basis for assigning environmental photon dose, a row of "7-yr Total" results would simplify comparison and harmonize the table with the relevant text at the bottom of page 23.

- Some tables and figures in Section 4.3.2 seem to be misplaced in relation to the text. Figure 4-1 would be more accessible on page 23, following the description of PMS locations. Tables 4-4 and 4-5 would be more accessible immediately after the paragraphs that describe the data (both are currently located on page 23). Table 4-5 seems particularly out of place, since it contains photon data and is located in a section discussing "Corrections on Environmental External Neutron Dose."

- Page 25, Section 4.4, third from last sentence: This sentence describes the last paragraph on page 23 as being located "above Table 4.5 [4-5]." It would be appropriate for this sentence to precede Table 4-5, but the table is currently located on page 25 in a different section of the site profile, as indicated in the previous observation.

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- Page 27, next to last paragraph: It is not obvious what this statement is intended to mean. Perhaps rewording it would help. Additionally, is the design dose limit initially 500 mrem per person over the entire life of the accelerator, or 500 mrem/year per person?

  > *The SLAC design dose limit was initially 500 mrem based on an extrapolation . . . of regulatory dose limits over time to when SLAC would be operating.*

- Pages 34 and 35, Tables 6-5 and 6-7: The term "(%)" in Column 6 in both tables should be deleted; most values are not presented as percentages. In Column 6 of Table 6-7, the number 20 should be changed to 0.20 and the number 80 should be changed to 0.80.

- Page 54, third paragraph: Last sentence should read Section 2.3.5, not Section 2.3.4.

- Concerning the calibration CF of 1.51, SC&A found that the wording on pages 37 and 59 of the TBD appear to contradict each other. Page 37 states (ORAUT 2007a):

  > *[13] Rohrig, Norman D. ORAU Team. Health Physicist. April, 2006. The correction is based on the ratio of the counts per nanorem for the PuF calibration spectrum and the SSRL LINAC spectrum for the PMS. Because the PMS will have a smaller response to the <u>FFTB2 spectrum, using it would result in a **larger** dose</u> by the factor 0.385/0.135.* [Emphasis added.]

  However, on page 59 it is stated (ORAUT 2007a):

  > *The correction is then 0.582 ÷ 0.385 = 1.51 with an uncertainty of 35% at 1 sigma based on the ratio 5.5/4.1 from the measured to calculated ratios for moderated TLDs for the CERN iron and concrete spectra. If the <u>FFTB2 was appropriate, the doses received would be **smaller**</u> by about a factor of 3 (0.385/0.135) [13].* [Emphasis added.]

From the rest of the TBD and Table A-1, SC&A assumes that the statement on page 37 is correct. However, this should be verified and the wording corrected.

The following are recommendations from SLAC staff during the site expert interviews.

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Table 7. Recommended Updates to Table 2-1, Pages 11–12 of the Site Profile.

Area	Period of Operation	Comment
LINAC Tunnel	1966–present	Since April 2008, only the last one-third of the tunnel has been used.
Klystron Gallery	1966–present	
End Station B	1966–1985 +/- 2 years	Since the B-Line was last used in the early 1980s, End Station B has housed the NLCTA.
End Station C	1966–present	The LCLS tunnel now passes through the area which was known as End Station C years ago.
BSY	1966–present	Up until the 1980s, the beam could be directed to one of three end stations A, B or C or to the PEP or SPEAR storage rings. Later, the SLC arcs were added. Now, the beams can be directed to the LCLS or End Station A.
SPEAR SSRL	1972–present	
PEP	1980–1991	
PEP-II	1998–April 2008	
SLC	1988–1998	
Next Linear Collider Test Accelerator	1993–present	

In addition, the first damping ring was built in 1978, rather than 1984, as stated on page 12 of the TBD, second paragraph.

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5.0 REFERENCES

42 CFR Part 82. 2002. *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000;* Final Rule, Federal Register/Vol. 67, No. 85/Thursday, May 2, 2002.

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

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

Busick, D.D., and G.J. Warren, 1969. *Operational Health Physics Associated with Induced Radioactivity at the Stanford Linear Accelerator Center*, SLAC-PUB-696, Stanford University, Stanford Linear Accelerator Center, Stanford, California, December. (SRDB Ref ID: 21518)

Charalambus, S., and A. Rindi, 1967. *Aerosol and Dust Radioactivity in the Halls of High-Energy Accelerators,* Nuclear Instruments and Methods, Vol. 56, pp. 125–135, North-Holland Publishing Co., Amsterdam.

DOE 1991. Tiger Team Assessment of the Stanford Linear Accelerator Center, DOE/EH-0243, November 1991.

Donahue, R. J., 1989. *Calculation of Internal Radiation Exposures at a High-Energy Electron Accelerator*, Radiation Protection Dosimetry, Vol. 29, pp. 189–194, Nuclear Technology Publishing.

Donahue, R.J., 1991. *Calculation of Internal Radiation Exposures at a High-Energy Electron Accelerator,* SLAC-PUB-4941, Rev. 2, Stanford University, Stanford Linear Accelerator Center, Stanford, California, January. (SRDB Ref ID: 21367)

Endo, A., M. Kikuchi, S. Izawa, and Y. Ikezawa, 1995. *Characteristics of the Chemical Forms of ^{11}C, ^{13}N, and ^{15}O, in Air by the Operation of a 100 MeV Electron Linear Accelerator,* Health Physics, 68(1):80-88, Health Physics Society.

Endo, A., Y. Oki, Y. Kanda, T. Oishi, and K. Kondo, 2001. *Evaluation of Internal and External Doses from ^{11}C Produced in the Air in High Energy Proton Accelerator Tunnels*, Radiation Protection Dosimetry, Vol. 93, No. 3, pp. 223–230, Nuclear Technology Publishing.

Endo, A., Y. Harada, K. Kawasaki, and M. Kikuchi, 2004. *Measurement of depth distribution of ^{3}H and ^{14}C induced in concrete shielding of an electron accelerator facility*, Applied Radiation and Isotopes, Vol. 60, pp. 955–958, Elsevier, Ltd.

Flood, J.R., 1995. "*Upper Useful Range of the Panasonic UD-802 Dosimeter*," Memorandum to Dosimetry Files, Stanford University, Stanford Linear Accelerator Center, Stanford, California, September 6, 1995. (SRDB Ref ID: 25385)

Flood, J. R., 2000. *"Revised Neutron Dose Conversion Factors for Personnel Dose Calculations*," Memorandum to Dosimetry Files, Stanford University, Stanford Linear Accelerator Center, Stanford, California, March 1, 2000. (SRDB Ref ID: 25386)

Gherman, M., 2006. Collection of medical documents including "Consent for Medical Care," "Employee Information," "Initial Medical History," "Physical Examination Form," "Audiogram," "Physical Worksheet," "Letter to employee re Periodic Medical Exam," and list of procedures. Stanford University, Stanford Linear Accelerator Center, Stanford, California, April 11, 2006. (SRDB Ref ID: 23308)

Gooch, A., 2005. *SLAC RP Radiological Air Sample Form*, completed. Stanford University, Stanford Linear Accelerator Center, Menlo Park, California, November 22, 2005. (SRDB Ref ID: 23198)

ICRP 1993. *Publication 65, Protection against Radon-222 at Home and at Work*. International Commission on Radiological Protection, approved September 1993. Pergamon Press, Oxford

ICRP 1994a. *Human Respiratory Tract Model for Radiological Protection,* ICRP Publication 66 (Ann. ICRP 24 (1/3). International Commission on Radiological Protection, Pergamon Press, Oxford.

ICRP 1995. *Age-dependent doses to members of the public from intake of radionuclides: Part 3*. ICRP Publication 69 (Ann. ICRP 25 (1)). International Commission on Radiological Protection, Pergamon Press, Oxford.

ICRP 1996. *Publication 72, Age-dependent Doses to Members of the Public from Intakes of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients*. International Commission on Radiological Protection, Pergamon Press, Oxford. Approved September 1995.

ICRU 1999. *Nuclear Data for Neutron and Proton Radiotherapy and for Radiation Protection*, Report 63, International Commission on Radiation Units and Measurements, Bethesda, Maryland.

Kanda, Y., A. Yoshioka, 2007. *Physical and chemical forms of radionuclides of* ^{38}S, ^{38}Cl, ^{39}Cl, *and* ^{82}Br*, produced at a high-energy proton accelerator facility*, Journal of Radioanalytical and Nuclear Chemistry, Vol. 273, No. 2, pp. 507–512, Akademiai Kiado, Budapest.

Kase, K.R., R. Sit, J. Liu, H. Tran, D. Busick, and M. Grissom, 1993. *Establishment of a Technical Basis for Internal Dosimetry at High Energy (50 GeV) Electron Accelerator Facilities*. SLAC ID001, July 14. (SRDB Ref ID: 23307, p. 497)

Kondo, K., H. Muramatsu, Y. Kanda, and S. Takahara, 1984. *Particle Size Distribution of* ^{7}Be *Aerosols formed in High Energy Accelerator Tunnels*. International Journal of Applied Radiation and Isotopes, Vol. 35, No. 10, pp. 939–944, Pergamon Press, Ltd.

Liu, J.C., B. Flood, S. Rokni, R. Seefred, and R. Sit, 2000. *Use of LiF and Panasonic TLDs inside 5" and 6" Polyethylene Moderators for Area Dose Monitoring at SLAC, RP Note 99-14*, Rev. 1, Stanford University, Stanford Linear Accelerator Center, Stanford, California, March 21, 2000. (SRDB Ref ID: 23300)

Lucci, F., S. Merolli, and M. Pelliccioni, 1973. *Measurements of Induced Radioactivity in Dust Around a 400 MeV LINAC,* Health Physics 24, 411-415, Health Physics Society.

McCall, R.C. and T.M. Jenkins, 1966. *Preliminary Plan for Environmental Monitoring at SLAC,* TN-66-9, Stanford University, Stanford Linear Accelerator Center, Stanford, California, March. [SRDB Ref ID: 23245]

Muramatsu, H., K. Kondo, and Y. Kanda, 1988. *Radioactive Airborne Species Formed in the Tunnels of a High Energy Accelerator Facility*, Applied Radiation and Isotopes, Vol. 39, No. 5, pp. 413–419, Pergamon Press, Ltd.

NCRP 1971. *Protection against Neutron Radiation*, Report 38, National Council on Radiation Protection and Measurements, Bethesda, Maryland. January 4, 1971. (SRDB Ref ID: 11520)

Nelson, W.R., 1987. *Properties of the EM Cascade*. SLAC-PUB-4203. February 1987.

Newton, G., M. Hoover, E. Barr, B. Wong, and P. Ritter, 1987. *Collection and Characterization of Aerosols from Metal Cutting Techniques Typically Used in Decommisioning Nuclear Facilities*, American Industrial Hygiene Association Journal 48 (11) (1987).

NIOSH 2006. Scanned elevated exposure incident memos, file name: 023151_Elevated Exposure Incidents (1970–1974).pdf, Division of Compensation Analysis and Support, Cincinnati, Ohio. From NIOSH Data Capture April 13, 2006.

Numajiri, M., Y. Oki, T. Suzuki, T. Miura, M. Taira, Y. Kanda, and K. Kondo, 1994. *Estimation of Nickel-63 in Steel and Copper Activated at High-Energy Accelerator Facilities*, Applied Radiation and Isotopes, Vol. 45, No. 4, pp. 509–514, Elsevier Science, Ltd.

OCAS 2009. *Worker Outreach Program,* OCAS-PROC-012, Office of Compensation and Analysis, National Institute for Occupational Safety and Health, Cincinnati, Ohio. March 2, 2009.

Oishi, K., N. Nakao, K. Kosako, H. Yamakawa, H. Nakashima, M. Kawai, H. Yashima, T. Sanami, M. Numajiri, T. Shibata, H. Hirayama, and T. Nakamura, 2005. *Measurement and Analysis of Induced Activities in Concrete Irradiated Using High-Energy Neutrons at KENS Neutron Spallation Source Facility*, Radiation Protection Dosimetry, Vol. 115, No. 1-4, pp. 623–629, Oxford University Press.

Oki, Y., M. Numajiri, T. Suzuki, T. Miura, K. Kondo, 1992. *Evaluation and Measurement of* ^{55}*Fe Radioactivity in Accelerator Hardware Activated at High Energy Accelerator Facilities*, Applied Radiation and Isotopes, Vol. 43, No. 11, pp. 1355–1362, Pergamon Press, Ltd.

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Oki, Y., M. Numajiri, T. Suzuki, Y. Kanda, T. Miura, K. Iijima, and K. Kondo, 1994. *Particle Size and Fuming Rate of Radioactive Aerosols Generated during the Heat Cutting of Activated Metals*, Applied Radiation and Isotopes, Vol. 45, No. 5, pp. 553–562, Elsevier Science, Ltd.

Oki, Y., K. Kondo, Y. Kanda, T. Miura, 1999. *Aerosol-size distribution of radon daughter ^{218}Po in the accelerator tunnel air*, Journal of Radioanalytical and Nuclear Chemistry, Vol. 239, No. 3, pp. 501–505. Akademiai Kiado, Budapest.

ORAUT 2005a. *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures*, ORAUT-OTIB-0006, Rev. 03-D, Oak Ridge Associated Universities Team, Cincinnati, Ohio. December 21, 2005.

ORAUT 2005b. *Conduct of the Worker Outreach Program*, ORAUT-PROC-0097, Oak Ridge Associated Universities Team, Cincinnati, Ohio. December 29, 2005.

ORAUT 2006. *Technical Basis for Conversion from NCRP Report 38 Neutron Quality Factors to ICRP Publication 60 Radiation Weighting Factors for Respective IREP Input Neutron Energy Ranges*, ORAUT-OTIB-0055, Rev. 00, Oak Ridge Associated Universities Team, Cincinnati, Ohio. June 5, 2006.

ORAUT 2007a. *Site Profile for the Stanford Linear Accelerator Center*, ORAUT-TKBS-0051, Rev. 01. Oak Ridge Associated Universities Team, Cincinnati, Ohio. August 17, 2007.

ORAUT 2007b. *Rocky Flats Plant – Occupational Medical Dose*, ORAUT-TKBS-0011-3, Rev. 01, Oak Ridge Associated Universities Team, Cincinnati, Ohio. April 23, 2007.

ORAUT 2010. *Site Profile for the Brookhaven National Laboratory*, ORAUT-TKBS-0048, Rev. 01, Oak Ridge Associated Universities Team, Cincinnati, Ohio. April 26, 2010.

Patterson, H.W., A. de G. Low-Beer, and T.W. Sargent, 1969. *Whole-Body Counting and Bioassay Determinations Made on Accelerator Workers*, Health Physics, Vol. 17, pp. 621–625, Pergamon Press.

Patterson, H., and R. Thomas, 1973. *Accelerator Health Physics*. Academic Press, Inc., New York, New York. 1973.

Pindar, F., 1965. "Blanket Order, Palo Alto Medical Clinic, Req. 24789M," Memorandum to D. Littlefield, Stanford University, Stanford Linear Accelerator Center, Stanford, California. June 29, 1965. (SRDB Ref ID: 23251)

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

SIT, R., 2000. *OHP Department Airborne Activity Control Levels*, SLAC-I-760-2A05O-009, FO#012, Rev. 6, Stanford University, Stanford Linear Accelerator Center, Stanford, California, October 5. SRDB Ref ID: 23364].

NOTICE: This report has been reviewed for Privacy Act information and has been cleared for distribution. However, this report is pre-decisional and has not been reviewed by the Advisory Board on Radiation and Worker Health for factual accuracy or applicability within the requirements of 42 CFR 82.

SLAC 1969. *^{181}Tungsten Contamination Incident,* by D. Busick and G. Warren, SLAC-Pub-543, January 1969, presented at Health Physics Society Mid-Year Topical Symposium, January 29–31, 1969.

SLAC 1994a. *PC ORPS Occurrence Report*, "Beam Switch Yard Swipes Analysis," SAN-SU-SLAC-1994-0012, Stanford Linear Accelerator Center, Menlo Park, California, November 3, 1994.

SLAC 1994b. *PC ORPS Occurrence Report*, "Loose and Fixed Radioactive Contamination," SAN-SU-SLAC-1994-0011, Stanford Linear Accelerator Center, Menlo Park, California, October 24, 1994.

Tesch, K., 1991. *The Ratio of Internal Dose Due to Inhalation to the External Dose When Machining Radioactive Accelerator Components*, Radiation Protection Dosimetry, Vol. 35, No. 3, pp. 167–171, Nuclear Technology Publishing.

Tran, H., 2005. *Technical Basis Regarding Routine Bioassay Measurements at SLAC*, DG #103, Rev. 3.0, Stanford University, Stanford Linear Accelerator Center, Stanford, California. April 15, 2005.

Vylet, V., J.C. Liu, S.H. Rokni, and L.–X. Thai, 1997. "Measurements of Neutron Spectra at the Stanford Linear Accelerator Center," *Radiation Protection Dosimetry*, Vol. 70, pp. 425–428. (SRDB Ref ID: 23306)

Yokoyama, S., K. Sato, K. Manabe, H. Noguchi, H. Kaneko, Y. Oki, T. Iida, and S. Tanaka, 2007. *Ratio of Aerosol and Gases of Radioactive Chlorine and Particle Size Distribution of Aerosol Formed By High-Energy Proton Irradiation*, Radiation Protection Dosimetry, Vol. 127, No. 1-4, pp. 392–397, Oxford University Press.

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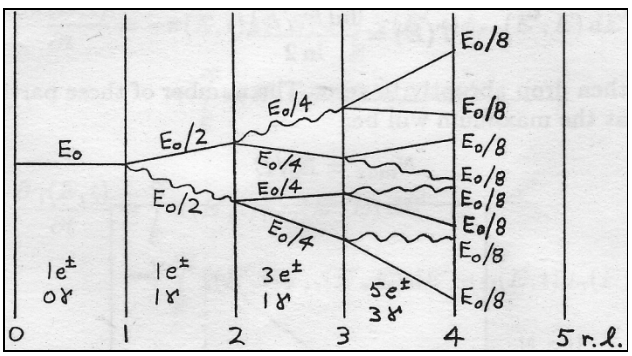
ATTACHMENT 1: POTENTIAL RADIATION FIELDS AT SLAC

A brief description of the process that creates the radiation fields at a high-energy electron accelerator is helpful in understanding the potential exposures at such a facility. The term "electron" will be used to mean both negatively and positively charged electrons (called negative electrons and positrons, respectively).

- At SLAC, electrons are accelerated in a 2-mile long pipe (beamline) up to 47 GeV (which is 47,000 MeV) of energy. Several smaller accelerators at the end of the beamline also accelerate electrons up to 120 MeV and 2.3 GeV. These beamlines are in a concrete tunnel covered with earth in most locations at SLAC.

- The accelerated electrons interact with the inside of the beamline/components, experimental targets, the shielding, and the beamstops to create high-energy photons.

- These high-energy photons interact with similar material to go on to create additional negative electrons/positrons. This is called an electromagnetic cascade or shower. The **number** of electrons and photons increases exponentially, and their energies decrease exponentially as they pass through material. This is illustrated in the following figure (Nelson 1987):



r.l. = radiation length = distance traveled to decrease energy by a factor of 1/e; about 8" in concrete.

Figure A-2. Electromagnetic Cascade

- The energy spectra of the photons created can range from several keV up to near the maximum energy of the electron beam. The photon energies that are of most concern from a health protection aspect, outside the shielding, range from approximately 30 keV to several MeV at SLAC.

- The high-energy (>10 MeV) photons go on to interact with material to produce neutrons. The three major interactions are as follows:

  - **10–30 MeV photons** create a peak of neutrons with an energy around **1 MeV** through the Giant Resonance (GR) interaction.

- o **30–300 MeV photons** create neutrons in the **10–20 MeV** range through the photo disintegration of nucleon pairs (so-called pseudodeuteron interaction).
- o **140 MeV–50 GeV photons** create a peak of neutrons around the **80 MeV**, (ranging from 50–200 MeV), through the photon-pion production (one, two, and three pion) reactions.

This is illustrated in the following diagram (Patterson and Thomas 1973):

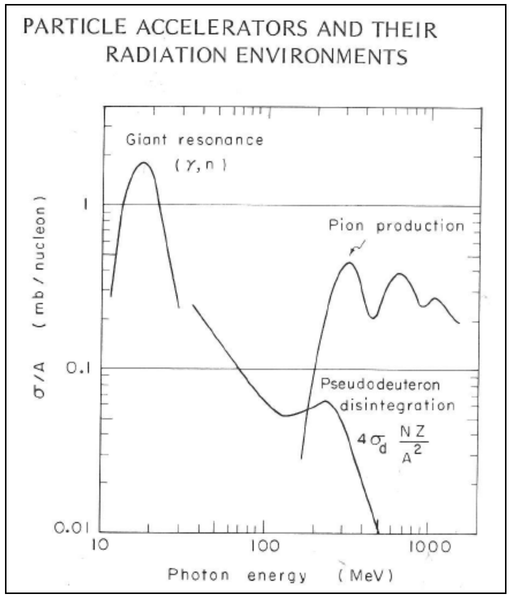


Figure A-3. Neutron Production from Electromagnetic Cascade

The magnitude and energy range of the neutrons produced depend upon the atomic number of the material that the photons interact with.

- Some high-energy neutrons are degraded in energy from interactions with materials, resulting in neutron energy spectra in the thermal (0.025 eV) to 1 MeV range.

- In combination, the photon and neutron interactions described above result in a broad spectrum of neutron energies, ranging from approximately 0.025 eV through 200 MeV.

- The electrons, photons, pions, and neutrons described above are produced in the beamline, tunnel, and shielding. Since charged particles and spallation products would not penetrate to work areas, the following radiation exposures are of primary concern for personnel dosimetry **while the accelerator is running**:

  - o Photons in the 30 keV–3 MeV range.
  - o Neutrons in the thermal (0.025 eV) up to several hundred MeV range.
  - o Both photons and neutrons could emerge horizontally from the direction of the accelerator and vertically from radiation reflected back down to ground level from skyshine. Except near experimental areas and

penetrations in the shielding, the geometry of exposure would most likely resemble isotropic irradiation.

- **When the accelerator is not operating**, the radiation types described above are not produced. Exposure during these times comes from activated materials (e.g., targets, beamline components, structural materials, and air); these materials emit gamma rays in the 30 keV to 3 MeV energy range and beta particles in the keV and MeV energy range.

This brief summary is a generalized view of the production of radiation fields at SLAC and leaves out many details; however, it will serve the purpose for health protection and dose reconstruction evaluation. Workers could potentially be exposed to the radiation fields listed below. Adequate monitoring would consist of dosimetry that is responsive to these fields, appropriate calibration of dosimetry, and availability of recorded results for dose reconstruction purposes.

- Photons: 30 keV–3 MeV, both while the accelerator is operating and when it is off.
- Betas: keV and MeV range, both while the accelerator is operating and when it is off.
- Neutrons: Energies from thermal to several hundred MeV, only when the accelerator is operating.
- Generally, neutrons do not dominate the radiation fields at electron accelerators, except in the case of skyshine. This is in contrast to proton accelerators, where neutrons are usually one of the dominate radiation exposures.

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ATTACHMENT 2: SUMMARY OF SITE EXPERT INTERVIEWS

As a technical support contractor assisting the Advisory Board on Radiation and Worker Health (Advisory Board), SC&A has been tasked with reviewing NIOSH's site profile for Stanford Linear Accelerator Center (SLAC) in Menlo Park, California. One component of SC&A's review is a series of interviews with site experts, including current site workers, former site workers, and worker representatives. The purpose of these interviews is to obtain first-hand accounts of past radiological control and personnel monitoring practices, and to better understand how operations and safety programs were implemented at the site over time. Interviewees were identified through available site reports, other interviewees, and site personnel. This report summarizes the results of those interviews that were reviewed and accepted by the interviewees.

SC&A interviewers William James and Kathryn Robertson-DeMers conducted interviews at SLAC in Menlo Park, California, between January 24 and January 28, 2011, as well as interviewing a couple participants by telephone. No Advisory Board members participated in these interviews. A total of 26 site experts were interviewed.

SC&A explained that the interviews were being conducted on behalf of the Advisory Board as part of their review of NIOSH's site profile report. Participants were told that the interviews were unclassified, and that they should not disclose any classified information. Interviewees were informed that interview notes with names (if authorized by the interviewee) would be made available to the Advisory Board. Summaries from each interview set were prepared and provided to the interviewees for review. Approximately 80% of the participants responded to the request for review; the information obtained from non-responders has been withheld from this master summary.

The workers whose interviews are summarized below represent the time period from 1963 through the present (January 2011). They worked throughout the research area and support facilities, including the 2-mile Linear Accelerator (LINAC), the Stanford Synchrotron Radiation Lightsource (SSRL), Stanford Positron-Electron Asymmetric Ring (SPEAR), the SLAC Linear Collider (SLC), the Positron Electron Project (PEP), the Next Linear Collider Test Accelerator (NLCTA), the Final Focus Test Beam (FFTB), the LINAC Coherent Light Source (LCLS), the Klystron Gallery, the Central Laboratory area, the Beam Switch Yard (BSY), the End Stations, Storage Areas, Building 44, Building 25, and Building 26. The areas represented by the interviewees include the following:

- Accelerator Engineering
- Accelerator Operations
- Accelerator Operations and Safety
- Central Laboratories
- Dosimetry (External and Internal)
- Environmental Compliance
- Environmental Monitoring
- Experimental Facilities Department
- Experimental Particle Physics

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- Klystron Department
- Mechanical Design
- Mechanical Fabrication
- Medical
- Operational Health Physics
- Radiation Physics
- Radiation Protection
- Security
- Waste Management (including Radioactive Waste)

The information provided by the workers and site experts is invaluable in helping SC&A to better understand the operations at SLAC. This summary report is not a verbatim presentation of the material contained in the interview notes, nor is it a statement of SC&A findings or opinions. It is a consolidated summary of statements, opinions, observations, and comments that the interviewees communicated to SC&A. Its sole intent is to communicate to the Work Group, the Advisory Board, and other interested parties information acquired by SC&A during these interviews. **Comments are included in brackets where SC&A has provided clarification on a statement.**

Information provided by the interviewees is based entirely on their personal experience at SLAC. It is recognized that the site experts' recollections and statements may need to be further substantiated. However, they stand as critical operational feedback and reality reference checks. These interview summaries are provided in that context. Key issues raised by site experts are similarly reflected in our discussion, either directly or indirectly. Interviews from all workers who reviewed and approved their individual interview summaries were consolidated into a single summary document. The information has been categorized into topical areas related to organization, facility security and access, accelerator operations, exposure potential, radiological control, external dosimetry, internal dosimetry, environmental monitoring, incidents and unusual events, radiological records, occupational medical exposure, comments on the site profile, and miscellaneous comments. Where conflicting observations and statements have been received, both perspectives have been retained in this summary report.

With the preceding qualifications in mind, this summary has contributed to SC&A's understanding of issues raised in the Site Profile Review report.

Organization

Historically, there were few divisions, each headed by an associate director who reported to the laboratory director. These divisions are now referred to as directorates, which have undergone name changes as well as organizational changes. For example, the Accelerator Directorate now includes most of the functions formerly included in the Technical Division.

The Accelerator Engineering Division now includes the Mechanical Fabrication Department, the Klystron Department, the Controls Department, the Power Conversion Department, the Metrology Department, and other smaller groups. The Mechanical Design group works on assembly of accelerator components, and assembly and disassembly of new components.

The RadCon program was initially divided into Radiation Physics and Operational Health Physics. The Radiation Physics group, part of the Research Division, worked on shielding, radiation safety commissioning, beam parameter approvals, beam authorization sheet sign-off, and other tasks. Operational Health Physics was responsible for day-to-day operations in the field, including surveys, posting, material control, writing/issuing Radiological Work Permits (RWPs), and 10 CFR 835 and DOE RadCon Manual compliance activities. Before 1991, the staff involved with health physics and other safety issues were scattered among the divisions. The Environmental Safety and Health (ES&H) Division came into existence in about 1991, with both the Operational Health Physics group and Radiation Physics group reporting to ES&H. In about 2000 or 2001, Radiation Physics and Operational Health Physics were merged into one group, Radiation Protection.

There are currently 30–34 personnel in the Health Physics organization. Each experimental facility has a safety officer, who is responsible for reviewing the hazards associated with experiments. Radiation Protection is brought in to consult on radiological hazards. Staff in the Radiation Physics group includes individuals certified as health physicists, many with PhDs.

Facility Security/Access Control

SLAC covers the 420-acre property. There is a perimeter fence around the entire site. There is nowhere in the restricted area where an individual can inadvertently enter the site.

Security has the responsibility for the badging office onsite. There are 30 officers at SLAC that support the facility, with 2 flex officers who have commensurate training. There are three patrol officers driving around the site on routine patrol from Monday to Friday, and two on the weekends and after hours.

There are two entrance gates to SLAC and two internal gates. The two main entrances are the Main Gate and the Alpine Gate. All employees entering the Main and Alpine gates must show a badge or decal, which is registered with Security. Decal registration information allows Security to identify the individual as necessary. Non-employees can pass through the Main Gate without a badge, but they must have formal business onsite. No visitor escort is required on the "Campus" area of the site. A badge is required to enter the Alpine Gate, Gate 17, and Sector 30 gate. Visitors entering the restricted area are issued a temporary badge and are required to be escorted by an appropriately trained individual.

Officers typically wear uniforms. They wear Personal Protective Equipment (PPE) like hard hats in construction areas as required, mainly for non-radiological hazards.

Officers occasionally walk through machine shops—only when no activities are going on. They keep their path to the aisles and corridors and do not go near the shop equipment. They utilize PPE if required.

Indefinite Delivery, Indefinite Quantity contractors, contractors that provide an indefinite quantity of supplies or services during a fixed period of time, have been here for non-radiological cleanups, but they did not require Security services.

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Officers at SLAC have not been loaned out to other DOE facilities.

Accelerator Operations

The budget for SLAC operations came/comes from the Department of Energy (DOE) and its predecessors, while Stanford University is responsible for the operation of the facility.

From 1961–1966, prior to start-up of the accelerator beam, some staff members were doing accelerator work at the Stanford University campus accelerator. Project M was run by a group of faculty members at Stanford University. Individuals involved in the construction of SLAC originally came from the campus. There was a 250-MeV accelerator set up to develop the prototype structures eventually used for the SLAC accelerator.

SLAC's focus is on conducting high-energy physics experiments. No isotope production or fuel production is done at the accelerator. SLAC is classified as a Radiological Facility.

2-mile Accelerator

The 2-mile long LINAC is the main accelerator at SLAC, providing beam to various facilities. The LINAC was commissioned starting in 1966. As one phase of the accelerator (SLAC) was completed, that part of the accelerator was started up.

Commissioning started at a low energy, but was increased as more of the LINAC became operational. In 1967, the beam energy was increased to a maximum of 20 GeV at 60 to 180 Hertz (Hz). The maximum number of electrons per pulse ranged from 10^{10} to 10^{11}. The Radio Frequency (RF) pulse length was approximately 3 micro-seconds. The number of particles per pulse times the energy is directly proportional to the beam power, which determines the amount of activation in targets and other devices that intercept the beam.

For a couple of years during the early 1970s, the accelerator was run at a maximum beam energy of 20 GeV and a pulse rate of 180 Hz. During this period, the average beam power was higher than in later years. From the late 1980s through June 1998, a beam energy of up to 47 GeV with a lower pulse rate of 120 Hz was used. This change in operating parameters was due to the ability to group particles together in a single RF bucket and to compress the RF pulse, resulting in a need for less power. As a result of this change, some experiments could be completed with a beam power an order of magnitude less than was needed in the early 1970s. The ability to control the beam has become significantly better over time, resulting in less beam loss. Currently, SLAC can produce a micrometer-wide beam versus the millimeter-wide beams in the early days. In almost all cases, the targets are stationary.

The power of an accelerator can be expressed by the following function:

$$\text{Power (watts)} = \text{energy (GeV)} \times \text{current (amps)} \times \text{repetition rate (pulses in Hz)}$$

SLAC was designed for about a 1-Megawatt (MW) power level, but has never run at that power level. The beam energy and the average beam power for experiments at SLAC were higher 10–

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15 years ago than it is currently. The beam energy has dropped from 50-GeV beam energy in the early years to less than 15 GeV in recent years for LCLS. The repetition rate has been reduced from 120 Hz to 60 Hz. The electrons per pulse have ranged from 10^9 to 10^{12}. The accelerator gains about 1 GeV per sector. The radiological hazards at the accelerator are proportional to the power of the accelerator. Thus, reduction in power has lowered the radiological hazards. In general, both prompt and residual radiation fields have been reduced in the last 20 years, compared to the periods of maximum power in the 1970s.

The beam is directed by a series of magnets, which direct, focus and defocus the beam in the x and y directions. The beam can also be narrowed in the z direction.

The accelerator normally runs 24 hours per day for 9–10 months per year. Presently, only the last one-third of the accelerator is used. SLAC was/is shut down every summer. The precision and accuracy of the machinery requires adjustment and maintenance. The summer was/is a good downtime, as the electrical load during the summer is unpredictable.

SLAC Linear Collider (also known as the Stanford Linear Collider or SLC)

SLC accelerated electrons (from the clockwise direction) and positrons (from the counter-clockwise direction), allowing them to collide at a fixed point in space. The collision point was centered in a detector at the SLC Experiment Hall in Building 750. There are two dump rooms for this process. Parts of the Linear Accelerator Facility were upgraded in 1987–1998 in preparation for the PEP II startup.

Stanford Positron-Electron Asymmetric Ring (SPEAR)/ Stanford Synchrotron Radiation Lightsource (SSRL)

Another major facility at SLAC is the Stanford Synchrotron Radiation Lightsource (SSRL), which is similar to the ANL Advanced Photon Source, the BNL National Synchrotron Light Source, and the LBNL Advanced Light Source.

The SPEAR is the accelerator that feeds the SSRL. The current has ranged from a few milli-amps (mA) to several hundred mA. In about 1973, it used 100 mA, but now is up to about 300–400 mA. SPEAR 2 was the result of hardware improvements on SPEAR. For SPEAR 3, the old machine was pulled out and replaced with an entirely new accelerator; shielding upgrades were added where necessary to improve the system. SPEAR and SPEAR 2 were used for colliding beam physics experiments. In the mid-1980s, the machine was shared between high-energy physics and SSRL. High-energy physics ran at <2.0 GeV and SSRL ran at 3.0 GeV. SSRL continues to operate at 3 GeV.

The SSRL produces synchrotron radiation by circulating electrons through magnetic fields, causing them to oscillate and give off photons. The photons are used for study of target material. SSRL is like a super x-ray machine that allows pictures to be taken at various depths within surface layers of a material. For example, it allows scientists to see the biological structures of molecules. SSRL will soon be able to operate up to 5 Watts. The SSRL gets about 3,000 users per year using its x-rays for research studies.

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In 1995 or 1996, a new program involving transuranic experiments was initiated at SSRL. By 1996, the Actinide preparation and handling room started up, and they received their first shipment of plutonium alloys for analysis. SLAC is a Radiological Facility, and the associated inventory of materials is kept to one-half the inventory limits specified for this type of facility (Category III). Activity of individual samples range from several Bq to 100s of MBq. SLAC has handled Pu-238, Pu-239, Pu-240, Pu-241, Np-237, Am-241, U-235, U-238, Tc-99, and europium isotopes in the Actinide Room. All samples are prepared at their originating facility [LANL, Pacific Northwest National Laboratory (PNNL), or LBNL], with no sample preparation occurring at SLAC. SLAC requires the initiating facility to contain the samples prior to shipment. Depending on the hazards class of the isotope, this could involve up to three containments; the samples are not handled in an uncontained situation. This is required not only for Radiation Protection, but also to prevent contamination of the accelerator vacuum system.

The inventory list is provided with each package, along with a list of isotopes and maximum activities. When samples are received, personnel swipe each container as they open the package and remove the sample. Monitoring of alpha-emitting isotopes takes place on a continuous basis, starting with receipt of samples and continuing until completion of the experimental analysis. If any contamination is detected on the container, it is packaged up and sent back to the originator. The unpackaging and handling of the samples is done in a HEPA-filtered glovebox. Workers have worn HEPA respirators to open the actinide containing shipping containers; however, this is not a requirement in most cases. The sample is taken to SSRL and inserted into the beam line for testing by Radiation Protection Field Operations technicians; handling of samples by experimenters is limited only to those personnel who have Radiation Worker II training.

The Actinide Room and beam hutches have an alpha continuous air monitor (CAM), and glove bags may be used in some experiments. CAM samples are decayed to zero. If they don't decay off, this would be an indication of true radioisotopes other than radon. No leaks or airborne contamination releases have ever been detected in the room.

A TBD for the actinide work in SSRL was prepared. In addition, there is a safety analysis report for the process used.

Positron Electron Project (PEP)

PEP started in about 1980 and ran to 1989. It was brought back up for a period in 1991. It was used for high-energy physics collisions of electrons and positrons at 15 GeV per beam. There was one beam pipe. The electrons were circulated in the clockwise direction and the positrons in the counter-clockwise direction. There were six points around the ring where collisions took place. There were five experimental halls at Buildings 620, 640, 660, 680, and 720. These were beam focusing points. PEP was designed to discover new families of quarks and leptons, to measure the lifetimes of various short-lived mesons, and to study other aspects of electron-positron annihilation physics.

PEP II (also known as the B-Factory) used the circular tunnel previously used by PEP. The original PEP machine was taken apart and replaced with two beam pipes. These beam pipes came together at one location—the Interaction Region Hall (IR2) in Building 620. Additional local shielding was added in the experimental hall, because of the higher stored currents. One beam ran at approximately 9 GeV, while another ran at approximately 3 GeV. There were various instruments around the area to measure beam losses and prompt radiation. Activation primarily occurred at the beam dumps.

Next Linear Collider Test Accelerator (NLCTA)

NLCTA is a small x-band linear accelerator. This is a self-contained accelerator, which uses x-band technology. It was constructed to demonstrate that x-band technology could work. There is about four times more acceleration per meter with x-band technology than with s-band technology. This accelerator is now used primarily for advanced accelerator technology research. The accelerator is turned on and off as needed.

Final Focus Test Beam (FFTB)

FFTB was the test facility used to focus LINAC beams to very small sizes and deliver them to various kinds of experimental apparatus and targets. In 2006, the FFTB was dismantled. As a part of the project, SLAC dug up the concrete floor and the activated soil below the structure. Low levels of radioactivity were identified by gamma spectroscopy in both the concrete and soil.

LINAC Coherent Light Source (LCLS)

The LCLS is a powerful x-ray laser. Its C-ray pulses are millions of times brighter than the SSRL. The LCLS uses stop-motion pictures and examines atoms and molecules in motion.

Beam Switch Yard (BSY), End Stations and Storage Areas

BSY is the transition area between the LINAC and the various End Stations or other machines. Targets are placed at the End Stations for various experiments. The BSY is approximately 0.75-miles long and allowed the transport of high-energy electrons and positrons to three beam lines—Beam Lines A, B and C. There are three large beam halls—End Station A (Building 62), End Station B (Building 61), and the Large Collider Hall (Building 750). The targets used at End Station A and End Station B were primarily liquid hydrogen. Other targets used have included deuterium and various other materials. SLAC has never done any heavy ion physics.

The beam travels through the End Stations to the Beam Dump, which is located on the hillside. There are about 150 separate low-conductivity water systems (i.e., cooling heat exchangers) for cooling parts of the accelerator and support structures.

SLAC scientists use very large detectors (i.e., the size of a truck or house) housed in shielded buildings to detect particles. There was 40 feet of iron shielding manufactured from World War II iron blocks to provide shadow shielding to protect the central beam detector from nuclear interactions generated by photons and secondary particles in the BSY.

The Radioactive Material Storage Yard (RAMSY) is located in the BSY. It is used to store old magnets, collimators, old beam stops, concrete blocks, and steel no longer needed for accelerator

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operation. SLAC initiated a natural Be-7 study in 2008. A couple of samples in the BSY showed elevated levels of Be-7 by gamma spectroscopy; no readings above background were identified by field instrumentation.

There were a couple of beam targets/dumps with lead shielding, which were stored in an outdoor storage area (magnet storage yard). Clean-up of the storage area and removal of the targets/dumps was required in 2004, due to the presence of small pieces of lead found in the surrounding area. Low levels of activation products originating from the targets/dumps were also detected in the soil via gamma spectroscopy (no readings above background were identified by field instrumentation). Six or seven drums of soil containing activation products were generated by this clean-up.

The Bone Yard was used for storage of shielding blocks from the 1960s. When experiments were completed, the blocks were stored here. Lead contamination was found in this area, requiring the area be cleaned up. Each of the shielding blocks underwent surveys by Radiation Protection. The blocks were moved to an area near Section 10, along the gallery, for storage.

Klystron Gallery

Equipment housed in the Klystron Gallery produces high-power microwave pulses that power the LINACs. Each klystron is like a mini-accelerator that uses bunched electron pulses to produce microwaves. A wave guide takes the electrons off the electron gun, runs them down to the tunnel, and adds them to the main beam. There are over 250 klystrons at the accelerator. Operations fires up as many as they need to get the desired power. Anywhere there is an accelerator, there is a klystron. The area around each LINAC klystron is roped off.

Klystrons were manufactured at the Machine Shop (Building 44) and taken to the High Bay (i.e., Klyston Test Building) to be tested. The "Yellow Coffin" is a shielded test facility for electron guns and other electron-emitting devices. It is located in the building where klystrons are manufactured, repaired, and tested.

Support Facilities

The Central Laboratory Area serves as an office building and houses Material Science and Chemistry laboratories. Radioactive samples are not supposed to be handled in this area. There are no radiochemical separations conducted here. The Central Laboratory has a quick turnaround Machine Shop.

The Vacuum Technicians are located at a central location and are sent out to areas throughout the site. Anyone from Building 25 can be sent anywhere to do a job.

Exposure Potential

The largest potential radiation exposure from the SLAC accelerator is a "beam-on" condition. Personnel entry to the 2-Mile LINAC and all experimental areas is therefore controlled if the accelerator is on or could be turned on. Prior to accelerator operation, all experimental areas

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where the accelerator particles can be present are physically searched and controlled by accelerator operators. The accelerator has an interlock system to keep individuals out while the accelerator is on or could be turned on. There has never been a "beam-on" accident at SLAC during its operation.

Historical studies indicate that principal worker radiation exposure was clearly from external radiation distributed deep in the beam stopper, beam dump, or collimator, usually made from copper. Lapel and high-volume air samplers were used during repairs. The results from machining irradiated devices clearly demonstrated that the external gamma radiation dose rate dominates the machinist's occupational radiation dose. The air samples revealed background radiation. Most of the exposure came from machine shop set-up and was from induced collimator material from the external source.

External

The highest doses typically occurred during major shutdowns for maintenance activities, such as repair or upgrading of magnets and other required devices. Activation of aluminum resulted in Na-22 and Na-24. Activation of steel resulted in Co-57 and Co-60. Induced activity occurs at the beam dump and in areas where there are beam losses. The electron beam is dumped after it passes the target at the beam dump. There are several areas along the accelerator where the beam is split or lost. These areas are shielded significantly.

The most predominant radiological exposure is from photons. During precision alignment of the beamline components, individuals could spend 40 hours per week in a low dose rate radiation field. Generally, personnel radiation doses were compressed into specific times of the year (i.e., during shutdown).

Dose rates at the beam dump could be up to 1,000 R/hr when the accelerator is running. As soon as it is shut down, the dose rates drop to 100–200 mR/hr on contact with a few components. The dose rates come from activation and short-lived radioisotopes during some experiments. The hottest hot spots can reach 25 R/hr.

Muons are generated from prompt radiation along the narrow beam. The FFTB housed a muon shield for its main dump. This area was shielded and roped off to [a point where the dose rate was] 0.5 mrem/hour. The shielding requirements for muons are known. External dose from muons is detectable by dosimeters. There are no neutrinos generated at SLAC due to beam operations.

In accelerators, the principal source of radiological exposure is from work with activated components. Synchrotron light sources have low average beam powers, and there are few beam components that can get activated. Main sources of radiation [at synchrotron light sources] are generated as a result of losses in the ejector and the ring transition of the beam.

A majority of the neutron exposure at the facility in the past was from exposure to neutron calibration sources. These calibration sources have included plutonium beryllium, plutonium lithium, plutonium fluoride, and Cf-252. As a result of exposure to these sources, in general, the

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RCTs have received the highest neutron doses at the site in the past. These sources were recently shipped to LANL due to security requirements.

Internal

Internal dose is negligible at SLAC. Contamination usually comes from activated dust or oxidation of metals, and there are some plastics and rubbers that get activated also. Contamination is seen on the beam dumps and 1–2 feet around the beam dump. Insulation around the beam dumps also gets contaminated. Contamination is mostly inside the materials, which is volumetric contamination throughout the objects.

Machining of radioactive (activated) components is a potential source of contamination. This activity occurs in both the accelerator area and at Buildings 25 and 26 in the Fabrication Shops, where activated materials are processed. Machining conducted at SLAC includes use of a Dremel tool or cutter to get parts out, lathing (round parts), milling (square parts), and drilling core samples out of the walls of the chamber (Building 26). Parts are also machined to get them ready for welders. There was no grinding of activated parts in Building 25; this process puts too many particulates in the air. Grinding (which is rarely used) is conducted at the accelerator area in a glove bag. They do not allow grinding or high speed cutting of activated materials in Building 25. When machining, a contamination area is established, and a HEPA-filtered vacuum is used for controlling the activated dust. This work is done under an RWP.

Some contamination detected at the site came about from past high-energy operations of the LINAC, the BSY, and the End Stations starting in the 1960s and ending in the mid-1970s.

There was a small-scale metallic Depleted Uranium (DU) Test Project in about the late 1960s/early 1970s, where DU was considered for shielding a new physics detector. The DU was stored in the east end of Building 61 in the original shipping containers. There were plans to build a small-scale prototype of the detector to determine if the DU would result in too high a background [for the detector]. The DU arrived in 1/8” to ¼” sheets by truck load from Oak Ridge. Some of these sheets were cut into smaller square sheets by machine pressure cutting. The DU was stored in shipping containers when not in use. The project lasted a few months. The researchers eventually decided to use lead sheets instead of DU for shielding the detector, probably because of the signal-to-noise ratio.

One site expert indicated there was a project in the late 1980s to measure radon levels in the tunnel. Staff placed about 50 track-etch dosimeters obtained from a radon analysis vendor laboratory in the field. The concentration results reported from the laboratory did not indicate a significant radon exposure issue.

Another site expert indicated there was likely an elevated natural background radon level from natural occurrence in the concrete tunnel. The 2-mile LINAC tunnel was ventilated with 15 fans before access was permitted.

A third site expert indicated there is not a lot of air movement down in the accelerator tunnel. There is a possibility of enhanced natural radon levels in the tunnel. This is demonstrated by

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observation of the occasional particulates with radon decay products collecting on hard hats, clothes, and badges. These items are identified as contaminated during frisking, confiscated, and held for survey until they decay to a non-detectable level. There are no radon exposure/dose issues known or currently being assessed. RadCon does a series of counts on air filters when a filter is suspected to have an elevated radon reading. Radon in the tunnel can be estimated from air sample multiple decay counts and other information, such as CAM data. These data are documented in survey reports.

A site expert indicated thorium used at SLAC consisted of commercial welding rods. Radium was used for calibration of instruments at the health physics lab.

One site expert indicated some thermal neutron activation occurs where cooling water and concrete are present. Another indicated the coolant loop does not get contaminated with activation products much, but is limited to tritium and Be-7. Beryllium-7 is filtered out in the resin bed. The highest concentration of tritium detected in water is 10^9 pCi/l. Levels greater than 20,000 pCi/l are controlled as contamination. Personnel have been exposed to tritiated water with 1,000–2,000 pCi/l during a skin contamination event. SLAC has not handled any tritides.

Radiological Control

Engineering Controls

Prior to turning on the accelerator, SLAC developed an administrative procedure requiring a documented physical search of all experimental areas. Health Physics and Operations personnel were responsible for this search.

All entrances into the tunnel have elaborate interlock systems. There is redundancy in the interlock system. If an individual opens the door when the accelerator is on, the interlock system trips a system that shuts the accelerator off immediately.

There is a 1-hour “cool down” period after shutdown at locations where the beam power could be lost. The “cool down” period is implemented at beam dump locations and locations where beam energy loss occurs (at points like collimators and beam dumps in the system). This is where the activation product hazards occur. For example, a 1-hour “cool down” period and initial entry radiological survey was required for Sectors 1, 2, 3, 4, 10, 18, 19, 28, 29, and 30. The doors stay interlocked through the “cool down” period. RadCon is the first to enter the tunnel to conduct surveys prior to entry of other accelerator staff. Most of the radioactive gases decay away within 15 minutes. In other areas, personnel can enter immediately after shutdown. Pocket Ionization Chambers (PICs) are assigned to personnel who enter high radiation areas. Each individual is responsible for recording the PIC reading upon entry and as they leave the tunnel.

There is no exposure issue at SSRL now, because the interlock system protects personnel from prompt radiation, and the residual activation is very small.

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Shielding calculations for accelerators and experiments have improved over time. Radiation physicists and Accelerator physicists work together to anticipate possible exposure scenarios that would produce the maximum dose. Controlled experiments are conducted, in which radiation levels are measured in accessible areas, while the beam is parked on various stoppers or is deliberately mis-steered. Additionally, there is a verification of exposure condition when machines are on.

The accelerator has 27 feet of shielding in some areas. The End Station A/B has local shielding. Experiment-dependent shielding may also be required. When determining the shielding requirements, the beam parameters and beam losses are taken into account. The highest power experiments occurred at the End Station A (ESA) and the Beam Dump. The ESA beams were approximately a factor of 10 higher in average power than the SLC beam.

One former worker indicated that the area behind ESA, including the Beam Dump East (BDE), was fenced off because of forward direction of secondary particles emanating from the ESA liquid hydrogen or deuterium target.

The only intrusions into the tunnel have been by cats and rodents that entered through the utility penetrations many years ago. In one case in the mid-1990s, a feral cat was accidently irradiated when it entered the tunnel through a cable penetration during operation of the accelerator. The utility penetrations were modified to prevent further entry by animals into the accelerator via this route.

Administrative Controls

Researchers send proposals for experiments to a committee for review. This committee approves the research and procedures prior to work proceeding.

An RWP is required when any machining occurs on activated materials. Prior to a job, ES&H comes in and does a pre-job survey of the area. Once they provide the numbers, the supervisor and his boss fill out the job description on the RWP form. This is signed off by the boss. ES&H adds the requirements for PPE, coverage, etc. Sometimes, there is an ES&H person present to monitor the job. The RWP is posted at the worksite.

Personal Protective Equipment/Frisking

A HEPA-filtered respirator is required for all welding operations as a matter of routine. Respirators used have either been half-face or full-face air purifying with HEPA filters (not Powered Air Purifying Respirators). The Mechanical Fabrication Department (MFD) has had various numbers of respirator-qualified staff over the years. At times, all staff was qualified, but the site has cut down on the number of personnel kept in the respiratory protection program over the years, limiting the number of staff that can perform respirator-required work.

For several years, there was a requirement for full-body frisking of all personnel entering the High Radiation areas. There is no routine contamination found on PPE. In the last 17 years,

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there have been less than 12 individuals with positive counts from frisking. Only a couple of these individuals had positive beta/gamma counts.

Radiological Surveillances/Instrumentation

There is an air sampling program, which includes grab air sampling prior to and during work where airborne radioactivity may be generated. In the last decade, there have been a small number of radiological jobs requiring the use of breathing zone monitoring (performed by taking 1-m^3 air samples within the worker's breathing zone). When general area air sampling is used, the sampler is positioned between the work area and the individual's breathing zone. Air sampling is conducted during the machining of activated samples. A general area air sample is collected in the breathing zone of the worker. Current staff has never had a hot air sample from machining operations of radioactive materials other than radon.

Contamination surveys of Experiment Hutches are conducted pre-job, during work by the scientists, and post-job.

A formal instrument calibration program was historically not in place. There was a departmental requirement to incorporate more sensitive and reliable instrumentation, both in the laboratory environment and in the field. Historically, radiological instrumentation included Victoreen 400s, Victoreen 410s, Z-tech instruments, Eberline E600s, GM detectors, and Victoreen Neutron Meters. At the present time, Sodium Iodide (NaI) detectors, plastic scintillators, GMs, Ludlum 2241-2s, Miridian Health Physics Instruments (HPIs), and Eberline ASPs are used. Instrument calibration sources include, but are not limited to, Cs-137, Co-60, Cf-252, plutonium beryllium (PuBe), plutonium lithium (PuLi), and plutonium fluoride sealed sources. Instruments are sent offsite for neutron calibration, allowing SLAC to dispose of some of their neutron sources. For some field instruments, the Radcal detector is often (but not exclusively) utilized for calibration. The RCTs are currently responsible for instrument calibration.

There is a tracking system maintained for all accountable and unaccountable sources. There is also a program in place for managing Radiation Generating Devices.

Other

Workers are allowed to have water down in the tunnel, because it is hot (110°F).

By agreement, LLNL is also responsible for HEPA filter certification and necessary changes every 6 months. All checks and certifications on the system are maintained by both SLAC and LLNL.

In 1992, the DOE Tiger Team came to SLAC and identified weaknesses in radiation safety training for staff, documentation of surveys, radiological records, etc. As a result, in about 1992, major improvements were made to the radiation protection program. Rigorous procedures and policies based on the Navy's Naval Sea System Command (NAVSEA) 0289-0388 were implemented. The documentation became more frequent, structured, and formalized. There were improvements in the radiological surveillance of work, which included a strong emphasis

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on continuous job coverage during radiological work. SLAC procured more sensitive instrumentation and implemented self-frisking practices. Training of technicians improved substantially after the audit.

Prior to 1985, the radiological training at SLAC was not standardized. In about 1993, after the Tiger Team audit and implementation of the Department of Energy (DOE) Radiological Control Manual, there was an improvement in the radiological control training program. This included developing and giving RCT Training, General Employee Radiation Training (GERT), and Radiological Worker Training.

External Dosimetry

There is good compliance with the requirement to wear personnel dosimeters in work areas. Personnel follow the RadCon rules at SLAC, because there is a high level of work ethics.

Starting in 1963, everyone onsite needing access to the research area was monitored with film badges. Initial experiments were conducted on campus, requiring monitoring prior to the start-up of SLAC. Film badges were still in use after the start-up. When the accelerator was first turned on, entry by visitors and non-SLAC personnel was restricted. This was done until the shielding could be verified as adequate. All non-SLAC personal entering the Research Yard were either escorted or assigned a personal monitor using a color-coded film badge holder.

When individuals passed through the Sector 30 gate into the research/accelerator area, they were required to show a dosimeter for entry. In 1966–1967, SLAC used a color-coded film badge holder, which was worn by staff in the research yard or areas surrounding the accelerator. Red and green badges were used for visitors or individuals who were not expected to receive a measurable dose and were provided with an escort. These badges were not read unless there was an accident/incident.

Security is responsible for issuing temporary dosimetry. If you enter the restricted area more than 8 hours in a calendar year, you must be assigned a dosimeter.

Any personnel assigned to work only in the support buildings and areas outside of the accelerator operations area (e.g., administrative staff that never entered radiological control areas), including contractors, probably would not have been issued neutron dosimeters; they were possibly issued the gamma dosimeters. Presently, in general, non-radiological worker personnel do not wear dosimeters continuously onsite; it depends on the area they are in. One site expert indicated that workers in the Klystron area or the Central Laboratory were not required to wear a dosimeter while he was assigned there.

All visitors were assigned dosimeters when entering the Accelerator Area in the past. Recently, DOE has recommended that SLAC reduce distribution of dosimeters for those not expected to receive 100 mrem/year.

Dosimeters are assigned based on the following frequencies:

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- Monthly for visitors or temporary badges (< 30 days)
- Quarterly for 'radiological worker trained and qualified' personnel (gamma/neutron – Luxel +, J Type Dosimeter)
- Annually for GERT qualified personnel who only enter Radiological Control Areas (gamma only, Luxel+, P type)

This frequency dates back to at least 1973. Radiation workers were initially on a monthly exchange, and then changed to a quarterly frequency. Other workers and visiting scientists were on an annual exchange frequency. [This population included] delivery personnel, visiting experimenters, and public relations tours. The primary reason for this procedure was to allow access to the research areas, and also to act as an accident radiation dosimeter (because this population was not expected to be exposed to >100 mrem per year). The archived record is from 1961–1973.

SLAC's current policy encourages individuals to leave dosimeters onsite in a rack. This is not enforceable at the present time. Historically, workers were allowed to take dosimeters home.

SLAC developed a TLD solid state system using Li6/Li7 powder. Later, a Teflon disk-type dosimeter from Teledyne was implemented. These dosimeters were about the size of a dime. The dosimeter was designed so that it could be carried in a worker's wallet.

Initially, SLAC had used Radiation Detection Company (RDC) as a processing vendor. After a few years, SLAC was using two-chip TLDs, which included lithium fluoride and calcium sulfate. From 1995 to 2001, SLAC had used a Panasonic dosimeter. Since 2002, SLAC has used Laudauer processing services. The Landauer dosimeter is a four-element dosimeter designed to measure shallow dose, lens of the eye dose, photon deep dose, and neutron deep dose. A study conducted on the level of beta exposure at SLAC found there was so little beta dose that SLAC was not required to be DOELAP-certified for beta. The photon energies encountered in the field range from hundreds of keV to MeV.

Neutron dosimetry has improved in quality over the years, but has always been as good as any in the industry for that era. NTA film was used for a short time to measure neutron dose—10%–20% of the neutron spectrum is below 500 keV–1MeV. Following NTA film, neutron dose was measured with CR-39 track etch. The CR-39 is effective for energies from ~100 keV to ~ 20 MeV, with a flat energy response from 0.1–20 MeV. Any neutron energies above 20 MeV are not measurable. Any positive neutron dose measured by the CR-39 is multiplied by a factor of two. These adjusted doses are accepted as the dose of record.

A fraction of the low-energy neutron dose is missed with both systems. SLAC worked with a team from Japan to measure the neutron energy spectra at SLAC. There was a comparison of special detectors with field instrument response. Based on field measurements and simulations, they were able to quantify neutrons by energy. The results of this study are included in Figure 2-4 of the NIOSH site profile. With this quantitative knowledge of the neutron energies, the undetected neutron dose from the NTA film or CR-39 can be calculated.

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The threshold reporting level, based on the uncertainty, is 10 mrem for quarterly and monthly dosimeters and 20 mrem for annual dosimeters. Values less than the Minimum Detectable Dose (MDD) are recorded as zero.

A fading study was completed for the Panasonic dosimeter. The results indicated there is an over-correction for fading.

Dosimeters are worn at the chest level. The source term is generally located in front of the individuals being exposed, because the bulk of the exposure occurs when individuals are fixing things. The use of extremity dosimetry is not routine, but special extremity dosimetry is used occasionally for assessment purposes. Multiple dosimetry is not used at SLAC.

The standard Landauer calibration is applied to the dosimetry system. Calibrations of the dosimeter tend to be conservative. SLAC conducts field verification studies to validate that the calibration is appropriate. Historically, TLDs were calibrated using a neutron source with a paraffin shield inserted between the source and the TLD at various distances. A moderated BF_3 detector was used for comparison.

Six Nano-dot Transit dosimeters come with each shipment from Landauer for evaluating transit dose. Dosimeters are processed by SLAC using a Micro Star reader. Quality Control (QC) and background control dosimeters are sent in with each batch. These QC controls and background controls are read by Landauer. SLAC evaluates the background levels and maintains these values in a background file.

In the early 1990s, SLAC participated in a blind dosimetry test of the personnel dosimetry system. Dosimeters were irradiated at Oak Ridge and returned to SLAC for evaluation. The results of the inter-comparison indicated that SLAC dosimeters had excellent precision and accuracy for neutrons, as well as gamma radiation.

Dose of record has only been adjusted once [for background/transit dose]. There was a problem associated with the background/transit dosimeter reading high for gamma dose as a result of a transit exposure. An adjustment of 10 mrem was removed from the gamma doses.

Administrative Control Level/Dosimetry Investigations

The first director at SLAC was one of the founders of accelerator Health Physics and believed Health Physics should be a part of accelerator research. He established an administrative control limit (ACL) of 1,500 mrem per year. A few years ago, the ACL was lowered to 500 mrem. As the energy and average power of the accelerator has dropped, a reduction in external dose and contamination has resulted.

Since 1993, only a few (maybe 1 or 2) employees have received doses of approximately 1 rem/year, and about 200 employees received 100–200 mrem/year. In recent years, about 10 to 15 employees get 100–200 mrem. The maximally exposed population is the MFD and the RCTs in Operational Health Physics. Last year's collective dose was 165 mrem for approximately

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3,000 users. The combination of accelerator power reduction, improvement in the ALARA and work planning program, and training have been important factors in lowering personnel doses.

Any dosimeter result of 500 mrem (administrative level) or more is considered an event that requires investigation. As a best-management practice, the dosimetry group investigates any situations where individuals receive greater than 0 mrem to verify that the dose is legitimate. In many cases, individuals receiving dose above 500 mrem usually received the dose as a result of a medical treatment or exposure offsite.

For lost dosimeters, a lost dosimeter form is completed. The form includes an area to record the activities conducted during the monitoring period, such as all areas where workers were performing their work. The individual has 15 days to locate and return the dosimeter. At the end of this time period, the dosimetry group starts an investigation. The dosimetry group evaluates the last four quarters of dosimeter results, coworkers' doses, and area monitoring doses. A dose assignment is made and recorded in the investigation and dosimetry records.

There are about 350 beta/gamma/neutron dosimeters onsite for the monitoring of area doses at SLAC, which are exchanged semi-annually. These dosimeters are used to verify the radiological postings. About 50 dosimeters are in general areas (offices, ordinary labs, etc.) outside of controlled areas and radiological controlled areas. These 50 dosimeters serve as background control dosimeters and can be used to estimate an external dose to staff members who do not wear dosimeters in these areas. The dosimeters used in the Radiological Environmental Monitoring program are processed by the dosimetry program. This program has been in place for quite some time.

Internal Dosimetry

There is a memorandum of understanding between SLAC and LLNL for bioassay services. Around 2007, personnel involved in the SSRL Nano-particle Program (maybe five or six) were sent to LLNL for baseline in-vivo counts and verification that no intakes had occurred since the Actinide Room started up in the 1990s. This in-vivo counting effort was done after the site profile was written, and therefore was not included in it. The amounts of actinides to be handled are limited by a "failure analysis" done for bounding doses (i.e., SLAC's goal is to remain a low hazard rated facility). LANL sent staff to SLAC to work with them on setting up the hazard controls in the room. Only a single site expert, who was involved in the Nano-particle Program, indicated he received an in-vivo count (body or chest count) and submitted bioassay samples.

Most of the contamination occurring at SLAC is from volumetric contamination. In 1993, the site issued the SLAC Internal Dosimetry TBD, which has undergone revision several times since then. This document provides justification for not conducting a routine bioassay program, and therefore, no routine urinalysis data are available.

Environmental Monitoring

For the potential radioactive effluent monitoring, the Environmental Protection Agency (EPA) has allowed SLAC to take confirmatory measurements. The confirmatory measurements utilize the Air Monitoring Systems (AMSs) at SLAC. Air is pumped from the vent in an accelerator housing into a pressurized and low-background tank where a GM detector is used to measure the short-lived airborne radionuclides produced inside the housing. The main long-lived radionuclides seen are Ar-41 and C-11. The tank has a filter on the entry point, so that potential radioactive particulate matter can also be filtered out and measured. All measurements are normalized back to the machine operation condition. The airborne radioactivity released in recent years is not measurable.

The beam dump for ESA is located under a hill that provides shielding. There is sufficient shielding for skyshine at the beam dump. In the skyshine process, neutrons can bounce 100 to 500 feet up into the air. The atmosphere scatters a portion of the neutrons back down and causes the skyshine.

The Perimeter Monitoring Station (PMS) sites were set up and running at least as early as 1965, before the accelerator was operational, in order to start collecting baseline background external radiation data. Site boundary PMSs measure potential real-time external dose, which includes skyshine or direct radiation doses that the public may receive. There is a book covering the complete initial construction of the accelerator facilities by R.B. Neal (nicknamed the "Big Book") that may help identify exactly when the PMS systems were installed.

These PMS locations were not moved from the start through the 1970s, and they collected both gamma/photon and neutron external radiation count data that were converted to dose. The gamma radiation was detected by a GM counting system, and the neutron radiation was detected by a BF_3 counting system at each station. Each detector system was connected to a printer that recorded the detected radiation. The printed data were collected and converted to average dose rates for both gamma and neutron dose separately. Each current PMS system includes a pair of BF_3 detectors and GM detectors to measure skyshine neutrons and photons, respectively.

SLAC conducted the first skyshine neutron studies, which were published in *Nuclear Instruments and Methods*. The major fraction of any doses detected above background, for example 90% or more, are caused by the skyshine from the accelerator from neutrons, as described in a 1974 *Health Physics Journal* published study. In 1990s, a semi-quantitative skyshine neutron spectra study was performed. This provided the calibration factors for the PMS neutron detection equipment. The doses are calculated using conservative neutron energy assumptions. Only a small fraction of neutron dose [from skyshine] is from high energy neutrons, because the scattering reduces energies. The results of the neutron study were presented at a Health Physics Society meeting.

SLAC prepared environmental monitoring reports prior to 1971. The external doses detected at the PMS sites were reported to the AEC in semi-annual "environmental radiation reports." The missing data records and reports through 1970 are likely to be in a records storage system at SLAC. The quality of the data from pre-1971 should be as good as the quality of the data from 1971 forward through the years of GM and BF_3 detector use at the PMS. There were no significant technical changes in the monitoring systems during these years.

The "Remote Monitoring System" (RMS) was designed and made at SLAC and was called BSOIC or "Beam Shutoff Ionization Chamber." The counting gas was ethane to make it sensitive to neutrons. A site expert believes it was a 1.5 liter ionization chamber with quality electronics. They were posted on the outside of each experimental building (Beam lines A, B, and C, and various other places); they worked very well, except when struck with a forklift. The ion chambers were checked with a small radioactive gamma-emitter as part of the Beam Checkout procedure.

SLAC has a site-boundary environmental dose measurement program using passive dosimeters for photons and neutrons (currently quarterly exchange). The state of California also has passive monitors at the boundary, but SLAC does not have the results.

There is a limited tritium plume near the Beam Dump East (near Building 730). A small fraction of the high-energy neutron beam penetrated the concrete shielding and activated the groundwater and soil during the 1970s. The tritium plume is about 20 feet underground, close to the beam dump, and is inaccessible. The situation was/is monitored and the activity has gone down over time.

No drinking water is coming from any groundwater on the site.

Waste Management

Any waste (hazardous or non-hazardous) containing a radioactive component is handled by the Radioactive Waste group. The Waste Management group handles only hazardous or non-hazardous (Class II) waste that does not contain a radioactive component.

Sources of radioactive waste include activated accelerator components, resin columns from the accelerator cooling water filtration system, radioactive samples from the Radiation Protection (RP) laboratory, old sealed sources, commercial items (i.e., smoke detectors), and shielding components. Radioactive waste items also include gloves, PPE, well water samples, core drillings, soil samples, Mixed Analyte Performance Evaluation Program (MAPEP) samples for laboratory quality assurance, and samples from radioactive components. SLAC does not generate any transuranic waste as a result of accelerator operations.

All offsite users of SSRL, and any other researchers, must take their samples back with their project when they leave. They do not dispose of anything the researchers bring with them.

When applicable, waste is analyzed using Gamma Spectroscopy or Liquid Scintillation Counting. Any detectable quantity is reported. The primary radionuclides identified in the accelerator-produced waste include Na-22, Mn-54, Co-57, Co-58, Co-60, Be-7, and tritium. Zn-65 has been detected in some waste accelerator components.

All waste coming out of radiological areas is surveyed and released by Radiation Protection prior to receipt by the Waste Management group. There is no removable radioactive contamination on external surfaces of waste containers routinely handled by the Radioactive Waste group.

The Radioactive Waste group handles about a half-gallon of tritiated vacuum pump oils per year, which they over pack into shipping containers and ship out. Any oil from a Radioactive Material

Management Area requires testing for radioactive material prior to receipt by waste management. Oil with any detectable radioactivity goes to the Radioactive Waste group. From time to time, there is a leak from the accelerator cooling system (containing tritiated water) into the vacuum pumps (with the pump oil) that are used to create a vacuum inside the accelerator beamline components. The Radioactive Waste group receives tritiated vacuum pump oil about once per year.

They have a storage area between Buildings 730 and 621 for large metal items that came from radiological areas, but are not radioactive per screening surveys (NaI and GM tube release surveys) and history knowledge. Shipment of this material offsite is not currently permitted, due to the existing DOE metal recycling moratorium for shipment. It is not likely for any surface soil to be contaminated from these items, as they are presumed non-radioactive. Hazardous waste is stored in a 90-day storage area under the requirements of Resource Conservation and Recovery Act.

SLAC de-waters radioactive resins and adds absorbent to waste items containing free-standing water. Radioactive waste is not held for decay of short-lived isotopes onsite.

SLAC disposes of radioactive waste in various ways. There are no burial grounds onsite. Commercial items, such as smoke detectors, are returned to the manufacturer for disposal when possible. In 2010, SLAC began a campaign to ship radioactive sources to the DOE Nevada Test Site for disposal. Starting in 2004, SLAC began shipping radioactive waste to Energy Solutions in Utah. Prior to this, waste was shipped to the DOE Hanford Site.

Typical shipping containers for radioactive waste include steel drums and boxes; super sacks are used for shipping radioactive soils.

An example of a work operation that potentially exposes personnel to radioactive contamination is handling radioactive resin containers. The containers are opened at the top to transfer the resin into a holding container, so that the water can be filtered/removed. During this work operation, personnel wear full personal protective clothing with RCT coverage for the job. When it is handled, the resin is wet.

Radiological Records

Following entry of dosimetry data into the Occupational Dose Tracking System (ODTS), there is follow-up quality control to ensure the data are correct. Reports on dosimeter results are sent to workers every cycle.

There is no incident database to the best of the current staff's knowledge. One site expert indicated that incident reports with personnel involvement should be in dosimetry files. Another site expert indicated that personal contamination events are documented on survey forms and include laboratory analysis to identify the radionuclide. These records are not likely captured in the dosimetry file.

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The radiological surveys and air samples have been scanned back to 1990 and are available electronically.

The first request for claimant dosimetry files was received in 2003. There are 5–10 requests for data per year. Information from the ODTS covering 1974 to present and RDC-archived hardcopy files from 1961 to 1973 are provided for claimants. The RDC printouts list multiple names per sheet. A summary of the dose is also provided.

Occupational Medical Exposure

The previous physician was a private subcontractor who provided medical services to SLAC. Prior to this, Palo Alto Medical Foundation staffed the physicians at SLAC. There was never an x-ray machine onsite. X-rays were done offsite if indicated. Site experts interviewed do not recall ever receiving medical x-rays as a part of medical physicals.

Through review of medical records, it appears that screening x-rays were not performed for routine medical surveillance at SLAC. There is currently no asbestos medical surveillance program at SLAC, as employees do not perform asbestos abatement. A limited number of SLAC employees have been screened for beryllium sensitization, and a screening chest x-ray was offered to these individuals and performed offsite if the employee consented to the x-ray. These x-rays were mostly performed at Alliance Occupational Health Center or Work Force Medical, and as far as Medical can see, only one-time chest x-rays were performed on those who consented (with no follow-up screening). It appears from review of the medical records that these were first offered in 1998.

Medical records are stored onsite for active employees only. Medical records for former employees are stored offsite. Medical has accession numbers available to retrieve records for employees whose employment ended after 1990. For those terminating prior to 1990, Medical currently does not have accession numbers and is not able to retrieve such records. Human Resources is involved in trying to locate these records.

[Note: One of four requested medical records was provided for review during the interview. The remaining three were not available, because no accession number could be provided for retrieval of the records from archive. The record reviewed indicated annual exams from at least 1966–1980. The Physical Examination Form and the Confidential Interim Medical History are two possible sources of information on x-rays.]

Incidents/Unusual Events

The Security Team is affiliated with the Emergency Response group. The site has its own fire department, which also responds to offsite emergencies. Officers are not authorized to go into the tunnels unless there is an emergency. There is a procedure in place that officers must contact the Radiological Control Organization (RCO) if they are required to respond to an emergency in a Radiological Control Area (RCA).

[Site experts collectively discussed the following incidents at SLAC.]

- In about 1994 or 1995, while drilling a hole in the klystron shielding, the oil that surrounds the electron gun shot radiated oil out all over the place. The individual involved ran from Building 26 to Building 25. The individual's clothing was confiscated as a result.

- There was an incident in 1967 where an individual brought a pipe bomb into the facility. The detonation caused damage to a part of the LINAC.

- A drum of radioactive concrete slurry from FFTB stored in RAMSY was found to be leaking in 2007. Gamma spectroscopy of a sample obtained from the general area prior to clean-up identified low levels of radioactivity (no readings above background were identified by field instrumentation). The area has been subsequently cleaned up.

- In approximately September 1998, an incident occurred in Sector 20 with a Positron Target. The Thullium/Tungsten target disintegrated, resulting in the largest surface contamination. Smears measured a maximum of 10,000 dpm/100 cm^2 beta. There was measureable clothing contamination as a result. One site expert believes individuals were sent to LBNL for chest counts following this incident. The incident was recorded in Occurrence Reporting and Processing System (ORPS).

- Prior to the startup of the Actinide Room, a staff member was sent to Technical Area (TA)-55 at LANL to observe the operation with Pu-239. He spent a few days getting training from LANL so he could learn how to monitor and take precautions for alpha emitters. During the visit, there was a release of Pu-239. As a result, LANL required submittal of bioassay (~1998). He was later sent to LLNL for a follow-up count.

One site expert indicated he was aware of no emergencies or fires in the history of SLAC involving dispersal of radioactive materials.

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Comments on the NIOSH Site Profile

Recommended updates to Table 2-1, pp. 11–12 of the NIOSH site profile.

Area	Period of Operation	Comment
LINAC Tunnel	1966–present	Since April 2008, only the last one-third of the tunnel has been used.
Klystron Gallery	1966–present	
End Station B	1966–1985 +/- 2 years	Since the B-Line was last used in the early 1980s, End Station B has housed the NLCTA.
End Station C	1966–present	The LCLS tunnel now passes through the area which was known as End Station C years ago.
BSY	1966–present	Up until the 1980s, the beam could be directed to one of three end stations (A, B or C) or to the PEP or SPEAR storage rings. Later, the SLC arcs were added. Now, the beams can be directed to the LCLS or End Station A.
SPEAR SSRL	1972–present	
PEP	1980–1991	
PEP-II	1998–April 2008	
SLC	1988–1998	
Next Linear Collider Test Accelerator	1993–present	

Recommended update to page 12, second paragraph, of the NIOSH site profile.

The first damping ring was built in 1978 rather than 1984.

[SC&A asked if it would be appropriate to apply the 1/r correction for estimating skyshine doses closer than the fence line, which would increase any environmental dose assigned as being same as the PMS doses.]

SLAC staff indicated if the location is within tens of meters close to the source point (which could vary, depending on which SLAC facilities are operating), the 1/r correction would be appropriate, but to estimate the far-distance public doses offsite, the $1/r^2$ is more appropriate.

Assuming the claimants get a fraction of the total dose detected by the environmental dosimeters is appropriate. Workers are at the site only a fraction of the total hours in a year, and the dosimeters record the dose at the stations every moment throughout the year.

There was a site visit conducted by Norm Rohrig [ORAUT] and two others in 2006. They went through a large amount of documents and scanned them. During this visit, the team interviewed [redacted] [SLAC], [redacted] [SLAC], and [redacted] [SLAC]. SLAC Radiological Protection staff received a copy of the draft NIOSH TBD and provided comments.

In 2007, SLAC had a DOE Compliance Audit by the Office of Independent Oversight (OIO). The OIO team raised several issues regarding the Radiation Protection program. They took exception to the way SLAC implemented radiological posting in some areas. Radiation Protection contracted with Norm Rohrig, the NIOSH Site Profile author, to work with ex-SLAC

Radiological Control Manager [redacted] on addressing the RWP and posting issues identified in the audit. SLAC did a benchmarking with similar facilities like BNL, Fermi National Laboratory, etc., and implemented best-management practices.

One site expert who reviewed the NIOSH TBD found it to be very general.

Miscellaneous

[SC&A asked one site expert to point out health physics related differences between different types of accelerators.]

There are significant differences between electron accelerators and proton and ion accelerators. The Fermi Accelerator is a proton accelerator and is not similar to the electron/positron accelerator at SLAC. Thomas Jefferson Laboratory is an electron/positron facility similar to SLAC. With a proton accelerator, there are approximately 100 times (2 orders of magnitude) more neutrons generated as prompt radiation over the whole neutron energy spectrum for the same power and energy of incident beam. Protons have higher mass than electrons and interact through nuclear reaction; they can more easily dislodge neutrons from an atom.

Beryllium exposure at the site is minimal. There is a small amount of Be-Copper alloy.

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