SC&A S. Cohen & Associates
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July 17, 2008

Mr. David Staudt
Center for Disease Control and Prevention
Acquisition and Assistance Field Branch
Post Office Box 18070
626 Cochrans Mill Road – B-140
Pittsburgh, PA 15236-0295

Re: Contract No. 200-2004-03805, Task Order 1: Draft Report SC&A-TR-TASK1-0019, Revision 1, *Pantex Plant Site Profile Review*

Dear Mr. Staudt:

SC&A is pleased to submit its draft report, *Pantex Plant Site Profile Review,* SC&A-TR-TASK1-0019, Revision 1. This report has been cleared by DOE and revised in accordance with a review for Privacy Act information, and is now cleared for unrestricted distribution.

Note that this draft report was the first one subject to DOE's still evolving review process, the objectives and elements of which were presented by DOE representatives at the last Advisory Board meeting in St. Louis. As such, SC&A experienced lengthy delays in both the initial security review of the report and a subsequent final review prior to public issuance. DOE is currently taking steps to reduce the cycle time for reviews of future SC&A reports.

Should you have any questions, please contact me at 732-530-0104.

Sincerely,

John Mauro, PhD, CHP
Project Manager

cc: P. Ziemer, Board Chairperson
Advisory Board Members
C. Branche, NIOSH
L. Elliott, NIOSH
J. Neton, NIOSH
S. Hinnefeld, NIOSH
L. Homoki-Titus, NIOSH
A. Brand, NIOSH
J. Broehm, NIOSH
C. Ellison, NIOSH
L. Shields, NIOSH
D. Sundin, NIOSH
A. Makhijani, SC&A
H. Behling, SC&A
M. Thorne, SC&A
H. Chmelynski, SC&A
J. Fitzgerald, Saliant
J. Lipsztein, SC&A
K. Robertson-DeMers, Saliant
S. Ostrow, SC&A
K. Behling, SC&A
T. Bell, Saliant
Project File (ANIOS/001/19)

Draft

ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

Pantex Plant Site Profile Review

Contract No. 200-2004-03805
Task Order No. 1
SCA-TR-TASK1-0019, Revision 1

Prepared by

S. Cohen & Associates
1608 Spring Hill Road, Suite 400
Vienna, Virginia 22182

Saliant, Inc.
5579 Catholic Church Road
Jefferson, Maryland 21755

July 2008

Disclaimer

This document is made available in accordance with the unanimous desire of the Advisory Board on Radiation and Worker Health (ABRWH) to maintain all possible openness in its deliberations. However, the ABRWH and its contractor, SC&A, caution the reader that at the time of its release, this report is pre-decisional and has not been reviewed by the Board for factual accuracy or applicability within the requirements of 42 CFR 82. This implies that once reviewed by the ABRWH, the Board's position may differ from the report's conclusions. Thus, the reader should be cautioned that this report is for information only and that premature interpretations regarding its conclusions are unwarranted.

S. Cohen & Associates: ***Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. SCA-TR-TASK1-0019 Effective Date: Draft — July 17, 2008 Revision No. 1 – DRAFT
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Project Manager: _____ Date: _____ John Mauro	

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ACRONYMS AND ABBREVIATIONS

AAO	Amarillo Area Office
ABRWH	Advisory Board on Radiation and Worker Health
AP	Anterior-Posterior
AEC	Atomic Energy Commission
ALOO	Albuquerque Operations Office
AMAD	Activity Median Aerodynamic Diameter
Bq	Becquerel
BWXT	BWX Technologies, Inc.
CFR	*Code of Federal Regulations*
Ci	Curie
CEDE	Committed Effective Dose Equivalent
DAC	Derived Air Concentration
DCF	Dose Conversion Factor
dpm	Disintegrations per Minute
DOE	Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
DU	Depleted Uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EPA	Environmental Protection Agency
ESE	Entrance Skin Exposure
EU	Enriched Uranium
FDA	Food and Drug Administration
GSD	Geometric Standard Deviation
HE	High Explosives
HEU	Highly Enriched Uranium
HP	Health Physics
HTO	Tritiated Water
HVL	Half Value Layer
IAAP	Iowa Army Ammunition Plant
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection

IMBA	Integrated Modules for Bioassay Analysis
IOP	Internal Operating Procedure
IREP	Interactive RadioEpidemiological Program
ISO	Isotropic
JTA	Joint Test Assembly
keV	Kilo electron Volt
kVp	Kilovolts-Peak
kg	Kilogram
LANL	Los Alamos National Laboratory
LAT	Lateral
LLNL	Lawrence Livermore National Laboratory
µCi	Microcurie
mA	Milliampere
MDA	Minimum Detectable Activity
MeV	Mega-electron Volt
MHSMC	Mason & Hanger-Silas Mason Company
mrad	Millirad
mrem	Millirem
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH Office of Compensation Analysis and Support Claims Tracking System
NTA	Eastman Kodak Nuclear Track Film Type A
NTS	Nevada Test Site
NVOO	Nevada Operations Office
NWAR	Nuclear Weapons Accident Residue
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
ORNL	Oak Ridge National Laboratory
OTIB	ORAU Technical Information Bulletin
PA	Posterior-Anterior
PFG	Photofluorography
pCi	Picocuries

POC	Probability of Causation
RFP	Rocky Flats Plant
ROT	Rotational
RPG	Radiation Protection Guideline
RST	Radiation Safety Technician
SC&A	S. Cohen and Associates
SEC	Special Exposure Cohort
SRDB	Site Research Database
SRS	Savannah River Site
TBD	Technical Basis Document
TEDE	Total Effective Dose Equivalent
TIB	NIOSH Technical Information Bulletin
TLD	Thermoluminescent Dosimeter
WLM	Working Level Month

1.0 EXECUTIVE SUMMARY

This report provides the results of an independent audit conducted by S. Cohen and Associates (SC&A) of the technical basis documents (TBDs) that make up the site profile for the Pantex Plant (Pantex) developed by the National Institute for Occupational Safety and Health (NIOSH). This audit was conducted in two phases. The first phase was directed at an evaluation of the Pantex TBDs and unclassified documentation available on the Site Research Database and in the public domain. It was conducted from November 1, 2006, to March 4, 2007. The second phase involved an onsite review of documentation (some of which is classified) and interviews with current and former workers. It was conducted from February 22 to March 9, 2007. This phased approach also enabled the onsite team to segregate its review of potentially "sensitive" information from other team members and the rest of SC&A until its resulting work had been reviewed and cleared by U.S. Department of Energy (DOE) classification reviewers. SC&A performed this audit in support of the Advisory Board on Radiation and Worker Health (Advisory Board) in the Board's statutory responsibility under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) to conduct such reviews and advise the Secretary of Health and Human Services on the "completeness and adequacy" of the EEOICPA program.

SC&A's review focused on the six TBDs that make up the Pantex site profile. These address the introduction to the issue, site description, internal dose, external dose, occupational medical dose, and occupational environmental dose as they pertain to historic occupational radiation exposure. These TBDs were issued from 2004 through 2006 and reissued in 2007 following a site visit by NIOSH in January 2007. As "living" documents, TBDs are constantly being revised as new information, experience, or issues arise. SC&A submitted questions to the staff of NIOSH and the Oak Ridge Associated Universities Team; however, responses were not available by the time this draft report was issued.

SC&A evaluated the TBDs for their completeness, technical accuracy, adequacy of data, compliance with stated objectives, and consistency with other site profiles, as stipulated in the *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). Attachment 1 provides a complete list of the TBDs and the supporting documents that SC&A reviewed. Supporting NIOSH technical information bulletins (TIBs) specifically applicable to the Pantex site profile are also included for completeness.

Pantex began operations for the Atomic Energy Commission in 1951 with a mission to machine precision high-explosive castings. The first operational activity at the Pantex Plant was weapons modification and assembly in the summer of 1952. The weapons dismantlement program has existed since 1952 (Pantex 1995). The early programs consisted of the inflight insertables design. In 1957, the complex implemented the use of a sealed plutonium pit design. The scope of operations expanded in 1975 with the transfer of similar weapons assembly and disassembly operations from the Iowa Army Ammunition Plant (IAAP) in Burlington, Iowa, to Pantex. An unprecedented expansion of operations took place following the end of the Cold War, beginning in the early 1990s, with the downsizing of the nuclear weapons inventory leading to increased disassembly operations and pit handling and storage.

Facilities at Pantex are primarily geared toward assembly, disassembly, retrofit, modification, and dismantling of nuclear weapons. These activities are conducted in bays and gravel gerties**.** Other key facilities include igloos for staging or interim storage of weapons, weapons components, and other process-related materials.

Assembly (and disassembly) involved the mating of high explosives (HE) with the nuclear components or physics package (i.e., bare as well as sealed pits). Once assembled, the physics package was inspected by means of radiography before final assembly of parts, including electronic components and the tritium reservoir. All of the processes are highly proceduralized and remain classified.

The major workplace radiation fields involve activities associated with nuclear weapons components, which contain plutonium, thorium, enriched uranium (EU), DU, tritium, and daughter products associated with these radionuclides. Maximum dose rates involve handling bare pits, and lower dose rates involve work with physics packages, fully assembled weapons, and pits in storage containers. Other sources of external exposures include high-energy x-rays produced by electron accelerators (and various sources, such as Co-60, Cf-252) used for radiography, testing, and instrument calibration.

The SC&A review found the Pantex site profile and its component TBDs to be, in places, inadequate in technical justification, incomplete in scope, and not representative of historic radiological exposure circumstances at the plant. In particular, reliance is placed on generalized dosimetry studies and hypothetical exposure assumptions that have not been confirmed as reflective of actual exposure conditions or dosimetry that had been in place at Pantex. While historic operations at IAAP and Pantex were almost identical in many respects, marked inconsistencies were found in how each set of site profile TBDs[1] characterized internal and external dosimetry. For example, the Pantex TBD (Hickey et al. 2007) gives a default maximum uptake for tritium of 5.8 microcurie (μCi) during the 1970s, whereas the TBD for IAAP gives an upper-bound chronic tritium intake of 4,902 μCi/year, or 13.4 μCi/day.

For internal doses, Pantex had no routine bioassay program before 1972 for uranium, thorium, and plutonium. In fact, with the exception of select radiological incidents, workers were not monitored for these radiation sources before 1991. Despite this, the internal dose TBD has as its central thesis the assignment of dose for unmonitored workers by using a single acute exposure of 40 derived air concentration (DAC)-hours per year for transuranics. Apart from the fact that the 40 DAC-hours per year benchmark was not even mandated for use at Pantex until 1991, with the issuance of the *Department of Energy (DOE) Radiological Control Manual* (DOE 1992), SC&A finds that the basis for its broad application is not supportable, given the inherent uncertainties involved over time (e.g., differences in work controls, monitoring sensitivities, and air-monitoring methods) versus the parameters cited, such as triggering air-sampling data, contamination levels, or numbers of assemblies or disassemblies (i.e., throughput). Likewise, the

[1] For IAAP, NIOSH replaced the prior set of detailed individual TBDs (internal, external, medical, environmental) with a single TBD following a Special Exposure Cohort determination for IAAP in 2005; for Pantex, NIOSH has updated each of the original TBDs (version "0") with new versions in 2007. In order to evaluate and compare the bases of comparable technical parameters, SC&A has made its comparisons between the original IAAP TBDs and the updated 2007 Pantex TBDs.

treatment in the TBD (Hickey et al. 2007) of the various radiological source terms at Pantex—tritium, uranium, thorium, plutonium, and radon—falls short of providing a technically plausible basis for performing dose estimation.

For tritium, the occupational internal dose TBD (Hickey et al. 2007) assumes that, "twice the highest uptake from the 1970s was to apply to all the years from 1957 to 1971," without any apparent foundation. For uranium, the modeling of DU exposures is based on severely limited monitoring data, incomplete exposure parameters, and questionable and unsupported assumptions, all of which when taken together undercut the technical credibility of the proposed approach. For uranium and thorium exposure sources, the use of a "scaling factor" for potential intakes as a means to reflect "improvements in radiation protection practice" over time is not justified. Sources of field data (e.g., air-sampling and smear results) are not available for comparison prior to the mid-1980s, since the decision was made by Pantex personnel to dispose of field monitoring records (see Attachment 4). Furthermore, missed dose is assigned for plutonium, while EU internal dose is not addressed.

For external doses, SC&A found that the early recorded deep doses at Pantex may not be reliable and that the TBD (Fix et al. 2007) does not recognize this issue. This discrepancy stems from the historic use of Cs-137 and Co-60 calibration sources for film dosimeters at Pantex, when in fact the dominant photon energy at the plant was due to the 60 kilovolt (keV) photon of Am-241 (from the plutonium pits), which is a factor of 10 lower, leading to an over-response for the open window of the film badge for deep dose. SC&A also found that key assumptions regarding the use of the 95th percentile neutron-to-photon ratio as bounding may not be correct, and that derived estimates of the photon and neutron doses for unmonitored workers may be too low. As was found with other site profiles, this TBD does not adequately acknowledge programmatic deficiencies in the Pantex personnel monitoring program, particularly the results of a 1980 DOE investigation (DOE 1980) that raise questions regarding the reliability of dose data generated by that program.

With respect to occupational environmental dose, SC&A believes that the limited data on meteorology presented in the TBD (Strom and Winslow 2007) and the lack of environmental surveys of onsite locations over time do not support these suppositions and conclusions regarding negligible dose. The TBD details some known episodic releases; however, it does not provide substantial or accurate estimates of dose for those episodes, and the TBD does not consider doses for unknown incidents. The lack of adequate environmental monitoring data indicates the need for alternative and more conservative approaches to estimate environmental dose contributions to workers. SC&A believes that NIOSH needs to reassess its chosen methodology to define a better upper-bound scenario to enhance claimant favorability.

Issues presented in this report are sorted into the following categories, in accordance with SC&A's review procedures:

(1) Completeness of data sources
(2) Technical accuracy
(3) Adequacy of data

(4) Consistency among site profiles
(5) Regulatory compliance

Following the introduction and a description of the criteria and methods employed to perform the review, the report discusses the major issues identified during SC&A's review. The issues were carefully evaluated with respect to the five review criteria. Several of the issues were designated as primary findings because they represent key deficiencies in the TBDs that need to be corrected and that have the potential to substantially impact at least some dose reconstructions. Others have been designated as secondary findings both to connote their importance for the technical adequacy and completeness of the site profile and to indicate that SC&A has judged them to have relatively less influence on dose reconstruction or the ultimate significance of worker doses so estimated.

1.1 SUMMARY OF FINDINGS

Finding 1: The internal dose TBD does not give sufficient attention to gaps in internal dose records and the historic lack of a routine bioassay program for internal dosimetry at Pantex. The proposed NIOSH approach is neither claimant favorable nor does it bound the conditions under which the employees were working. Although the presence of radioactive material at the site has existed since 1952, the bioassay program was limited to incident-based sampling for a majority of the Pantex operating period. Limited routine monitoring for tritium was initiated in 1976, although there were a few samples prior to that time. Thorium and plutonium bioassay began to a minimal extent in 1991 and 1992, respectively. Pantex did not have, and still does not have, a lung-counting capability for in vivo measurements of plutonium, americium, or uranium in the lungs of workers. Without lung-counting capabilities, there is no effective means of determining the buildup of chronic low-level exposures of insoluble plutonium, americium, uranium, and thorium. Air-sampling data may not be retrievable and, even if located, is not representative of the workers' breathing zone. As such, there is some reliance on source term data to determine which radionuclides posed potential internal exposure hazards, and regulatory limits of the time are in question. This makes it particularly important to understand the source terms introduced at Pantex and the issues associated with handling these source terms. Workers have provided valuable insight into which programs had the highest potential for internal exposure and what exposures likely occurred. In order to adequately characterize exposures at Pantex, a thorough understanding of radiological conditions and operations conducted is critical, which necessitates the consultation of classified references. Under ideal conditions with comprehensive personnel monitoring, the classified nature of a facility's operation might only have a marginal impact on the quality of the dose reconstruction methodology; however, in the near absence of internal monitoring data, the limited disclosure of processes and the compensatory use of dose models poses a serious handicap.

Finding 2: The TBD uses insufficient internal models for the assignment of internal dose from uranium. The TBD uses unsupported assumptions for modeling DU exposures and makes inappropriate use of the air-sampling detection limit for assigning uranium worker exposures. After reviewing the approach provided in the TBD (Hickey et al. 2007) and its use of a 19 picocuries (pCi) intake per day, SC&A finds too much inconsistency and an inappropriate

approach to dose reconstruction for Pantex workers exposed to uranium. Scaling factors for modeling DU exposures from 1994 to the present appear to have no clear technical basis. The internal DU model for unmonitored workers (1980–1993) may be inappropriate and not claimant favorable. Given that bioassay data at Pantex are very limited and have been event driven since 1993, NIOSH elected to use a worker bioassay data set that was derived from a radiological incident in February 1989. The TBD provides no confirmatory information that characterizes the "1989 contamination incident" in terms of verifying that the 305 assessed workers, in fact, represent assemblers/disassemblers, radiation safety technicians, and quality assurance personnel who, moreover, were employed for a full 10-year period, as assumed in the model. SC&A questions the basis of the assumption that unmonitored workers were no different from the 305 workers monitored in 1989, given the planned use of a median value that implies 50% of unmonitored workers will be assigned intakes and doses that are less than their true intakes/doses. The statement that "…doses to workers were reduced considerably from 1994," as indicated in Table 5-7 of the TBD, is inappropriate and misleading, given that all uranium bioassays only started in 1993 and were conducted in response to select events (most notably air-monitoring data) as opposed to routine worker bioassays. Finally, kilogram quantities of EU were handled at Pantex. The internal dose TBD recognizes that plutonium was handled in a sealed form and assigns a potential missed dose from plutonium. EU presents the same potential for exposure, yet the TBD has not addressed potential missed dose from this source.

Finding 3: The internal dose TBD has insufficient consideration of potential dose from thorium and transuranics. The TBD does not adequately justify use on a scientific basis of an assumed single acute exposure of 40 DAC-hours per year to assign internal doses for thorium and transuranics to unmonitored workers, and the practice may not be claimant favorable. In the absence of routine bioassay data for plutonium and thorium, a single acute exposure of 40 DAC-hours per year is assigned to unmonitored workers. This is not adequately justified prior to 1991 and may not be claimant favorable. The use of the 40 DAC-hour annual exposure recommended by this TBD, which equates to 100 mrem total effective dose equivalent (TEDE), may not be detected, and is not supported by the DOE findings and investigation report (DOE 2001), even for workers as late as 2000, with all the latest sensitivities and air-monitoring capabilities taken into consideration. For workers that had in fact been monitored based on the 40 DAC-hour criterion (but for whom no records exist), the assigned value of 40 DAC-hours may only represent a lower bound or threshold value. For thorium, the assumption of an acute uptake in unmonitored thorium workers during disassembly is inconsistent with the TBD argument for chronic exposure to DU workers during disassembly, given documented incidents of thorium contamination problems as early as the 1960s, although the exposure conditions for both types of workers are similar. The internal dose TBD also incorrectly indicates that thorium exposures did not occur prior to 1980 and does not account for potential thorium exposure prior to 1980. Furthermore, for each of the four annual assigned intakes of thorium, NIOSH employed a DAC value of 1×10^{-12} μCi/milliliter (ml). This value corresponds to the value in International Commission on Radiation Protection (ICRP) 30 (ICRP 1979), which has been significantly revised upward in ICRP 68 (ICRP 1994). Thus, all annual thorium intakes derived above are a factor of 3 too low if the more current DAC value applies. In summary, the dose assignments stipulated do not represent a maximum bounding dose for workers under conditions that existed at Pantex, especially during disassembly operations.

Finding 4: Methods for assignment of photon and neutron dose are not clearly defined within the external dose TBD and are likely too low for unmonitored workers. Derived estimates of the photon and neutron dose for unmonitored workers are likely to be too low. Pantex worker photon dose statistics, as defined in the TBD (Fix et al. 2007), are based solely on dosimeter records for monitored workers whose photon dose was equal to or greater than 30 mrem per monitoring period. For the 10-year period of 1952–1962, dosimeters were exchanged weekly, which may explain the fact that for the period 1952–1958, all Pantex recorded doses (for monitored workers) were less than 30 mrem. Thus, on the basis of these statistics and guidance, all unmonitored workers would also not be assigned any photon or neutron doses for the years 1952–1958. For years 1959 to the present, the exclusion of missed photon doses for deriving the median dose of monitored workers will also impact the estimated dose for unmonitored workers. SC&A does not consider the current guidance for dose reconstruction of unmonitored workers claimant favorable. For deriving photon and neutron doses for unmonitored workers, missed photon doses for monitored workers should be included.

Finding 5: The TBD provides criteria that appear to be contradictory for determining which Pantex workers were monitored. There is an apparent contradiction in the historic benchmark cited as determining who would have been assigned a dosimeter at Pantex—(1) those who could receive an external radiation dose greater than 10% of the radiation protection guideline of **5 rem**/year or (2) those (in the early years) who could receive a **weekly** dose control of **0.3 rem.** Both are cited in the TBD without clarification of when and how they would have been applied.

Finding 6: The interpretation of the external dosimetry data may not be reliable. This concern is manifest in at least two aspects of the historic external dosimetry program at Pantex:

(a) **Early recorded deep dose (Hp10) may not be reliable.** It is clear that for proper assessment of a film dosimeter, calibration curves must be used that resemble photon energies of the work environment. The dominant photon energy for Pantex workers was the 60 keV photon associated with Am-241, which is a factor of 10 lower than the calibration photon energy for Co-60 and/or Cs-137, which had been used historically at the plant. The use of Cs-137 or Co-60 as the calibration source for the dominant workplace photon energy of 60 keV would lead to an **over-response for the open window** (as a result of photographic film containing silver bromide with Z values of 47 and 35, respectively) and an **under-response for the deep dose**, which is subject to the attenuation effects of 1000 milligrams per centimeter squared (mg/cm^2) (or 0.88 millimeters (mm)) of lead, which has a Z value of 82.

(b) **Calibration and dosimeter processing methods by outside contractor services cannot be assumed without further information.** The TBD acknowledges the use of three contractor services between 1952 and 1973 for processing film dosimeters. While the competency of these vendors is not questioned, it is without basis to assume without further information that each would have used the proper calibration curves that matched the expected photon energies of the Pantex work environments, with the proper calibration sources and their corresponding calibration curves. Given the variability of photon energies to which workers may have been exposed and the highly classified

nature of the Pantex operations, it is reasonable to question whether vendor dosimeter services can be expected to have known which calibration curves to apply to individual Pantex dosimeters.

Finding 7: The assumption that the 95th percentile neutron-to-photon ratio is bounding is incorrect for some exposure scenarios. NIOSH's assumption that the post-1993 neutron-to-photon ratio of 1.7 is a bounding value is based on the fact that post-1994 data reflect reduced photon doses associated with dosimeter readings under a lead apron, which heavily attenuated the 60 keV photon from Am-241 and, therefore, maximized the neutron-to-photon ratio. Surveys reviewed indicated ratios from particular weapons exceeded the 1.7 ratio established as bounding. SC&A identified empirical measurements made by instruments that suggest neutron-to-photon ratios for pits in shipping containers and pits with HE that exceed the 95th percentile value of 1.7 (DOE 1980, Pantex 1992, Pantex 1993, Pantex 1994, Pantex 1995a, Pantex 1995b). A review of survey records for weapons in various configurations indicates that the neutron-to-photon ratio is dependent on weapons type, shielding, and distance between the individual and the source. Survey information showed that work with units in stands or units stored in containers resulted in an increased neutron-to-photon ratio (Pantex 1992, Pantex 1993, Pantex 1994, Pantex 1995a, Pantex 1995b), as compared to bare components. Although lead aprons do reduce the photon component of the ratio, this does not compensate for all variables that influence the neutron-to-photon ratio. Based on the DOE study in 1980, a neutron-to-photon ratio of about 8:1 was also observed for workers monitored in 1960; and when the inefficiency of Eastman Kodak Nuclear Track Film Type A film is taken into consideration, the neutron-to-photon ratio for 1960 dosimetry data may actually exceed 30:1. These higher neutron-to-photon ratios would apply to selected workers associated with assembly/disassembly, shipping and receiving, inspection, storage, transportation, and support services.

Finding 8: The external dose TBD does not adequately consider workplace exposure conditions. In its analysis of workplace radiation fields, the external dose TBD has not provided an adequate basis for assigning partial body exposures during weapons component handling. Dosimeters were worn at the collar, as instructed by health physics staff. The highest exposures may have been at the waist or lower, resulting in an underestimate of dose to organs at waist level. The assignment of whole-body penetrating dose in situations where nonpenetrating dose is unavailable may underestimate the dose, particularly in situations where uranium is involved. Exposures from skin contamination were possible with weapons programs involving oxidized metal. External exposure from this route should be considered for skin cancers.

Finding 9: Radon doses are inappropriately assigned to underground workers and no radon dose is assigned to aboveground workers:

(a) **The use of 0.4 as the equilibrium factor is inappropriate and without scientific basis.** A review of these references indicates that the value of 0.4 was intended to serve as a "typical" value for the indoor air of **residential homes** and not for unique facilities, such as a gravel gertie or bay. Given the unique function and design of gravel gerties and bays, an equilibrium factor should be based on building ventilation specifications, which should be readily available.

(b) **The use of a median radon value representing all "underground" buildings at Pantex is inappropriate.** The TBD (Hickey et al. 2007) shows that for **all** underground buildings at Pantex, measured radon levels varied from 0.8 pCi/liter (l) to 7.1 pCi/l, with a geometric mean of 1.5 pCi/l. It should be noted that for any given building, the estimated radon concentration was limited to a single measurement. Since it is unlikely that workers were periodically rotated among these buildings, the use of the geometric mean would severely underestimate radon exposures to those workers assigned to buildings with the highest levels.

(c) **The TBD fails to assign radon exposure doses to workers/personnel assigned to aboveground buildings.** The TBD (Hickey et al. 2007) indicates that radon levels for aboveground buildings were comparable to underground buildings. In fact, the single highest radon measurement for **all** buildings at Pantex was the aboveground DOE building with a radon level of 8.1 pCi/l.

Finding 10: The internal dose TBD fails to consider early tritium exposures and does not consider all chemical forms of tritium. SC&A questions NIOSH's assumption that 99% of the tritium source term at Pantex is in the form of gaseous molecular hydrogen, with only 1% as tritiated water vapor. The TBD does not mention supporting evidence that the tritium from these aged units had not reacted with the metal reservoir and formed a tritide. Compounds other than tritiated water, such as metal tritides, would be expected to have substantially longer residence times in the body and, therefore, a higher dose than what is assumed for tritiated water. In document searches and interviews performed by SC&A, some of the Pantex workers recognized that tritides were present in some of the operations. Issue A in RSD-TBD-0036, *Metal Tritides—Technical Basis Document* (Jones and Levell 2004), addressed some of the concerns and issues regarding tritides and the disassembly program types that may have metal tritides present. Bioassay techniques for monitoring exposure to tritium do not work for monitoring metal tritides, as has been noted in previous SC&A reviews, such as those for the Mound and Savannah River sites.

Finding 11: Table 5-8 in the TBD contains unexplained and unreasonable extreme changes in sensitivity values for uranium urinalysis and minimum detectable activity (MDA), as well as significant data gaps. The TBD (Hickey et al. 2007) shows an apparent improvement in sensitivity values of two orders of magnitude between 1960 and 1963, which then diminishes by a factor of 50 between 1968 and 1978. Gaps also appear in the data with no historical information on sensitivity from 1968–1978, 1978–1983, and 1983–1990. With these inherent uncertainties and wide variations in values, SC&A does not believe the TBD provides a technically valid basis for applying uranium bioassay analysis data to coworker applications and intake calculations spanning these gaps and years.

Finding 12: Improper adjustment factors are applied for lead apron use. SC&A questions how NIOSH will establish whether workers actually used lead aprons appropriately and wore their dosimeters under their aprons, as required, given the acknowledged lack of procedures regarding wearing lead aprons. While SC&A agrees with NIOSH's use of its adjustment factor of 1.5 as an upper-bound value for converting under-the-apron recorded dose to a dosimeter dose for a photon spectrum "hardened" by the steel containers (for workers exposed in igloos), for

other locations and source terms where the radiation fields were dominated by low-energy photons (e.g., 60 keV) and an anterior-posterior geometry, adjustment factors considerably larger than 1.5 must be assumed.

Finding 13: Adequate consideration has not been given to the potential exposures at the firing sites. Consideration of dose assignment from hydroshot and burning operations should be conducted to adequately reflect potential internal and external exposures, particularly from cleanup activities and incidental entries into these areas. Based on a limited amount of air-sampling data, NIOSH developed inhalation dose models for site operators and drivers that are based on 95th percentile values and appear to be claimant favorable. SC&A reviewed available air-sampling data from Firing Station 4 starting October 27, 1959, and ending December 22, 1961, and compared these data with information presented in Figures 5-1 and 5-2 of the TBD (Hickey et al. 2007). The raw data SC&A reviewed does not support use of the 95th percentile of the 1960s outside air concentration of 24 pCi/m^3 as appropriate or claimant favorable. SC&A questions the use of 1 DAC-hour in this case and finds it inconsistent with other calculated intakes for unmonitored workers, particularly considering the nature of the fired materials that were being remediated. Finally, the 19 pCi/day intake factor at Pantex is inconsistent with that used for IAAP.

Finding 14: Inconsistencies exist between the principal assumptions in the Pantex TBDs and the original IAAP TBDs. Given the similarity of the two plants, their operations, and missions, it is not surprising that most descriptions, information, data, and references cited in ORAUT-TKBS-0018, *Technical Basis Document for Atomic Energy Operations at the Iowa Army Ammunition Plant (IAAP)* (ORAUT 2005), are either identical to or closely parallel to those cited in the Pantex site profile, including those involving external radiation exposure. However, SC&A found notable differences between ORAUT-TKBS-0018 and the Pantex TBDs regarding how early recorded film dosimeter measurements are viewed and employed for dose reconstruction. The IAAP TBD indicates that there is considerable uncertainty as to whether the IAAP dosimeter badge could reliably measure a penetrating dose from the 60 keV photons from Am-241, while the Pantex TBD (Fix et al. 2007) concludes that photon doses measured at Pantex by film badges were reliable. Moreover, the Pantex TBD states that photon exposures from 60-keV Am-241 photons were not underestimated, and the total photon dose was probably slightly overestimated because of the over-response to photons in the 100- to 200-keV energy region. These respective interpretations are apparently derived from the same site experts and historic references.

Finding 15: The TBD does not sufficiently discuss internal incidental exposures. SC&A is concerned about radiological incidents not identified in the TBD and for which the personnel files do not include bioassay data. The internal dose reconstruction assumptions for plutonium and thorium indicate that a single acute intake should be assumed. Exposures to these radionuclides are usually the result of incidental exposure to radionuclides, rather than continuous exposures. The TBD should outline incidents resulting in exposure to workers to inform the dose reconstructor of potential exposure situations. Furthermore, the monitoring for incidents and exposure to cleanup workers from these incidents should be carefully evaluated to determine the completeness and adequacy of monitoring data available.

Finding 16: The TBD fails to adequately define and assess the occupational medical dose to workers. SC&A's concern is that specified "high-risk" workers, those most likely to be exposed to radiation and beryllium, would be at risk of having an incomplete medical dose assessment if all radiation associated with medical screening for job-related activities were not included. Given that all radiation provides some risk and, arguably, is cumulative, all forms of work-related x-ray exposure warrant consideration for purposes of claimant favorability. SC&A believes NIOSH should review its interpretation of included medical exposures as a condition of employment and should reasonably adopt a broader interpretation of occupational medical dose, as provided in ORAUT-TKBS-0013-3 (Winslow and Thomas 2007). The TBD (Winslow and Thomas 2007) does not provide documentation for the types of equipment in use at Pantex prior to 1967. SC&A believes it is not claimant favorable to instruct dose assessors to assume no use of photofluorography (PFG) units at Pantex. To be fully claimant favorable, it would be more appropriate to instruct dose assessors to use an annual dose estimate of 3.0 rem per year for each chest radiograph prior to 1957, in accordance with guidelines set forth in ORAUT-OTIB-0006 (Kathren 2005).

Finding 17: The TBD does not address internal and external exposure from offsite and nonroutine operations conducted by Pantex workers as employees of Pantex. Pantex workers were involved in offsite operations, such as the Tweezer Project at Nevada Test Site (NTS), weapons accident recovery, and field modifications of weapons. Pantex also received and evaluated debris and components from joint test assembly operations and weapons accidents. This extramural work potentially exposed Pantex workers to different source terms while at other facilities and while working with damaged weapons components. The TBD should evaluate the details of personnel monitoring and its adequacy for these source terms as well as unique exposure conditions. Verification that Pantex claimant files include exposures from these activities is necessary.

2.0 SCOPE AND INTRODUCTION

2.1 REVIEW SCOPE

Under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) and federal regulations defined in Title 42, Part 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational illness Compensation Program,* of the *Code of Federal Regulations* (42 CFR Part 82), the Advisory Board on Radiation and Worker Health (Advisory Board) is mandated to conduct an independent review of the methods and procedures used by the National Institute for Occupational Safety and Health (NIOSH) and its contractors for dose reconstruction. As a contractor to the Advisory Board, S. Cohen and Associates (SC&A) has been charged under Task 1 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 following six technical basis documents (TBDs) related to historical occupational exposures at the Pantex Plant (Pantex):

- ORAUT-TKBS-0013-1, *Pantex Plant—Introduction,* Revision 02, Oak Ridge Associated Universities Team, May 11, 2007 (Martin 2007a)

- ORAUT-TKBS-0013-2, *Pantex Plant—Site Description,* Revision 02, Oak Ridge Associated Universities Team, May 8, 2007 (Martin 2007b)

- ORAUT-TKBS-0013-3, *Pantex Plant—Occupational Medical Dose,* Revision 02, Oak Ridge Associated Universities Team, February 1, 2007 (Winslow and Thomas 2007)

- ORAUT-TKBS-0013-4, *Pantex Plant—Occupational Environmental Dose,* Revision 01, Oak Ridge Associated Universities Team, June 22, 2007 (Strom and Winslow 2007)

- ORAUT-TKBS-0013-5, *Pantex Plant—Occupational Internal Dose,* Revision 01, Oak Ridge Associated Universities Team, June 22, 2007 (Hickey et al. 2007)

- ORAUT-TKBS-0013-6, *Pantex Plant —Occupational External Dose,* Revision 01, June 22, 2007 (Fix et al. 2007)

These documents are supplemented by NIOSH technical information bulletins (TIBs), which provide additional guidance to the dose reconstructor. Attachment 1 provides a complete list of these documents.

NIOSH also developed "workbooks" for selected sites to provide implementation guidance and more definitive direction to the dose reconstructors on how to interpret and apply TBDs and other available information.

SC&A, in support of the Advisory Board, has critically evaluated the revised Pantex TBDs to achieve the following:

- Determine the completeness of the information gathered by NIOSH for the site profile 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 use of the data in dose reconstructions.

SC&A's review of the six TBDs focused on the quality and completeness of the data that characterized the facility and its operations and the use of these data in dose reconstruction. The review was conducted in accordance with *Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004), which was approved by the Advisory Board.

SC&A directed the review 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 deriving dose reconstructions, bridging uncertainties, or correcting technical inaccuracies. This review does not explicitly address the issue of radiation exposures to cleanup workers and decommissioning workers, as that issue is not addressed in the TBDs.

The six TBDs serve as site-specific guidance documents used in support of dose reconstructions. These site profiles provide the dose reconstructors with consistent general information and specifications to support their individual dose reconstructions. SC&A prepared this report to provide the Advisory Board with an evaluation of whether and how the TBDs can support dose reconstruction decisions. The criteria for evaluation include whether the TBDs provide a basis for scientifically supportable dose reconstruction in a manner that is adequate, complete, efficient, and claimant favorable. Specifically, SC&A evaluated these criteria to ascertain if dose reconstructions based on the TBDs would provide for robust compensation decisions.

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

This review is based on the evaluation of public documents (e.g., TBDs, TIBs, and other documents in the public domain) and classified documents. A classification officer at BWX Technologies, Inc. (BWXT) Pantex examined the report and redacted sensitive information to facilitate release of the document to the Advisory Board and members of the public. Redactions were minimal and primarily involved limited issues with external dosimetry and site expert interviews.

For this review, the need to assess classified information mandated significant changes to the standard review process. To accommodate this issue, only two members of the SC&A team with appropriate clearances reviewed classified documents. Initial inspection of these documents

occurred at the Pantex Plant during the site visit. Select classified documents were sent to the DOE Richland Document Control Center for further review. Classified versions of interview and document notes were also sent to this location. A limitation imposed by classified data is that no open discussion among SC&A team members was permitted. Under the rules that govern classified data, only redacted "information" that provides limited insight regarding the technical issues can be provided to those noncleared SC&A members or other members without an established need to know.

2.2 REVIEW APPROACH

SC&A used a two-phase approach for the Pantex review. The first phase involved a review of existing public documentation, primarily including the TBDs, TIBs, and other documents that describe historic operations or dosimetry practices. Questions identified during this phase were compiled and submitted to NIOSH on January 22, 2007, for review and response (see Attachment 2), although to date responses have not been received. The second phase involved interviews and document retrieval at the Pantex site, some of which involved classified or otherwise sensitive information. Information from these data sources were incorporated into the TBD review, and the draft report was provided to DOE for classification review. The report was redacted as necessary by DOE and turned over to members of the SC&A team not involved in the onsite visit to prevent introduction of classified information into the report.

3.0 ASSESSMENT CRITERIA AND METHODS

SC&A was charged with evaluating the approach set forth in the site profiles that is used in the individual dose reconstruction process. SC&A reviewed these documents 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). As part of its evaluation, SC&A attempted to (1) identify and verify sources of information used by NIOSH for developing dose models, (2) critically evaluate assumptions in instances where data were unavailable, and (3) compare the dose reconstruction methodology proposed for Pantex with other comparable DOE facilities for consistency. This review is specific to the Pantex site profile, supporting TIBs, and dose reconstruction worksheets; however, items identified in this report may be applied to other facilities, especially facilities with similar source terms and exposure conditions. This 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.

3.1 OBJECTIVES

SC&A reviewed the site profile with respect to the degree to which technically sound judgments or assumptions are employed. In addition, the review identifies assumptions by NIOSH that give the benefit of the doubt to the claimant.

3.1.1 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 two elements examined under this objective include (1) determining if the site profile made use of available data considered relevant and significant to the dose reconstruction, and (2) investigating whether other relevant/significant sources are available but were not used in the development of the site profile. For example, if data are available in site technical reports or other available site documents for particular processes, and if the TBDs have not taken these data into consideration where they should have, this would constitute an issue related to the completeness of data. SC&A evaluated the NIOSH site profile document database, including the referenced sources in the TBDs, to determine the relevance of the data collected by NIOSH to the development of the site profile. Additionally, SC&A evaluated records related to the Pantex site, both those publicly available and those provided by site experts.

3.1.2 Objective 2: Technical Accuracy

SC&A reviewed the site profile with respect to Objective 2, which requires SC&A to perform a critical assessment of the methods used in the site profile to develop technically defensible guidance or instruction, including evaluating field characterization data, source term data, technical reports, standards and guidance documents, and literature related to processes that occurred. The goal of this objective is first to analyze the data according to sound scientific principles and then to evaluate this information in the context of compensation. If, for example,

SC&A found that the technical approach used by NIOSH was not scientifically sound or claimant favorable, this would constitute a technical accuracy issue.

3.1.3 Objective 3: Adequacy of Data

SC&A reviewed the site profile with respect to Objective 3, which 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. Review of 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.

3.1.4 Objective 4: Consistency among Site Profiles

SC&A reviewed the site profile with respect to Objective 4, which requires SC&A to identify common elements within site profiles completed or reviewed to date, as appropriate. In order to accomplish this objective, SC&A compared the Pantex TBD to the current TBD (OCAS 2005b) for IAAP, which was a sister plant to Pantex. Attachment 3 provides a detailed analysis of this review. In the case of Finding 13, SC&A used the data derived for dose assignment from ORAUT-TKBS-0018 (ORAUT 2005) to evaluate the difference between values originally assumed for IAAP and those assumed in the current Pantex TBDs. When the IAAP TBD (OCAS 2005b) was reissued, sections on internal and environmental dose were removed or substantially shortened as a result of the SEC status adopted for IAAP. This revised TBD indicates that internal dose reconstruction is not possible at IAAP.

3.1.5 Objective 5: Regulatory Compliance

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 the 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 used for the performance of dose reconstructions. In order to place the above objectives into the proper context as they pertain to the site profile, it is important to briefly review the key elements of the dose reconstruction process, as specified in 42 CFR Part 82. Federal regulations specify that a dose reconstruction can be broadly placed into one of three discrete categories. These three categories differ greatly in terms of their dependence on and the completeness of available dose data, as well as on the accuracy/uncertainty of data.

Category 1: Least challenged by any deficiencies in available dose/monitoring data are dose reconstructions for which even a partial assessment (or minimized dose(s)) corresponds to a probability of causation (POC) value in excess of 50% and ensures compensability to the claimant. Such partial/incomplete dose reconstructions with a POC greater than 50% may, in some cases, involve only a limited amount of external or internal data. In extreme cases, even a total absence of a positive measurement may suffice for an assigned organ dose that results in a

POC greater than 50%. For this reason, incomplete/missing data or uncertainty of the measurements may only marginally affect dose reconstructions in this category. In fact, regulatory guidelines recommend the use of a partial/incomplete dose reconstruction, the minimization of dose, and the exclusion of uncertainty for reasons of process efficiency, as long as this limited effort produces a POC of greater than or equal to 50%.

Category 2: The second category of dose reconstruction defined by Federal guidance involves the use of "worst case" assumptions. The purpose of worst case assumptions in dose reconstruction is to derive maximal or highly improbable dose assignments. For example, a worst case assumption may place a worker at a given work location 24 hours per day and 365 days per year. The use of such maximized (or upper-bound) values, however, is limited to those instances where the resultant maximized doses yield POC values below 50%, which are not compensated. For this second category, the dose reconstructor needs only to ensure that all potential internal and external exposure pathways have been considered.

The obvious benefit of worst case assumptions and the use of maximized doses in dose reconstruction is efficiency. Efficiency is achieved because maximized doses avoid the need for precise data and eliminate consideration for the uncertainty of the dose. Lastly, the use of bounding values in dose reconstruction minimizes any controversy regarding the decision to deny a claim.

To satisfy this type of dose reconstruction, the TBD must provide information and data that clearly identify all potential radionuclides, all potential modes of exposure, and upper limits for each contaminant and mode of exposure. For external exposures, therefore, maximum dose rates must be identified in time and space that correspond to a worker's employment period, work locations, and job assignment. Similarly, in order to maximize internal exposures, highest air concentrations and surface contaminations must be identified.

Category 3: The most complex and challenging dose reconstructions consist of claims where the case cannot be dealt with under one of the two categories above. For example, when a minimum dose estimate does not result in compensation, a next step is required to make a more complete estimate. Alternatively, when a worst case dose estimate that has assumptions that may be physically implausible results in a POC greater than 50%, a more refined analysis is required. A more refined estimate may be required either to deny or to compensate. In such dose reconstructions, which may be represented as "reasonable," NIOSH has committed to resolve uncertainties in favor of the claimant. According to 42 CFR Part 82, NIOSH interprets "reasonable estimates" of radiation dose to mean the following:

> *…estimates calculated using a substantial basis of fact and the application of science-based, logical assumptions to supplement or interpret the factual basis.*
> ***Claimants will in no case be harmed by any level of uncertainty involved in their claims, since assumptions applied by NIOSH will consistently give the benefit of the doubt to claimants.*** [Emphasis added]

In order to achieve the five objectives described above, SC&A reviewed each of the six TBDs, their supplemental attachments, and related TIBs, giving due consideration to the three categories of dose reconstructions that the site profile is intended to support.

ORAUT-TKBS-0013-1, *Pantex Plant—Introduction* (Martin 2007a), explains the purpose and the scope of the site profile. SC&A was attentive to this section because it explains the role of each TBD in support of the dose reconstruction process. During the course of its review, SC&A was cognizant of the fact that the site profile is not required by EEOICPA or by 42 CFR Part 82, which implements the statute. NIOSH developed site profiles as a resource to the dose reconstructors for identifying site-specific practices, parameter values, and factors that are relevant to dose reconstruction. Based on information provided by NIOSH personnel, SC&A understands that site profiles are living documents, which are revised, refined, and supplemented with TIBs as required to help dose reconstructors. Site profiles are not intended to be prescriptive nor necessarily complete in terms of addressing every possible issue that may be relevant to a given dose reconstruction. Hence, the introduction (Martin 2007a) helps in framing the scope of the site profile. NIOSH may want to include additional qualifying information in the introduction to this and other site profiles describing the dose reconstruction issues that are not explicitly addressed by a given site profile.

ORAUT-TKBS-0013-2, *Pantex Plant—Site Description* (Martin 2007b), describes the facilities, processes, and historical information that serve as the underpinning for other Pantex TBDs. Specifically, this document provides an overview of the processes and operations that were conducted at the various facilities on the Pantex site and the associated sources of exposure relevant to dose reconstruction. SC&A's review of this section specifically addresses whether all of the potentially important site activities and processes are described, and whether characterization of source terms is complete/sufficient to support dose reconstruction. Characterization of the site for dose reconstruction is complicated by the significant amount of classified data, which provide more complete information on operations at Pantex. The TBD was issued as an unclassified document and, thus, does not clearly reflect all operations and source terms present at the site.

ORAUT-TKBS-0013-3, *Pantex Plant—Occupational Medical Dose* (Winslow and Thomas 2007), provides a set of procedures for reconstructing the radiation exposures of workers from medical radiographic procedures that were required of employees at the Pantex site. SC&A reviewed this section for technical adequacy and consistency with other NIOSH procedures and compared these with the Pinellas, Paducah, Mound, Oak Ridge National Laboratory (ORNL), and Los Alamos National Laboratory (LANL) site profiles.

ORAUT-TKBS-0013-4, *Pantex Plant—Occupational Environmental Dose* (Strom and Winslow 2007), provides background information and guidance to dose reconstructors for reconstructing the doses to unmonitored workers outside of the facilities at the site who may have been exposed to routine and episodic airborne emissions from these facilities. SC&A reviewed this section from the perspective of the source terms and the atmospheric transport, deposition, and resuspension models used to derive the external and internal doses to these workers.

ORAUT-TKBS-0013-5, *Pantex Plant—Occupational Internal Dose* (Hickey et al. 2007), presents background information and guidance to dose reconstructors for deriving occupational internal doses to workers. SC&A reviewed this section with respect to background information and guidance regarding the types, mixes, and chemical forms of the radionuclides that may have been inhaled or ingested by the workers, the recommended assumptions for use in reconstructing internal doses based on whole-body counts and bioassay data, the methods recommended for use in the reconstruction of missed internal dose, and the methods recommended for characterizing uncertainty in the reconstructed internal doses.

ORAUT-TKBS-0013-6, *Pantex Plant —Occupational External Dose* (Fix et al. 2007), presents background information and guidance to dose reconstructors for deriving occupational external doses to workers. SC&A reviewed this section with respect to background information and guidance regarding the different types of external radiation (i.e., gamma, beta, and neutron) and the energy distribution of this radiation to which the workers may have been exposed. SC&A also reviewed the recommendations for converting external dosimetry data to organ-specific doses, the methods recommended for use in the reconstruction of missed external doses, and the methods recommended for characterizing uncertainty in the reconstructed external doses.

In accordance with SC&A's site profile review procedures, SC&A performed an initial review of the six TBDs and their supporting TIBs. Attachment 4 documents interviews with site experts. SC&A will revise the interview summary as additional comments are received from workers and information is reviewed and redacted by Pantex. SC&A submitted questions to NIOSH (see Attachment 2) with regard to assumptions and methodologies used in the site profile, but has not received responses as of the issuance of this report. Following this "unclassified" review, SC&A undertook an onsite review of records and interviewed identified site experts. After clearance of the draft text by DOE, SC&A developed this final draft document for further internal review by SC&A personnel (including Pantex review team members not involved in the onsite review). This draft version was delivered to the Advisory Board and NIOSH. In accordance with the procedures followed during previous site profile reviews, SC&A anticipates that the report will then be published on the NIOSH Web site and discussed at an upcoming Advisory Board meeting. An issues resolution matrix will be prepared and submitted by SC&A, as well. This last step in the review cycle completes SC&A's role in the review process, unless the Advisory Board requests SC&A to participate in additional discussions regarding the closeout of issues, or if NIOSH issues revisions to the TBDs or additional TIBs and the Advisory Board requests SC&A to review these documents.

Finally, it is important to note that SC&A's review of the six TBDs and their supporting TIBs is not exhaustive. These are large, complex documents and SC&A used its judgment in selecting those issues that it believes are important with respect to dose reconstruction.

4.0 SITE PROFILE STRENGTHS

In developing a TBD, the assumptions used must be fair, consistent, and scientifically robust, and uncertainties and inadequacies in source data must be explicitly addressed. The development of the TBD must also consider efficiency in the process of analyzing individual exposure histories, so that claims can be processed in a timely manner. With this perspective in mind, SC&A identified a number of strengths in the Pantex TBDs, described below.

4.1 COMPLETENESS OF DATA

SC&A identified the following strengths related to the completeness of data:

- The environmental dose TBD provides a comprehensive summary of the environmental monitoring program, including air monitoring and elevated ambient radiation.
- The internal dose TBD provides a comprehensive summary of the occupational internal monitoring program implemented at the Pantex site over the period of operation.
- The external dose TBD provides a comprehensive summary of the external monitoring program implemented at the Pantex site over the period of operation.
- NIOSH interviewed key former and current health physics personnel regarding the dosimetry program, potential exposures, and major incidents.
- NIOSH made good use of unclassified data sources.

4.2 ADEQUACY OF DATA

- The four elements of administrative practices in the external dosimetry program (i.e., dosimetry technology, calibrations practices, workplace radiation fields, and dosimeter response to radiation fields) were evaluated.
- The internal dose TBD (Hickey et al. 2007) has included discussions of major incidents that may impact dose reconstruction for some claimants. This reduces the reliance on other sources, such as Computer Assisted Telephone Interviews where an employee or survivor may not remember the details of these incidents.
- NIOSH/ORAUT have interviewed site experts actively involved in the dosimetry and radiation protection program at Pantex since its inception.

4.3 TECHNICAL ACCURACY/CLAIMANT FAVORABILITY

- Dosimetry methods used for beta, photon, and neutron dose monitoring were described separately, and also as a function of time and technology changes.

- The external dose TBD (Fix et al. 2007) also presents summary statistics for Pantex claimants as well as specific job titles.

- Consideration has been give to the impact of wearing lead aprons on protected and unprotected body locations. This is something that has not been considered in other site profiles.

- Internal monitoring methods for tritium, depleted uranium, plutonium, thorium, and radon are described as a function of time. A statistical summary of the number of workers monitored in various bioassay programs as a function of time was included in the internal dose TBD. This assists dose reconstructors in identifying potential gaps in data.

- In most cases, the assumption that exposures to plutonium were acute rather than chronic is reasonable, since exposure to plutonium would be incident based.

4.4 CONSISTENCY AMONG SITE PROFILES

The implementation of ORAUT-OTIB-0006, *Dose Reconstruction for Occupationally Related Diagnostic X-Ray Procedures*, Revision 3 PC-1 (Kathren 2005), has provided a great deal of consistency between different site profile assumptions.

4.5 REGULATORY COMPLIANCE

The use of personnel monitoring data and environmental monitoring data (where readily available) in the TBDs to determine dose is consistent with the requirements outlined in 42 CFR Part 82, as follows:

- Where in-vitro analyses are available, this information is provided for use in the determination of internal dose or the determination of models for dose reconstruction.

- Where routine beta/gamma and neutron dosimeters are available and adequate, this information is provided for use in the determination of external exposure.

- Where environmental measurements are available, these data are used as the basis for environmental dose.

5.0 FINDINGS

5.1 FINDING 1: INSUFFICIENT CONSIDERATION OF POTENTIAL INTERNAL EXPOSURES

The major workplace radiation environments that contribute to internal exposure involve nuclear weapons components assembly and disassembly, high explosives (HE) research and development, weapons evaluation, and storage of components. This has historically included tritium, uranium (U-234, U-235, U-238, and uranium metal), thorium (Th-232), and plutonium (Pu-238 and Pu-239). Modification operations, assembly, and disassembly activities started at the Pantex plant in 1952 (DOE 1995):

> *The first production was a modification in the summer of 1952 and the first assembly occurred in the summer of 1952. The weapons dismantlement function has existed since 1952.*

Depleted uranium (DU) was present starting in 1952, and enriched uranium (EU) was introduced in the 1950s. Weapons with thorium-containing components were assembled and modified. Modifications occurred regularly on some weapons after assembly and prior to final disassembly, requiring some degree of handling (BWXT 2003, DOE 1997a). Additionally, workers may have been exposed to indoor radon and its short-lived radioactive daughter products at select facilities within the Pantex complex.

A health physics review of the Pantex plant by the Health Protection Branch in 1989 stated the following:

> *Evaluation of current Internal Dosimetry Program: Internal exposures have historically been very low at the Pantex Plant, and the Internal Dosimetry Program has been of equally low priority. DOE Order 5480.11* [DOE 1988] *and the recent incidents at Pantex with tritium and depleted uranium have raised the level of concern about internal exposure and have resulted in a significant increase in the immediate program and long range plans.* (DOE 1989, p. 19)

The health physics review further stated the following:

> *In addition to tritium and uranium, slight potential exists for acute, accident-related exposure to plutonium, americium, thorium, and enriched uranium. Except for the recent tritium incident, reported internal doses have not exceeded 100 mrem annually, and typically have involved minor tritium exposures of less than 10 mrem for individuals in a given year.* (DOE 1989, p. 19)

The review noted that there was limited use of respirators, and voluntary washing of hands upon leaving bays and cells within the material accountability areas (DOE 1989, p. 22). The review also made reference to the wound counter system in place at that time (DOE 1989, p. 27):

> *The documentation of the system and for the procedure is limited, through discussions, it appears that only the 60 keV gamma ray of Am-241 is counted. Although* ***there is no calibration procedure, the technician sets the region of interest for 60 keV*** *with the check source, but attempts no efficiency check. Backgrounds range from 300–700 counts in the standard 1 minute interval, and decisions about contamination are subjectively made at "about 1000 counts."* ***This is a very poor detection sensitivity for weapons grade plutonium.*** [Emphasis added.]

Although routine internal exposure was not on a scale with radiological production operations at other DOE sites, an intake potential existed in a number of instances, including, but not limited to, the following:

- A tritium release event in 1989
- Uranium and thorium intakes from assembly/disassembly of weapons
- DU intakes from early period machining
- Intakes from hydroshots and burning of resulting contaminated HE
- Major incidents associated with radioactive material (e.g., the 1961 cell incident with plutonium [see pages 38 and 39 of the TBD (Hickey et al. 2007)], the 1978 storage cylinder incident)

Section 5.1.3 of the occupational internal dose TBD (Hickey et al. 2007) notes the following:

> *There was no routine bioassay program at Pantex before 1972 for uranium, thorium, or plutonium.*

In fact, with the exception of select radiological incidents, workers were not monitored for thorium before 1991 and for plutonium before 1992. Only with the issuance of Mason & Hanger-Silas Mason Company (MHSMC) Pantex Plant Procedure IOP D5466, *Analysis of Biological Samples for Uranium, Thorium, and/or Plutonium*, in January 1991 (MHSMC 1991) were personnel monitored in significant numbers. However, even these bioassays were not routine but were event driven, as acknowledged by NIOSH. The principal criterion from the 1990s onward for requesting a bioassay was a worker's accumulation of 40 derived air concentration (DAC)-hours in a given year, as measured by air-monitoring data. This policy remains in effect today. It is, therefore, fair and accurate to state that a conventional routine bioassay program has never been implemented at Pantex.

Pantex did not have, and still does not have, a lung-counting capability for in-vivo measurements of plutonium, americium, or uranium. Without lung-counting capabilities, there is no way of knowing if there has been a buildup of chronic low-level exposures of insoluble plutonium in the workers exposed during disassembly operations or deposition in the lungs of those exposed in the 1961 cell incident. The TBD (Hickey et al. 2007) has not addressed the lack of in-vivo monitoring. Urine bioassay cannot quantify the amount of insoluble material deposited in the lung compartment when monitoring for plutonium inhalation of low-level exposures and

insoluble forms. The fact that the urine bioassays were below detection limit does not mean there may not have been a significant exposure. The TBD notes multiple incidents of possible exposures:

> *Several individuals who had urine bioassays for plutonium in the 1960's were identified as claimants, and their claimant files were reviewed. The analysis found no indication of the bioassay history or doses from these bioassays in threcords. Therefore, claimant files probably will not contain reliable bioassay data.* (Hickey et al. 2007, Section 5.2.4.1, p. 37)

Even if urine bioassay data were found, it does not preclude the possibility for undetected lung depositions. Therefore, with no lung-counting capabilities available at Pantex, it is not possible for NIOSH to conduct a reasonable dose reconstruction for lung depositions of insoluble plutonium in workers who had the potential for inhalation intakes during disassembly operations.

The attempt to assess the uptake of the three individuals in the cell incident is based on air-sample data and breathing rates. Air-sampling data have never proven to be very useful in trying to estimate the actual uptakes to the lungs by individuals involved in plutonium incidents. This is because air-monitoring data tends to be unpredictable because of air flows and the variability in solubility and particle size of the contaminants themselves. Workplace general area air sampling would not be representative of the workers' breathing zone because of the placement of sampling heads. In addition, the disposal of early radiological field records in the 1980s brings into question whether air-monitoring data are even available for all periods of time and areas (see Attachment 4). The 40 DAC-hour criterion was only introduced at Pantex in 1991. Experience at other plutonium facilities has proven that dependence upon smear sampling, air monitoring, or even nasal swipes as workplace indicators does not preclude undetected uptakes by workers.

Although radioactive material has been present at Pantex since 1952, the bioassay program was limited to incident-based sampling for a majority of the site's operating period. Limited routine monitoring for tritium was initiated in 1976, although a few samples were taken prior to this time. Thorium and plutonium bioassay began to a minimal extent in 1991 and 1992, respectively. Air-sampling data may not be retrievable and, even if located, is not representative of the workers' breathing zone, as noted above. As such, there was a reliance on regulatory limits and source term data to determine which radionuclides posed potential internal exposure hazards. This makes it particularly important to understand the source terms introduced at Pantex and the issues associated with handling these source terms. Workers have provided valuable insight into which programs had the highest potential for internal exposure (see Attachment 4). It is important to note that many processes and activities associated with Pantex remain classified. Under ideal conditions with comprehensive personnel monitoring, the classified nature of a facility's operation might only have a marginal impact on the quality of the dose reconstruction methodology; however, in the near absence of internal monitoring data, the limited disclosure of processes and the compensatory use of dose models pose a serious handicap to outside reviewers (e.g., NIOSH, ORAUT, and SC&A), as discussed in the findings that follow.

5.2 FINDING 2: INSUFFICIENT INTERNAL MODELS FOR ASSIGNMENT OF INTERNAL DOSE FROM URANIUM

In order to understand the potential issues associated with the models developed for internal exposure for unmonitored workers, the following background information is presented.

Section 5.2.2.1 of the internal dose TBD (Hickey et al. 2007) states the following:

> ***Since 1993,*** *monitoring of uranium exposures has been event-driven and is identified by air monitoring data. Since the* ***middle*** *1990s, Pantex has used* ***lapel air samplers*** *to monitor for intakes and trigger bioassay measurements.* [Emphasis added]

Section 5.2.2.3 further states the following:

> *Dose reconstructors should use bioassay data for uranium in worker files to calculate intakes.* ***However, uranium bioassays in the files are scarce.*** [Emphasis added]

Given these limitations, NIOSH has elected to make use of a worker bioassay data set that was prompted by a radiological incident in February 1989. However, urinalyses for 305 workers were not performed until February 1 to April 1, 1990 (or more than 1 year after the incident). Section 5.2.2.3.1 of the TBD (Hickey et al. 2007) states the following:

> *This data set was analyzed to establish a baseline for unmonitored workers (or workers whose bioassay results are not found).*
>
> *The 305 "P" sample measurements, associated with real individuals, averaged 1,635 ±384 g urine and 0.229 ±0.168 dpm total uranium per sample. …*
>
> *Assuming an acute inhalation intake of absorption class S DU 14 months before the excretion results in a median intake of 75,000 dpm. Although the urine samples were taken in response to a specific event, the measured uranium excretion could have been the result of years of accumulation of DU in the body from smaller, frequent, intermittent intakes…. The measured excretion probably resulted from a combination of contributions from chronic intakes since 1980 and the acute intake in 1989, [however], the chronic intake scenario is the more plausible for most workers.*
>
> *Using the IMBA internal dosimetry software, the* ***median*** *inhalation intake for absorption type M uranium was determined to be* ***2.8 dpm/d*** *based on the midpoint (5 yr) of the chronic intake period. ... [and] the median inhalation intake for absorption* ***type S*** *uranium was determined to be 41.5 dpm/d based on the midpoint (5 yr) of the chronic intake period.* [Emphasis added]

Based on the 305 "P" urinalyses and their interpretation by means of Integrated Modules for Bioassay Analysis (IMBA) (James 2003) that assumed a 10-year chronic intake, NIOSH is recommending the following DU intakes for assembly/disassembly workers, radiation safety technicians (RSTs), and quality assurance technicians:

- For inhalation of type M, the median intake of 1.3 pCi/day (or 2.8 dpm/day)
- For inhalation of type S, the median intake of 19 pCi/day (or 42 dpm/day)

On the assumption that a sizeable fraction of the total pool of assembly/disassembly workers, RSTs, and quality assurance workers who may have been employed between 1980 and 1989 may not have been among the 305 "P" workers assessed for DU, the applicability of this model is questioned on two levels.

NIOSH provides no reference that characterizes the "1989 contamination incident," which prompted the assessment of 305 workers some 14 months later. In the absence of confirmatory information, it is not possible to verify that the 305 assessed workers did, in fact, represent assemblers/disassemblers, RSTs, and quality assurance personnel who, moreover, were employed for a full 10-year period, as assumed in the model. Secondly, on the highly questionable assumption that unmonitored workers were no different from the 305 workers monitored in 1990, the use of a median value implies that 50% of unmonitored workers will be assigned intakes with doses that are less than their true intakes/doses. The use of this model for the assignment of internal dose from DU for unmonitored workers from 1980–1993 may be inappropriate and/or not claimant favorable.

5.2.1 Inappropriate Use of Air-Sampling Detection Limit for Assigning Uranium Worker Exposures

The occupational internal dose TBD (Hickey et al. 2007, p. 20-21) states that during disassembly, aged uranium components from certain weapons programs had a coating of oxide in the form of black dust that was potentially present as airborne contamination. The TBD (p. 21) further states that, "...there is no evidence that workers were routinely monitored for uranium before 1991...," and, "Since 1993, monitoring of uranium exposures has been event-driven and is identified by air-monitoring data." The TBD (Hickey et al. 2007) states that since the mid-1990s, Pantex used lapel air samplers to monitor for intakes and to trigger bioassay measurements. Because Pantex performed bioassays on more than 300 workers since 1993, the implication is that there must have been workplace indications of potential uranium intakes. Pantex Plant Procedure IOP D6466 (MHSMC 1991) provided the following workplace indicators that would trigger bioassay:

- *All personnel ... not wearing ... respiratory protection whose tracked internal annual exposure is equal to 40 DAC-hours*

- *All personnel whose breathing zone monitor indicates that they have been exposed to 40 DAC-hours* [also lists the DAC for U-238 as 6×10^{-11} uCi/ml]

- *All personnel found to have skin contamination equal to or greater than ... 1000 dpm/]00 cm^{2} ^{238}U*

The TBD (Hickey et al. 2007, p. 26) uses the air-sampling detection limit, which it states to be 2×10^{-12} uCi/ml, as the exposure rate to assign as the upper bound of intake for uranium workers. However, since Pantex did not have routine bioassay sampling for uranium, monitoring of uranium exposures was event driven, triggering bioassay sampling at 40 DAC-hours (DAC being listed for U-238 as 6×10^{-11} µCi/ml). The authors of the TBD appear to use the same approach and assumptions cited in TBD Section 5.2.2.6.3 (p. 33), which is inconsistent and not claimant favorable, as stated previously. The basis for SC&A's position is the same as that cited in Finding 2, above, for the same use of 40 DAC-hour for thorium, plutonium, and other actinides.

The rationale in the TBD for applying the air-sampling detection limit for area air samplers is questionable given that such air sampling should not be assumed to be representative of the breathing air. The TBD (Hickey et al. 2007) does state that for the cleanup work at the Firing Site, five lapel samplers were used as a means to enable the "triggering" of the 40 DAC-hour provision, but the TBD does not provide any information on the detection limits of the lapel samplers that were used nor what the upper bounds of the missed dose may have been.

It is unclear if area air monitoring was used for tracking the 40 DAC-hour triggering of bioassay monitoring prior to the late 1990s. Certainly lapel sample results would be more sensitive and representative than area air samples. The current version of the TBD does not clarify such issues as (1) whether air samplers were used for tracking in the 1960s through the 1980s, (2) whether any lapel monitors were used prior to the mid-1990s, and (3) after the 1990s, whether all workers wore lapel monitors or whether representative individuals wore them and the exposures were assigned to others within the group.

5.2.2 Unsupported Assumptions for Modeling Depleted Uranium Exposures

Workers 1994 to Present

The TBD (Hickey et al. 2007) provides the following instructions for dose reconstructors:

> *To account for potential unmonitored dose, dose reconstructors should assign a claimant who worked in a job with a high potential for intake with an intake that is 0.2 times the intake from 1980 to 1993 to account for improved radiation protection barriers and procedures (lognormal, median, GSD = 3) (based on the ratio of urine excretion in the 1994 dataset to the 1989 dataset).*

The TBD then proceeds to note that this is based on the ratio of urine **excretion** in the 1994 dataset in Table 5-7 to the 1989 dataset. The data in Table 5-7 were event-driven samples, not routine, and the next to the bottom paragraph of page 22 notes that "these doses are **not** [Emphasis added] directly relevant to dose reconstruction," yet it is suggested on page 24 of the same document that dose reconstructors use them for dose reconstruction.

For a claimant who worked in a job with a high potential for intake, Section 5.2.2.3.3 of ORAUT-TKBS-0013-5 states that dose reconstructors should assign an intake that is 0.2 times the intake from 1980 to 1993 to account for improved radiation protection barriers and procedures based on the ratio of urine excretion in the 1994 dataset to the 1989–1990 dataset. This use of the 0.2 value is not valid. The ratio comes from urine excretion data, not intake values. In addition, a problem arises when one looks at the median excretion activity for the 1994 data (cited on page 24, fifth paragraph) of 0.040 dpm/day and the minimum detectable activity (MDA) of approximately 0.15 dpm/sample (Hickey et al. 2007, Table 5-8, p. 21). The 1994 value to be used for the ratio is only about one-fourth of the MDA quoted for 1994 uranium urinalysis in Table 5-8. The ratio approach is not scientifically valid or claimant favorable.

Workers 1980–1993

Section 5.2.2.3 of the TBD (Hickey et al. 2007, p. 22) notes that references to uranium bioassays in the files are scarce and that if workers were not involved in incidents with a potential for intakes, some production line workers may not have had uranium bioassay. Therefore, a missed dose calculation for what may be relatively frequent, intermittent intakes from disassemblies may not be possible. The authors suggest an approach based on a group of samples taken approximately 1 year after a February 1989 contamination incident; the overriding assumption is that this is a representative set of data to apply for all unmonitored workers from 1980 through 1993. The TBD derives the median value from the lognormal distribution of the urine excretion of this group and assumes it came from a chronic uptake over 10 years. It then determines the intake at the midpoint of the period, which is then applied to all unmonitored workers during this time period. However, this approach may not be claimant favorable for this group of individuals. They may have had a recent acute uptake in 1989 in addition to the 10-year chronic uptake. An excretion value to the midpoint calculation of a 10-year chronic uptake may be appropriate. The authors recognize that the chronic intake scenario leads to smaller calculated doses until about 7 to 8 years after the start of intakes.

From the TBD (Hickey et al. 2007), it is not clear whether NIOSH has confirmed that the 299 samples used in the 1990 uranium bioassay sampling represent all the workers, as indicated by Pantex management on page 23. It is also not clear whether the use of the midpoint of the 10-year chronic intake assumption is sufficiently conservative, given the uncertainties involved. Likewise, it is unclear why the data presented in Table 5-7 do not include the analyzed urine samples from the 305 workers in 1990. This apparent oversight is one of several examples of inconsistency throughout this TBD.

Workers 1961–1979

The TBD (Hickey et al. 2007) acknowledges the use of a small set of uranium urinalysis results with analysis dates ranging from February 1963 to March 1967. The dates and circumstances for the samples are not known in terms of whether they were routine or following an accident. These data for the 34 samples were analyzed as a group assuming a lognormal distribution and coworker analysis method. The analysis determined a median excretion rate of 0.375 dpm/d with a geometric standard deviation (GSD) of 4.1. The TBD further states that this excretion rate compares reasonably well with the median excretion of 0.188 dpm/d assuming chronic intake

for the samples collected in 1990; however, it should be noted that the excretion rates between these two populations differ by at least a factor of 2.

Thus, Section 5.2.2.3.4 of the TBD (Hickey et al. 2007) suggests the use of the same intake values used for 1980–1993 exposures that are questioned previously:

> *The first disassembly of a weapon with DU oxide at Pantex occurred in 1961*
>
> *… and from 1966 to 1975, disassemblies were performed at Pantex and the Iowa Army Ammunition Plant*
>
> *… because the documentation of the number of disassemblies and partial disassemblies and the contamination levels are not specifically available, it is* ***favorable to the claimant*** *to assign unmonitored workers an intake that is the* ***same as that from 1980 to 1993****...* [Emphasis added]

SC&A questions how the same suspect choice of intake values used for 1980–1993 exposures can be applied to 1961–1979 exposures. The few (34) analyzed "real" samples in 1963–1967 were as much as two-fold greater than this back-calculated value with all of its assumptions. It is unclear from the TBD how the 1989 contamination incident and the 305 "P" urinalysis data set were used to estimate unmonitored worker doses for 1980–1993 and were considered equally applicable for unmonitored workers for the earlier years of 1961–1979. At a minimum, issues remain regarding the lack of reference characterizing the "1989 contamination incident" and the absence of a basis for assuming unmonitored workers are equivalent to the 305 workers monitored in 1990. Notwithstanding this problem, however, the degree of relevance and uncertainty that would allow the extrapolation of urine bioassay data in time from a single contamination incident in 1989 back to 1961 makes this approach even less credible for dose reconstruction.

Interviews with workers and review of documents associated with the burn yard and the disassembly of certain units revealed that these practices produced large quantities of uranium oxide, which workers described as black dust that collected on the floor of the bays, their clothing, and their skin. In interviews, the workers observed that when they blew their noses their tissues appeared to be covered in "coal dust." In some cases, the workers handled pieces of uranium covered with oxide. The existence of these operations, which apparently went on for years, undercut the ability to consider the use of 19 pCi intake per day as claimant favorable.

After reviewing the approach provided in ORAUT-TKBS-0013-5 (Hickey et al. 2007) and its use of a 19 pCi intake per day, SC&A finds too much inconsistency and an inappropriate approach to dose reconstruction for Pantex workers exposed to uranium. With the quantities of uranium oxide in respirable form and the level of contamination associated with certain weapons programs and burning operations, an intake of 19 pCi per day is not claimant favorable. Finally, the intake values to be used for disassembly appear to be the same as those applied by the authors to uranium machining without any technical basis or explanation.

5.2.3 Use of a Scaling Factor without Sufficient Basis for Modeling Depleted Uranium Doses for Workers from 1994 to the Present

Proposed DU intakes for assembly/disassembly unmonitored workers for 1994 to the present are based on assumptions without scientific basis. Section 5.2.2.3.3 of the Pantex TBD (Hickey et al. 2007) states the following:

> *As indicated in Table 5-7, doses to workers were reduced considerably from 1994 to the present due to better procedural controls and barriers. All of the 1995 238U bioassay results, for instance, were below detection. To account for potential unmonitored dose, dose reconstructors should assign a claimant who worked in a job with a high potential for intake with an intake that is **0.2 times** the intake from 1980 to 1993 to account for improved radiation protection barriers and procedures (lognormal, median, GSD = 3) (based on the ratio of urine excretion in the 1994 dataset to the 1989 dataset).* [Emphasis added]

Use of the scaling factor of 0.2, as suggested in the TBD and arrived at from Table 5-7, has no clear scientific and quantitative basis. In addition, the statement that "...doses to workers were **reduced considerably** from 1994" [emphasis added], as indicated in Table 5-7 of the TBD, is inappropriate and misleading at best, as explained below.

Section 5.2.2.1 of the Pantex TBD (Hickey et al. 2007), states the following:

> *Since 1993, monitoring of uranium exposures has been **event-driven** and is identified by **air-monitoring** data.*
>
> *…Although these doses are not directly relevant to dose reconstruction, the **overall** trend is indicative of reduced uranium intakes after 1993.* [Emphasis added]

It is important to note that all uranium bioassays, which only started in 1993, were conducted in response to select events (most notably air-monitoring data) as opposed to routine worker bioassays.

5.2.4 Insufficient Evaluation of Potential Intakes from Enriched Uranium

Weapons processed at Pantex contained EU as a part of the primary and/or secondary component. Their composition was up to 93.5% in some units. Many of the weapons containing EU have been modified or dismantled since the closure of the Medina, Clarksville, and Iowa weapons plants. In addition, some weapons had composite pits that contained both uranium and plutonium. The internal dosimetry TBD (Hickey et al. 2007) states the following:

> *Uranium at Pantex was enriched, natural and depleted. Natural uranium was in a form referred to as tuballoy. Enriched uranium (EU) was in a sealed component with little likelihood of release. No data are available to indicate that EU was ever a contaminant in the workplace. The internal dosimetry technical*

> *basis document (BWXT Pantex 1992) stated, "All of the unsealed uranium used at the Pantex facility is either depleted uranium or natural uranium."*

Kilogram quantities of EU were processed through the Pantex plant. The internal dosimetry TBD recognizes that plutonium was handled in a sealed form and assigns a potential missed dose from plutonium. EU presents the same potential for exposure; however, the TBD does not assign potential missed dose from this source. The TBD acknowledges that some activities occurring at Pantex are classified. Without comprehensive review of classified as well as unclassified documents, the basis for assuming that there was no EU contamination at the site is not supportable.

5.3 FINDING 3: INSUFFICIENT CONSIDERATION OF POTENTIAL DOSE FROM THORIUM AND TRANSURANICS IN THE INTERNAL DOSE TBD

5.3.1 Thorium

Thorium was handled during assembly, modification, and disassembly of particular weapons programs. Section 5.2.3 of the Pantex TBD (Hickey et al. 2007) addresses potential exposure to thorium. A components list compiled in 2002 (Pantex 2002b) identified thorium as a contamination concern in a number of the weapons programs. Site experts raised concerns about the oxidation of thorium components creating a potential for internal exposure. The *Pantex Plant Radiological Investigation Report* (BWXT 2003) describes the complications with oxidation of DU and thorium:

> *Specifically, Pantex handled un-encapsulated radioactive weapon sources containing depleted uranium and thorium metal components. The older metal components were not alloyed as is currently practiced, and, like most metals, oxidized with time.*

Monitoring criteria for thorium exposures were event driven since at least 1991, as noted by the TBD (Hickey et al. 2007):

> *Because there is no evidence that workers were routinely monitored for thorium before 1991, unless the worker records clearly indicate bioassay for thorium, dose reconstructors should interpret routine occupational records before 1991 that show "0" for internal dose as no information available rather than necessarily as a dose below detectable levels.* [Hickey et al. 2007, Section 5.2.3, p. 35]

Reference to the 40 DAC-hour criterion for monitoring workers was found in Pantex Plant Procedure IOP D5466 that was issued on January 1, 1991 (MHSMC 1991). After 1991, the criteria for triggering bioassay monitoring were (1) exposure to 40 DAC-hour of thorium in the workplace air after accounting for use of respiratory protection (if applicable) or (2) skin contamination equal to or exceeding 200 dpm/100 cm^2 (MHSMC 1991). The **only reported doses** occurred since 1999, and analysis of them revealed no bioassay data for thorium before 1983. Due to the limited amount of monitoring data and the frequency of handling thorium-

containing weapons, NIOSH provided the following guidance for dose reconstruction (Hickey et al. 2007):

- *Years 1980—2000:*
  1. *For workers with the highest possibility of intake for each year from 1980 to 2000, assume a single acute intake of 40 DAC-hours of Th-232 (in equilibrium with progeny), as given by the following equation:*

$$\begin{aligned} 40\ \text{DAC-hrs/yr} &= (DAC_{Th\text{-}232})(40\ \text{hrs})(1.2\ m^3/\text{hr}) \\ &= (1 \times 10^{-12}\ \mu\text{Ci/ml})(40\ \text{hrs})(1.2\ m^3/\text{hr}) \\ &= 48\ \text{pCi/yr} \end{aligned}$$

  2. *For category 2 workers with lower potential for thorium exposure, assign 0.1 times this intake or 4.8 pCi/yr.*

- *Years 2000 to Present:*
  1. *For workers with highest potential for thorium intake, assign an annual intake of 4 DAC-hrs or 4.8 pCi/hr;*

  2. *Assign 0.1 times this intake to Category 2 workers (or 0.48 pCi/yr).*

A triangular distribution with the minimum 0 and the maximum of 10 times the mode is used to account for the possibility of more than one intake in a year and the possible unrepresentativeness of the air-sampling system. Between 1992 and 1996, 258 worker urine samples were analyzed to evaluate the reasonableness of this approach (Hickey et al. 2007). Page 36 of the TBD (Hickey et al. 2007) notes that an acute intake of 48 pCi in a year would result in less than 0.32 pCi/d excretion over about 6 days after the intake (which is the intake when assuming a single acute intake of 40 DAC-hour of Th-232 (in equilibrium with progeny)). The TBD has not evaluated the basis for the claim that operations in these years are representative of those of earlier years. In addition, the 0.1 scaling factor was applied to Category 2 workers for the years 2000 to the present does not appear to have a scientific basis.

The assumption for acute uptake in unmonitored thorium workers during disassembly is inconsistent with the TBD argument for chronic exposure to DU workers during disassembly, particularly given the documented incidents of thorium contamination problems as early as the 1960s. The concerns related to the application of an intake exposure of 40 DAC-hours per year to unmonitored thorium workers are the same as those raised for uranium in the Section 5.2. **For workers who had, in fact, been monitored based on the 40 DAC-hour criterion (but for whom no records exist), the assigned value of 40 DAC-hours may only represent a lower bound or threshold value.** NIOSH should also consider thorium exposures received by waste management personnel from thorium-contaminated waste. The period of exposure for this group would not necessarily be the same as that for assembly and disassembly workers.

For each of the four annual assigned intakes of thorium, NIOSH employed a DAC value of 1×10^{-12} µCi/ml. This value corresponds to the value in International Commission on Radiological Protection (ICRP) 30 (ICRP 1979), which has been significantly revised/increased

in ICRP 68 (ICRP 1994). Thus, all annual thorium intakes derived above are a factor of **three too low** if the more current DAC value applies. Not only does this present a technical issue, but 42 CFR Part 82 mandates the use of the most current model. The use of ICRP 30 is contrary to this requirement.

Potential internal thorium exposures occurred as a result of thorium oxidation in particular Pantex weapons programs (see Attachment 4). Review of classified incident reports identified a thorium incident that took place in December 1968. This coincides with the period of initial retirement of thorium-containing weapons. A gap in thorium dose characterization clearly exists in the internal exposure TBD. For example, Section 5.2.3 of ORAUT-TKBS-0013-5 on page 36 states the following:

> *There is no record of disassembly of thorium weapons before 1980.*

Based on SC&A's review, this statement is not correct if one considers the complete set of site records. The failure to account for thorium exposure prior to 1980 is of concern, particularly given the thorium oxidation problems encountered. Furthermore, investigation into the handling of thorium-containing weapons by Pantex workers is essential to accurately calculating internal dose from thorium.

5.3.2 Plutonium

Weapons components containing plutonium were hermetically sealed units. These units have been inventoried and tracked since the 1950s. Particular radionuclides of plutonium were also used in other capacities in the weapons system. The components were surveyed upon arrival at the plant and through various stages of assembly and disassembly. Pantex serves as the interim storage for plutonium components and continues to monitor them.

Section 5.2.4 of the TBD (Hickey et al. 2007) provides the following general information on plutonium:

> *Plutonium at Pantex is in the encapsulated pits of nuclear weapons. Workers handle the pits during weapons assembly and disassembly.* ***Strict*** *workplace* ***monitoring*** *practices ensure the integrity of the encapsulation including contamination smear checks during assembly and disassembly. … Table 5-13 lists the number of workers given plutonium bioassay by year. There were* ***no recorded internal doses*** *associated with these 1991 to 2002 bioassays.* [Emphasis added]

Pantex did not have a routine bioassay program for transuranics before 1991. Section 5.2.4.1 of the TBD (Hickey et al. 2007) notes that 23 nonincident plutonium urinalysis results have been recorded in the Pantex Dosimetry Records Management System since 1989, and apparently none were recorded in the years before this time period.

These sampling results were obtained in 1995 and 1996. The extremely small number of samples analyzed in Table 5-13 (which appear to be special bioassay samples taken as a result of

workplace indicators during 1991 through 2004) suggests that no **routine** bioassay program existed at Pantex as recently as 2004, as noted by the TBD:

> *There was no routine bioassay program at Pantex before 1972 for uranium, thorium, or plutonium. Bioassay was performed for specific events; for instance, bioassay was obtained from workers involved in a plutonium contamination event in 1961 and from those involved in decontamination of the facility after the event. A 1967 report describing an inspection of the radiation protection program states that Pantex used air samples and contamination surveys to indicate the need for bioassay and not maintain a routine plutonium or uranium bioassay program (Davis 1967).* [(Hickey et al. 2007, Section 5.1.3, p. 9)

Table 5-13 of the TBD (Hickey et al. 2007) is reproduced herein as Table 1.

Table 1. Number of Workers Monitored for Pu by Year

Year	Number of workers monitored for plutonium
1991	0
1992	12
1993	0
1994	0
1995	28
1996	17
1997	18
1998	2
1999	1
2000	8
2001	1
2002	10
2003	9
2004	0

The TBD further states the following (Hickey et al. 2007, p. 10):

> *A review of all worker files in the NIOSH Office of Compensation Analysis and Support Claims Tracking System (NOCTS) revealed that only 10% of the files had any bioassay data and most of the data was for tritium results. Only 3% of the files had uranium bioassay results and all but one of the results were for samples collected since 1986. No plutonium or thorium bioassay results were found in the NOCTS files. Therefore, this TBD provides other approaches for determining intakes of radionuclides that dose reconstructors can use when bioassay data are not available.*

With respect to time periods before 1991, the TBD (Hickey et al. 2007) states the following:

> *Although exposure to plutonium has been **strictly** controlled at Pantex, there is indication of past concern about potential plutonium intakes. Based on two sets*

> *of bioassay data, it **appears** that in 1963 and 1966 monthly urine sample collection and analysis occurred for workers who could have been exposed to plutonium. This analysis found additional bioassay data for 1961, 1968, the early 1980s, and 1994 to present. A 1961 incident that resulted in the release of plutonium is discussed below.*
>
> *Dose estimates from these bioassays were not found and, because they are not listed in the records, doses were **probably** determined to be less than whatever recording level was used at that time. …*
>
> *… Therefore, claimant files probably will not contain reliable bioassay data. If bioassay data are **not** available, dose reconstructors should use the following approach for assigning potentially missed doses to workers.* [Emphasis added]

Routh (1959) describes the process for determining contamination levels on radioactive material received at Pantex:

> *These swipes were surveyed with a portable alpha survey meter and if significant readings were obtained the readings were verified with a scintillation counter. When positive swipes were obtained and verified the container was cleaned; using a damp Kleenex was sufficient.*

The goal was to ensure that no detectable, removable contamination was allowed into the assembly area. The subsequent step required that the container be opened and the unit itself checked for contamination. Contamination ranging from 204 dpm to 1,532 dpm was found on four units within a 2-month period in 1959 (Routh 1959). Those individuals responsible for receiving material, performing the swipes, and cleaning components had a potential for exposure to loose contamination.

Section 5.1.4 of the TBD (Hickey et al. 2007) further states the following:

> *Pantex does not have a routine bioassay program for actinides, but uses occurrence-based bioassay sampling to confirm intakes and calculate internal dose.*

Reference to the 40 DAC-hour criterion for monitoring workers was found in the 1991 Pantex Plant Procedure IOP D5466 (MHSMC 1991). The procedure stated that urinalysis was to be conducted for personnel exposed to 40 DAC-hour integrated air concentrations as measured by breathing zone monitors or, alternatively, was to be estimated if not specifically monitored (MHSMC 1991).

Likewise, SC&A's review of classified and unclassified documents did not reveal adequate or reliable air-monitoring data to use for dose reconstruction. SC&A's concern related to air monitoring involves the reliance on air monitoring for triggering bioassay sampling. Questions exist with regard to the sensitivity, calibration, and location of these air samplers. Workers interviewed told SC&A that the air samplers were located outside the cells and bays, which

would bring into question the usefulness of these data as representative breathing zone air for initiating bioassay sampling. The *1989 Health Physics Review of Pantex Plant* (DOE 1989) does note at that time the existence of 184 constant air monitors in operation and 92 REDECO Selective Alpha Air monitors and 92 Johnson Tritium monitors installed in the various work stations. One of the documents reviewed by SC&A, *Preliminary Assessment of the W76 Air Sampling Program* (Vickers 1996), notes the following:

> *The Avg Dose/y (50 wks) was calculated to be 51.4 mrem/y CEDE. This CEDE value is the expected CEDE that would nominally be incurred in one year provided the exposure were 2 hours per week for 50 weeks. Therefore, the 51.4 mrem/y CEDE, which is less than 100 mrem, does not warrant monitoring.*

Two hours per week does not seem reasonable or compatible with statements made by workers in interviews. The statements made by workers certainly bring into question the rationale for not conducting monitoring.

DOE requirements stipulated that air-monitoring equipment was to be routinely calibrated and maintained and should be capable of measuring one DAC when averaged over 8 hours. The DAC for insoluble, type 5, plutonium was, and is, 6.0×10^{-12} µCi/ml. The air-sampling limit given in Section 5.2.2 is at the DAC level for type W plutonium (2×10^{-12}) and not 10% of a DAC as required in DOE Order 5480.11, much less the 2% needed to reach the 40 DAC-hour level. Even at a level of detection of 10% of a DAC, the dose would be 500 mrem annually rather than the 100 mrem annual dose that the TBD would assume for the unmonitored claimants.

The TBD (Hickey et al. 2007, p. 37) indicates that for plutonium, claimant files probably will not contain reliable bioassay data, and that dose reconstructors should use the following approach for assigning potentially missed doses to workers:

- *For workers who had the highest possibility of intake (from Table 5-2), for each year of possible exposure from 1980 to 2000, when the number of disassemblies was highest,* ***assume a single acute intake of 40 DAC-hr (290 pCi)****. Assign 0.1 times this intake for category 2 workers in Table 5-2.* [Emphasis added]

- *For each year from 2001 to the present, for workers with the highest possibility of intake,* ***assume a single acute intake of 4 DAC-hr (29 pCi)****. Assign 0.1 times this intake for category 2 workers in Table 5-2.* [Emphasis added]

- *For the period 1958 to 1979 (except 1961), --- assign unmonitored workers an intake that is the same as the intake from the 1980 to 2000 period based in accordance with their risk potential from Table 5-2.*

The use of a single acute intake of 40 DAC-hour is 2% of the maximum annual exposure limit. **This is not a maximum bounding dose** for workers under conditions that existed at the Pantex

site, especially during disassembly operations. SC&A does not agree that the preceding approach is acceptable and claimant favorable for the reasons that follow.

The TBD further states the following:

> *However, because the documentation of the number of disassemblies and the contamination levels is not available, it is claimant-favorable to assign unmonitored workers an intake that is the same as the intake from the 1980 to 2000 period in accordance with their risk potential from Table 5-2.*

This stated position seems illogical in the face of the unknowns that are acknowledged. Given these unknowns (e.g., differences in work controls, monitoring sensitivities, air-monitoring methods) between 1958 and the 1990s, SC&A finds that the basis for the existing approaches and assumptions in this TBD are not given sufficiently from a scientific and operational standpoint to enable individual dose reconstruction with acceptable accuracy. Likewise, no triggering air-sampling data, contamination levels, or numbers of disassemblies are given as parameters to enable use of the default methodologies in OTIB-0018 (Brackett and Bihl 2005) and OTIB-0033 (Brackett 2005).

It should be noted that NIOSH acknowledges the unsupported application of the 40 DAC-hour criterion before 1991 with the following statement in the TBD (Hickey et al. 2007, Section 5.1.3):

> *The TBD research did **not** reveal the level of air concentrations or other workplace indicators that triggered special bioassays before 1991.*

The 40-DAC-hour value equates to an exposure of 100 mrem total effective dose equivalent (TEDE); likewise, 4 DAC-hours would equate to an exposure of 10 mrem TEDE. The use of air concentration monitoring has not proven to be protective of workers at other sites, including Rocky Flats, Hanford, and Savannah River. Experience at Rocky Flats in Colorado in 2000 demonstrated that chronic low levels of air concentration exposures below 4 DAC-hours led to exposures to workers in the area that were not detected in urine bioassay. They were only found when fecal analysis was performed on some of the workers. In the investigation of this incident, DOE concluded that, "Workplace indicators are not capable of detecting low levels of plutonium contamination in equipment and materials or as airborne radioactivity," and, "urinalysis and lung counting do not have the sensitivity necessary to detect intakes of plutonium at the DOE investigation level of 100 millirem" (DOE 2001). Section 5.1.4 of the TBD (Hickey et al. 2007) states that since 2001, the plant internal dosimetry program is capable of detecting intakes equal to or greater than 10 mrem H_E,50 based on ICRP 30 (ICRP 1979). This statement appears to directly contradict the statement by DOE in its investigation at Rocky Flats. As late as 2000, the 40-DAC-hour annual exposure recommended by this TBD, which equates to 100 mrem TEDE, is not supported by the DOE findings and investigation report.

The 40-DAC-hour criterion was introduced at Pantex only in 1991 and may, therefore, have no relevance to assigned doses for years prior to 1991. Experience at other plutonium facilities has proven that dependence upon smear sampling, air monitoring, or even nasal swipes as workplace

indicators does not preclude undetected uptakes by workers. It is SC&A's view that use of the 40-DAC-hour criterion for modeling doses prior to 1991 is without basis.

In summary, in the absence of routine bioassay data for plutonium and thorium, a single acute exposure of 40 DAC-hours per year is assigned to unmonitored workers. This is not adequately justified on a scientific basis and may not be claimant favorable. For thorium, the assumption of acute uptake in unmonitored thorium workers during disassembly is inconsistent with the TBD argument for chronic exposure to DU workers during disassembly, particularly in light of the documented incidents of thorium contamination problems as early as the 1960s, although the exposure conditions are similar. The internal dose TBD also indicates incorrectly that thorium exposures did not occur prior to 1980 and does not account for potential thorium exposure prior to 1980. Furthermore, for each of the four annual assigned intakes of thorium, NIOSH employed a DAC value of 1×10^{-12} µCi/ml. This value corresponds to the value in ICRP 30 (ICRP 1979), which has been significantly increased in ICRP 68 (ICRP 1994). Thus, all annual thorium intakes derived above are a factor of 3 too low if the more current DAC value applies. The dose assignments do not represent a maximum bounding dose for workers under conditions that existed at the Pantex site, especially during disassembly operations.

5.4 METHODS FOR ASSIGNMENT OF PHOTON AND NEUTRON DOSE ARE NOT CLEARLY DEFINED WITHIN THE EXTERNAL DOSE TBD AND ARE LIKELY TOO LOW FOR UNMONITORED WORKERS

5.4.1 Derived Estimates of the Photon and Neutron Dose for Unmonitored Workers are Likely to be too Low

Section 6.5.5.4 (page 34) of the Pantex TBD (Fix et al. 2007) provides guidance for dose reconstruction of unmonitored workers who by today's standards would be monitored. Guidance includes the following:

> *Photon doses to unmonitored workers can be estimated from the median photon doses for radiation workers listed in Table 6-17. A neutron dose can be derived from the median value of neutron-to-photon dose ratios … of 0.8 applied to the median photon dose for radiation workers will provide a claimant favorable estimate of the calculated neutron dose to unmonitored workers. The sum of the median photon dose and the calculated median neutron dose will provide a claimant-favorable total dose estimate for unmonitored workers.*

It is important to note that Pantex worker photon dose statistics as defined in Table 6-17 of the TBD are based solely on dosimeter records for monitored workers whose photon dose was **equal to or greater than 30 mrem per monitoring period.**

While the criterion of 30 mrem per dosimeter readout is not a concern, it must also be recognized that for the 10-year period of 1952 to 1962, the dosimeter exchange frequency was **weekly** and may explain the fact that for the period 1952 to 1958, **all Pantex** recorded doses (for monitored workers) were less than 30 mrem (as indicated by footnote "b" of Table 6-17). Thus, on the

basis of these statistics and guidance, all unmonitored workers would, therefore, also **not** be assigned any photon or neutron doses for the years 1952 through 1958.

For years 1959 to the present, the **exclusion of missed photon doses** for deriving the median dose of **monitored** workers will also impact the estimated dose for unmonitored workers. The extent to which the exclusion of missed photon dose for monitored workers negatively impacts the estimated **photon** and **neutron** dose for unmonitored workers is affected by the dosimeter exchange frequency that varied over time. For example, Table 6-17 of the TBD (Fix et al. 2007) identifies the following data for 1959, when dosimeters were issued weekly to monitored workers:

	No. of Workers Reported with		Dose (mrem)
Year	Photon Doses >30 mrem/dosimeter	Mean	Maximum
1959	[redacted for privacy reasons]	36.3	40

On the basis of the 30 mrem/dosimeter selection criteria, the data for 1959 imply the following:

- For all of 1959, a few workers had at least one dosimeter reading greater than 30 mrem.
- On the basis of the mean and maximum values, it is concluded that each of these workers only had one dosimeter reading greater than 30 mrem.
- This further implies that, for these workers, all other weekly dosimeter readings were less than 30 mrem and, therefore, excluded from consideration in estimating photon and neutron doses to unmonitored worker.

In summary, SC&A does not consider the current guidance for dose reconstruction of **unmonitored** workers claimant favorable. For deriving photon and neutron doses for **unmonitored** workers, **missed photon doses for monitored workers should be included.**

5.4.2 Contradictory Criteria Apparently Provided for Monitoring Workers or Ascertaining the Completeness of Monitoring Data

Section 6.4 of the TBD (Fix et al. 2007, p. 11) states the following:

> *At first, Pantex issued dosimeters only to **workers likely to receive a radiation dose.** From 1952 through 1957, this included only radiographers. From 1958 through 1988, only radiation workers were monitored...From 1989 to the present, all Pantex workers have been monitored for external radiation exposure.*
> [Emphasis added]

Section 6.5.5.3 of the external TBD indicates that neutron dose information was not properly measured until 1994 (Fix et al. 2007, p. 33):

> *In summary, all neutron dosimeters used at Pantex prior to 1994 underestimate actual neutron doses. The neutron doses of record are unreliable and should not be used by dose reconstructors.*

Although the term "likely to receive a radiation dose" from Section 6.4 is not quantitative, Section 6.5.1 of the TBD (Fix et al. 2006, p. 15) attempts to identify a threshold value by the following:

> *At a minimum, Pantex routine practices **appear to have required assigning dosimeters to** personnel designated as radiation workers who could receive an external radiation dose greater than 10% of the Radiation Protection Guideline (RPG) of **5 rem/year**.* [Emphasis added]

However, Section 6.5.2 (Fix et al. 2006, p. 16) contains the following statement, which apparently contradicts the *5* rem/year RPG**:**

> *During the early stages of the program to monitor individual Pantex workers, a weekly dose control of **0.3 rem** was in effect.* [Emphasis added]

Standards Mason & Hanger—Silas Mason Co., Inc., Pantex Plant, Safety, Issue of Radiation Dosimeters (Pantex 1980) defines those assigned dosimeters as follows:

> *Policy: The Company will provide radiation dosimeters for personnel where the potential exists to receive a dose or dose commitment in any calendar quarter in excess of 10% of the quarterly standards in Safety Standard 321, paragraph 5.*

Further clarification is provided (Pantex 1980) on who was likely to receive 10% of the quarterly standards referred to above:

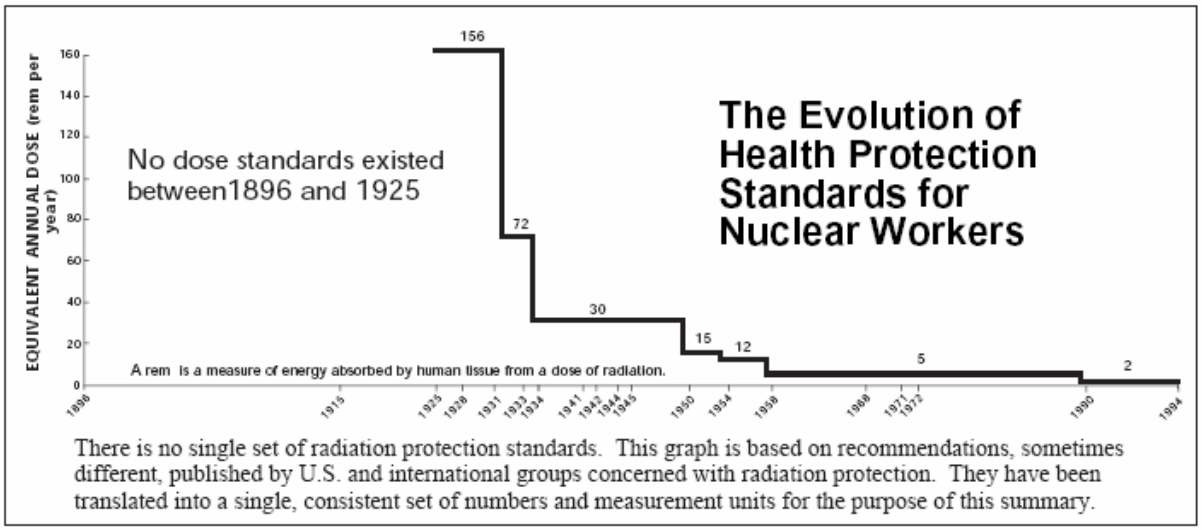
> *Monthly beta/gamma dosimeters were issued to (1) individuals who work with and around isotopic radiographic sources, x-ray machines, or accelerators; (2) any regularly assigned quarterly personnel who exceed 1250 mrem in one calendar quarter or 2000 mrem (total) in any two consecutive quarters; (3) all women who are regularly assigned to work in critical assembly areas, or locations where uranium, thorium, or plutonium components are processed and/or stored.*
>
> *Monthly beta/gamma/neutron dosimeters were issued to (1) those assigned to work in pit storage vaults; (2) those assigned to work in the pit weigh room; (3) designated maintenance personnel who are responsible for calibrating neutron detectors and/or performing maintenance on the Van de Graaff accelerator; (4) quality personnel who operate the Van de Graaff accelerator; (5) the health physics group; and (6) manufacturing and quality personnel who hold Category I certifications for W48, W55, W56, W58, B61, W62, W68, W76, W78, and W79.*

Extremity dosimeters were issued to (1) operators of x-ray diffractometers, x-ray spectrometers, and electron microscope during x-ray spectrometry work; (2) health physics doing semi-annual source leak tests; and (3) as determined by the Health Physicist.

Quarterly issue, whole body dosimeters are assigned to employees who are regularly assigned to or spend at least 4 hours per day in critical assembly areas, or locations where uranium, thorium, or plutonium components may be processed and/or stored, or other radioactive material with an exposure rate of greater than/equal to 2 mrem/hour. Employees who request dosimeters are also put on a quarterly issuance.

This indicates that Pantex based its 10% limit on the criterion of 3 rem per 13 weeks rather than the criterion of 5 rem per year. It is important to note that the referenced RPG of 5 rem per year was not fully implemented until 1968 (see Exhibit 1).

EXHIBIT 1
(Source: DOE 1996)



There is no single set of radiation protection standards. This graph is based on recommendations, sometimes different, published by U.S. and international groups concerned with radiation protection. They have been translated into a single, consistent set of numbers and measurement units for the purpose of this summary.

1896 Henri Becquerel discovers radiation. First radiation injuries are reported, but no protection standards exist.

1915 Protection standards describing "safe practices" for handling radium and X-ray machines are published in Sweden and Germany. Radiologists are advised to stay as far away from their equipment as possible, to handle radium vials with tongs, and to work no more than 35 hours a week. The U.S. and Britain soon follow suit, but no dose limits are set because measurement techniques and units do not yet exist.

1925 Swedish and German scientists publish estimates of "tolerance doses," the amount of radiation a person is thought to absorb without harm. Based on the amount of radiation that would burn skin, the tolerance dose is initially estimated to be the equivalent of about 156 rem per year (over 45 times the current standard), although the estimates vary widely.

1928 The first internationally accepted X-ray protection standard, 1 one-hundredth of the amount that burns skin per month, is accepted at an international congress.

1931 The tolerance dose is standardized at 6 rem per month (72 rem per year).

1933 The genetic effects of radiation on fruit flies are studied by German scientist A. Mueller. He learned that radiation caused genetic mutations.

1934 First international radiation safety standards based on measurements of damage to human tissue are published in Zurich by the International Commission on X-Ray and Radium Protection. Workers are allowed up to 0.1 rem per day (30 rem per year).

1941 Recommended tolerance for ingested radium is initially set at 1 ten-millionth of a curie per person by the National Commission on Radiation Protection. This recommendation is based on studies of radium-watch-dial painters.

1942 The Manhattan Project begins. The 1934 radiation exposure standards of 30 rem per year are accepted by the University of Chicago's Metallurgical Laboratory after experimental verification. The "tolerance" concept is discarded in favor of the "maximum permissible exposure."

1944 The initial tolerance limit for plutonium inhalation is set at 5 millionths of a gram per person by the Manhattan Project's radiation protection laboratory.

1945 The first atomic bombs are produced, tested, and used. Weighting factors for the different types of radiation are introduced to account for their different health effects. The plutonium tolerance limit is lowered to 1 millionth of a gram per person.

1950 Scientists discard the idea of a "maximum permissible exposure," recognizing that any amount of radiation may be dangerous. Radiation protection scientists recommend that exposure be "as low as reasonably achievable." Concern over latent cancer, life shortening, and genetic damage also causes standards to be halved: 0.3 rem per week (15 rem per year).

1954 A quarterly limit of 3 rem per 13 weeks (12 rem per year) is introduced by the U.S. National Bureau of Standards to allow more flexibility in exposure patterns. Workers are still allowed 0.3 rem per week up to this limit.

1958 In response to a study by the National Academy of Sciences of the genetic effects of radiation, a new dose limit is introduced, using a formula that allows workers to receive 5 rem per year after the age of 18. Annual doses are allowed to exceed this level up to 3 rem per 13 weeks (12 rem per year). To protect the gene pool, a lower standard of 0.5 rem per year is set for the general public.

1968 The Federal Government updates its protection standard to the 5 rem per year recommended in 1958. This standard has not been changed since.

1971 Radiation protection standard is restated by the National Committee on Radiation Protection but not really changed: 3 rem per 13 weeks in the past, 5 rem per year in the future. By including exposure from internal radiation ("body burden"), the standard is effectively lowered by a significant amount.

1972 The National Academy of Sciences publishes its first study of the health effects of radiation since 1956. The report, Biological Effects of Ionizing Radiation I (BEIR I) becomes the first of a series.

1990 The National Academy of Sciences BEIR V report asserts that radiation is almost nine times as damaging as estimated in BEIR I. Annual doses may no longer exceed 5 rem per year. The International Commission on Radiation Protection recommends that an average dose of 1 or 2 rem per year not be exceeded.

5.5 FINDING 5: THE RELIABILITY AND INTERPRETATION OF THE DOSIMETRY DATA ARE QUESTIONABLE

The external TBD implies that early film dosimeter data for Pantex are reliable, and for dose reconstruction NIOSH does not provide any "adjustment" factor for recorded deep dose measured by film dosimeters. Section 6.5.4.2 of ORAUT-TKBS-0013-6 (Fix et al. 2007, p. 28) states the following:

> *Photon radiation in the workplace would have been readily measured at Pantex, with available dosimeter technology, during **all years of operation.*** [Emphasis added]

While the dominant photon energy at Pantex may have represented the 60 keV gamma of Am-241, there were other high-energy photon sources, as acknowledged in Section 6.5.4.2 of the TBD (Fix et al. 2007):

> *Photon radiations encountered at Pantex have **widely varying energies**, ranging from about **30 keV** to a few **MeV**.* [Emphasis added]

The external TBD does not recognize the inaccuracies in calibration methods and uncertainties introduced into the dosimetry program by poor or improper practices. Furthermore, the International Agency for Research on Cancer (IARC) models have been misinterpreted.

5.5.1 No Adjustment Factor for Recorded Dose is Applied to Dose of Record

In Section 6.5.3 (Fix et al. 2007), NIOSH states the following:

> *Potential error in doses of record depends on the methods used to calibrate dosimeters and the extent of the **similarity** between the radiation fields used for **calibration** and those encountered in the **workplace.** The potential error is much greater for dosimeters with significant variations in response, such as film dosimeters for **lower** energy photon radiation and NTA and neutron TLDs for neutron radiation.* [Emphasis added]

It goes on to state the following:

> *Pantex Plant film badges and TLDs were **originally calibrated with Co-60 and Cs-137** sources with exposure measured by Victoreen R chambers (Pantex 1972).* [Emphasis added]

The statement given above regarding film calibration techniques does **not** comply with statements contained in Section 6.5.4:

> *Radiation fields were measured with TLDs positioned on a polymethyl methacrylate phantom and exposed under controlled conditions. The radiation*

> *fields were also characterized with several instruments used to measure the photon, neutron, and beta dose rates.* (p. 25)

It goes on to state the following:

> *The photon dose rates were measured with a Victoreen Model 530 electrometer in conjunction with the Victoreen Model 550-3 ion chamber... using four different X-ray techniques: M50 (22 keV), M100 (39 keV), M200 (90 keV), and M250 (180 keV)* (Pantex 2002a). *The appropriate correction factors were chosen based on gamma spectroscopy measurements made during the field measurements.* (p. 25)

Section 6.5.4 also states the following:

> *The predominant source of radiation dose at Pantex is photons from ^{241}Am, with the 60 keV photon being the most significant energy* (Pantex 2002a). (p. 25)

The dominant photon energy for Pantex workers was the 60 keV photon associated with Am-241, which is a factor of at least 10 lower than the calibration photon energy for Co-60 and/or Cs-137. For 60 keV or low-energy photons, the dominant interaction is by the photoelectric interaction, and attenuation is a function of the atomic number raised to the third power (i.e., Z^3). For photon energies from Cs-137 and Co-60, interaction and attenuation are dominated by the Compton effect, which is Z independent. Thus, it is clear that for proper assessment of a film dosimeter, calibration curves must be used that resemble photon energies of the work environment.

It is concluded that the use of Cs-137 or Co-60 as calibration sources for the dominant workplace photon energy of 60 keV would lead to an **over-response for the open window** (as a result of photographic film containing silver bromide with Z values of 47 and 35, respectively), and an **under-response for the deep dose,** which is subject to the attenuation effects of a 1000 mg/cm^2 (or 0.88 mm) of lead, which has a Z value of 82.

For the deep dose, the effect of a high-Z filter, when exposure involves a low-energy photon, is quantitatively demonstrated by comparing the mass attenuation coefficients and fractional photon transmission (or intensity) between lead (Pb) and tissue equivalent material.

Table 2. Comparison of Mass Attenuation Coefficients with Fractional Photon Transmission

Photon Energy	Mass Attenuation Coefficient (cm^2/g)		Fractional Intensity* for 1000 mg/cm^2	
(keV)	Tissue	Pb	Tissue	Pb
30	0.373	29.7	0.69	1.3×10^{-13}
60	0.206	4.87	0.81	7.7×10^{-3}
80	0.183	2.33	0.83	9.7×10^{-2}
150	0.149	1.97	0.86	1.4×10^{-1}
500	0.096	0.161	0.91	8.5×10^{-1}
1000	0.070	0.0708	0.93	9.3×10^{-1}

*$I = I_0 e^{-(\mu/\rho)(\rho)(x)}$ where,

μ/ρ = mass attenuation coefficient (g/cm^2)
ρ = density (g/cm^3)
x = thickness (cm)

The TBD (Fix et al. 2007) does not identify the time period during which the calibration of film dosimeters was based on the use of Cs-137/Co-60 calibration sources. However, SC&A extracted the following conclusion from a DOE investigation report issued by DOE in 1980 (DOE 1980, p. 47) regarding an event involving a high radiation dosimeter;

> *Calibration response curves are not generated for radiation sources other than Cesium-137 and Californium-252. There are other sources of electromagnetic radiation at the Pantex Plant such as low energy X-rays (X-ray diffractometer) and high energy radiographic equipment (Linac) where specific TLD responses are not understood. Neutron calibration response curves are also not understood, i.e., TLD response to a broader neutron spectrum. The Health Physics personnel do not understand the effects of aging, handling and radiation on TLD response.*
>
> *The M&H Health & Safety Department voluntarily participated in a national performance criteria evaluation of personnel dosimetry conducted by the University of Michigan during the period May 1978 to September 1979. Problem areas were identified and the University of Michigan has volunteered to assist Pantex in the resolution of these problems. Participation in other similar national studies is encouraged.*

The TBD (Fix et al. 2007) acknowledges the use of three contractor services between 1952 and 1973 for processing film dosimeters. The competency of these vendors is not questioned here, but it is without basis to assume that proper calibration curves would have been used that matched the expected photon energies of the Pantex work environments with the proper calibration sources and their corresponding calibration curves.

While the dominant photon energy at Pantex may have represented the 60 keV gamma of Am-241, there were other high-energy photon sources, as acknowledged in Section 6.5.4.2 of the TBD (Fix et al. 2007):

> *Photon radiations encountered at Pantex have **widely varying energies,** ranging from about **30 keV to a few MeV.*** [Emphasis added]

Given this variability of photon energies to which workers may have been exposed and the highly classified nature of the Pantex operations, it is reasonable to question whether vendor dosimeter services can be expected to have known which calibration curves to apply to individual Pantex dosimeters. It is not clear that vendors have known to process dosimeters according to, for example, whether worker exposures involved bare pits, linear accelerators, a Co-60 source, prompt gamma from activation products, or high-energy bremsstrahlung.

In summary, calibration and dosimeter processing methods by outside contractor services cannot be blindly assumed. The TBD (Fix et al. 2007) acknowledges the use of three contractor services between 1952 and 1973 for processing film dosimeters. The dominant photon energy for Pantex workers was the 60 keV photon associated with Am-241; however, photon calibrations were done with Co-60 and/or Cs-137, and therefore, the calibration curves from Co-60 and Cs-137 would not resemble photon energies of the work environment.

5.5.2 Misuse of Recent Study Data Regarding Historical Dosimeter Reliability and the Failure to Acknowledge Programmatic Deficiencies Identified by DOE in 1980

In the early years of the nuclear weapons program, the science that currently defines the discipline of health physics and its application to monitor radiation workers were in the early stages of a long evolving process that continues to this day. For this reason, the reliability of early dosimetry data must be assessed more critically and in context with the time period during which these dosimeters were used.

In evaluating the credibility of historical external monitoring data for Pantex (as well as most other DOE facilities), NIOSH has taken an approach that is not only generic but inappropriately draws conclusions from study data that are unlikely to be representative of the actual operations at a given facility and time period. For example, Section 6.5 of the TBD (Fix et al. 2007) discusses how NIOSH evaluates historical monitoring data and provides summary conclusions:

> *NIOSH's evaluation of historical dosimetry systems used at Pantex (as well as other DOE facilities) to monitor workers are largely based on two studies that included the International Agency for Research on Cancer (IARC) study (Thierry-Chef 2002) and the Hanford intercomparison dosimeter study (Wilson 1990). Fix et al. (2007) states in the TBD (p. 19): Analyses of dosimeter performance data and workplace collective dose patterns in Table 6-1 enable some judgments about consistency in historical measured radiation doses. The **International Agency for Research on Cancer (IARC)** conducted a comparison study of 10 commonly used dosimetry systems from around the world (Thierry-Chef et al. 2002). **Three of the designs were from the United States: a two-element film dosimeter previously used at the DOE Hanford Site (identified as US-2), a multielement film dosimeter previously used at Hanford (US-8), and the Panasonic 802 TLD used at the DOE Savannah River Site (US-22) (and at Pantex from 1980 to 2000).** The study concluded that exposure to workers could be characterized as a*

> *combination of anterior-posterior (AP), rotational (ROT), and isotropic (ISO) irradiation geometries. Dosimeter responses for these geometries were investigated using two phantoms to represent the torso of the body. The first phantom was a water filled slab phantom with polymethyl methacrylate walls, an overall width of 30 cm, an overall height of 30 cm, and an overall depth of 15 cm. This phantom is widely used for dosimeter calibration and performance testing by the International Standards Organization. The second phantom was an anthropomorphic Alderson Rando Phantom. This realistic man-type phantom has a natural human skeleton cast inside material that has a tissue-equivalent composition. Table 6-5 lists the results of this study for the U.S. dosimeters. The two-element film dosimeter significantly overestimated Hp(10) at the lower photon energies of 118 keV and 208 keV. As noted above, the multielement film badge was used at Pantex in essentially the same manner as the two-element film badge.*
>
> ***To evaluate the dosimeter response to lower energy (ie., less-than-100-keV) photons that are significant in plutonium operations, Hanford conducted intercomparison testing of all Hanford historical dosimeter film designs (Wilson et al. 1990) using AP irradiations only. Although there are differences in films and filters used in multielement dosimeters, good comparison in energy response for both Pantex and Hanford dosimeters is probably based on similar design characteristics. The results of this testing for energies greater than 100 keV are consistent with the IARC results, showing an overestimate of Hp(10) for the two-element dosimeter used from 1944 to 1956***. [Emphasis added]

In summarizing the results of the 2002 IARC study (James 2003), NIOSH correctly stated that "the two element US-2 film dosimeter significantly overestimated Hp(l 0) at the lower photon energies of 118 keV and 208 keV." However, the US-2 dosimeter (which used 1 mm Ag) was only one of many early film dosimeters employed at DOE facilities. Other early film dosimeters employed lead filters solely or in combination with other metal filters (e.g., silver, cadmium, tin). With regard to test results for these dosimeters, IARC also observed significant **under-responses,** as given in the following conclusions:

> *Old film dosimeters (generally made with only one or two windows) have either over- or underestimated doses at low energies, depending on the filters used. If the thickness of the filter was not sufficient to compensate for the over-response of the film, doses were overestimated (FR-1). Conversely, thick filters such as the 1mm Pb filter (UK-2) have led to* ***underestimation*** *of doses. . . . [and] Results of experiments are in agreement with what was expected.' major over- and* ***underestimations*** *of doses were obtained with old dose-meters irradiated to low energy photon radiation.* [Emphasis added]

Furthermore, the degree to which the results of these two generic laboratory-controlled studies apply to historical Pantex dosimetry data cannot be judged solely based on whether similar (or even identical) dosimeters were used. Important to the performance of a given dosimeter is a

thorough understanding of its limitations and variable response to workplace radiation fields. As already noted, NIOSH acknowledged the need for proper calibration methods in Section 6.5.3 of the TBD (Fix et al. 2007) when it cautioned the following:

> *Potential error in doses of record depends on the **methods used to calibrate dosimeters and the extent of the similarity between the radiation fields** used for calibration and those encountered in the workplace. The potential error is much greater for dosimeters with significant variations in response, such as film dosimeters for lower energy photon radiation...* [Emphasis added]

For this reason, results of highly controlled laboratory studies by trained scientists who understood the importance of energy-dependent calibration methods may only have limited relevance to the credibility of historical Pantex dosimetry data, which may reflect inappropriate calibration methods. NIOSH acknowledged the under-response of film Hp(10) doses for IAAP by assuming a reduced efficiency of only 30%.

Pantex Deficiencies as Noted in a 1980 DOE Investigation. At this time, information that would allow for a complete assessment of all historical dosimetry data is unlikely to exist. However, deficiencies in personnel monitoring practices that include calibration methods at Pantex are documented for a select time period in an unclassified report issued in 1980 by DOE, titled, *Report of the Investigation of a Radiation Exposure Incident at the Pantex Plant During September 1979* (DOE 1980).

In response to a high dosimeter reading reported by Pantex in 1979, DOE appointed an Investigation Board, whose charter was to do the following:

> *…investigate the occurrence and determine the cause(s) for the occurrence and prepare and submit to the manager a written report, including recommendations for appropriate corrective action(s) to prevent or minimize similar occurrences.*

The following conclusions stated by the Investigative Board (DOE 1980, p. 30) regarding personnel responsibilities and qualifications are relevant to this report.

> *The dosimeter program is the responsibility of the Environmental Health Section of the M&H Health and Safety Department. The assembling, cleaning, annealing, reading, distribution and accountability of all the dosimeters processed at Pantex is performed by two Laboratory Technicians. Laboratory Technician No. 1 has worked in this position for approximately seven years whereas Laboratory Technician No. 2 has one month of experience. The Laboratory Technicians are supervised by a Scientist who has been employed by M&H for approximately six months. The Scientist was assigned full responsibility for the Pantex Dosimeter Program in mid-August 1979 by the Environmental Health Section Head.*
>
> *The Laboratory Technicians have **never received any formalized training for their responsibilities**. Their training has consisted of observation of others and on-the-job training. This is also true of the recently appointed Scientist.*

> *However, he had approximately 14 months of health physics experience prior to his employment by M&H but none in personnel dosimetry.* ***Although there are no official written procedures for either the Laboratory Technicians or the Scientists, a draft Internal Operating Procedure for the Pantex Dosimetry Program has been written but is not approved to date.*** *Interviews indicated that there is minimal communication between the Environmental Health Section Head and his staff.* [Emphasis added]

The following from the same source regarding the quality of the dosimetry program are also relevant (DOE 1980, pp. 33 and 47):

> *The assembly of dosimeter for the most part is accomplished by Laboratory Technician No. 1. The insertion of TLDs into the routine use portion of the dosimeter is a tedious routine function. No one checks the technicians in this function and occasionally there are instances where TLDs are left out, but this is a very rare occurrence. Laboratory technicians read the digital printout on the TLD reader and enter this number on the computer worksheet. This function is also not verified.*
>
> *During the third quarter of 1979 the policy of recording glow curves (photomultiplier tube response from the TLD reader) was reinstated. However, the glow curves are not compared with the computer worksheet data. The scientist reviews the computer worksheets only for gross errors prior to them being sent to the Data Center.*
>
> ***Calibration response curves are not generated for radiation sources other than Cesium-137 and Caljfornium-252. There are other sources of electromagnetic radiation at the Pantex Plant such as low energy X-rays (X-ray diffractometer) and high energy radiographic equipment (Linac) where specific TLD response are not understood. Neutron calibration response curves are also not understood, i.e., TLD response to a broader neutron spectrum. The Health Physics personnel do not understand the effects of aging, handling and radiation on TLD response.***
>
> *The Environmental Health Section Head does not conduct periodic checks or discuss problem areas with his staff on a frequent basis on the Pantex Dosimetry Program.* [Emphasis added]

In the report, the Investigative Board cited key findings that concluded the following (DOE 1980, p. 51):

- *Gamma calibration response curves for TLDs … did not have sufficient range.*
- *The scientist and laboratory technicians assigned to the Pantex dosimeter program were inadequately trained.*

- *There were no formal operating procedures for the Pantex dosimetry program.*

- *The quality of the Pantex dosimetry program was less than adequate.*

In response to these and other findings, the Investigative Board issued a total of 18 recommendations for improvement, which are enclosed herein as Exhibit 2 in their original format.

SC&A considers the deficiencies identified by the DOE Investigative Board to be highly relevant to the credibility of dosimetry data for Pantex. NIOSH needs to consider these deficiencies for their implications on the accuracy of external dose reconstruction.

EXHIBIT 2
(Source: DOE 1980)

MAY 19 1980

Herman E. Roser, Manager, ALO

REPORT OF THE INVESTIGATION OF A RADIATION EXPOSURE INCIDENT AT THE PANTEX PLANT DURING SEPTEMBER 1979

In accordance with your October 18, 1979 memorandum, attached are four copies of the subject report.

The following recommendations emanated from the investigation of the incident and are considered by the Investigation Board as necessary to prevent or minimize the probability of recurrences:

1. M&H shall correct the permanent radiation dose file of Assembly Operator No. 1 by deleting the September radiation dose of 3.6 Rem whole body and assigning a 200 mRem dose for September and a 1170 mRem dose for the third quarter of 1979.

2. M&H shall ensure that the Health Physics Laboratory initiates an internal comprehensive record keeping system for the issuance, receipt, and evaluation of duplicate dosimeters.

3. M&H shall improve the quality of the Pantex Dosimetry Program by implementing, as a minimum:

   a. Semiannual calibration of each TLD lot,

   b. Calibration response curves for low energy x-ray and high energy radiographic equipment,

   c. Calibration response curves which reflect a range appropriate for Pantex operations,

   d. An evaluation of TLD response to a broader neutron spectrum and

   e. An evaluation of the effects of aging, handling, and radiation on TLD response.

EXHIBIT 2 (Continued)

4. M&H shall upgrade the equipment, procedures and hardware used in the Pantex Dosimetry Program in order to provide more rapid and accurate TLD dose evaluations to M&H management and the DOE.

5. M&H shall evaluate the processing techniques for the teflon TLDs used as a backup dosimeter.

6. M&H shall evaluate the need for a supervisor to be assigned full time to the Pantex Dosimetry Program.

7. M&H shall develop and implement concise internal operating procedures for the Pantex Dosimetry Program.

8. M&H shall provide training commensurate with responsibilities for personnel assigned to the Pantex Dosimetry Program. Consideration should be given for training to be provided by an outside professional organization.

9. M&H shall ensure compliance with their Safety Standard 321.3 relative to the issuance of monthly dosimeters.

10. M&H shall revise Safety Standard 321.3 to include provisions and to delineate responsibilities for the issuance of monthly dosimeters to temporary certified Category I assembly operators.

11. M&H management shall ensure that:

    a. Complete records of personnel dosimeter distribution and return are initiated and maintained, and

    b. The importance of dosimeter use and accountability be emphasized to all personnel.

12. M&H management shall ensure that supervisory personnel receiving radiation dose data become more knowledgeable of the radiation dose limits as established in Safety Standard 321.

13. M&H shall disseminate radiation dose data down to the appropriate first line supervision.

14. M&H shall prohibit the use of security badges and personnel dosimeters as work tools on nuclear explosives.

EXHIBIT 2 (Continued)

Herman E. Roser - 3 -

15. M&H shall strengthen safety training relative to evacuation, radiation alarms and nuclear criticality for personnel assigned to the assembly cells.

16. M&H shall require the Environmental Health Section Head to conduct more frequent audits of the Health Physics Laboratory.

17. M&H management shall closely monitor the radiation overexposure potential should substantial amounts of overtime work be required on Program C and some future programs.

18. M&H Health & Safety Department should continue to participate in national intercomparison studies for personnel dosimetry and should accept the University of Michigan's offer of assistance to resolve the problem areas identified by their study of the Pantex Dosimetry Program.

Original Signed
David A. Gurule"

David A. Gurule, Chairman
Investigation Board

Attachment:
Investigation Report (4 cys)

5.5.3 Effective Implementation of the Dosimetry Program May Not Have Occurred Even if Workers Were Assigned Dosimetry

DOE 1980 (pp. 37–38) describes the procedures and work practices governing the assignment and the observed field uses of dosimetry:

> *The issuances of dosimeters to the assembly operators are governed by the Safety Standard 321.3 (Appendix B). Monthly dosimeters are assigned to Manufacturing personnel who hold Category I Certification as defined by Safety Standard 330.4, "Training and Certification of operative Personnel for the DOE Nuclear Explosive Safety Program," (Appendix D) for designated nuclear explosive Programs.* ***Programs A and B require assembly operators to be issued monthly dosimeters... It was very obvious to the Investigation Board that this Standard is not being followed in that 12 of the 14 assembly operators reviewed by the Board had quarterly dosimeters, whereas Safety Standard 321.3 requires that for Program A and B these assembly operators are to be issued monthly dosimeters.***
>
> *During the October 17 tour of the call area by the Investigation Board, assembly operations were observed using their security badges as a work tool. During subsequent interviews with assembly operators, the Board learned that dosimeters are also used as work tools. In both instances the security badge and dosimeter were in close proximity to the nuclear explosive pit surface. The Board also determined from interviews that safety procedures relative to evacuation, radiation alarms and nuclear criticality were not fully understood by the assembly operators and their supervision. Additionally, the New Assembly Department Head was not knowledgeable of dose rate limits as reported on the* ***PX-445 nor the dosimeter issue policy.*** [Emphasis added]

The report further explains the significance of erroneously assigning quarterly badges to pit assembly operators in Programs A and B (DOE 1980, p. 49):

> *The Health and Safety Department is responsible for assigning monthly and quarterly dosimeters to appropriate personnel. Assembly operators working in Cell Nos. 3 and 5 on Programs B and A, respectively, are required to have monthly dosimeters. However, 12 out of 14 of these assembly operators working in August and September were issued* ***quarterly dosimeters. In addition to only being evaluated quarterly, a quarterly issue dosimeter does not measure neutron radiation.*** [Emphasis added]

The failure to evaluate 12 out of 14 assembly operators (along with potentially other programmatic deficiencies) may shed light on the unexplained fluctuations of neutron-to-photon ratios over time and among workers with common job functions as noted by NIOSH in Section 6.6.3 of the Pantex TBD (Fix et al. 2007).

Further complicating matters are issues with individuals not wearing their dosimeters all the time. During a survey of film badge utilization in June 1969, Poynor found the following (Poyner 1969):

> *The subject survey indicated a total of 108 persons were not wearing their badges during the period June 18, 19, and 20, and recommends that the Safety Inspector should conduct spot checks to insure the personnel requiring film badges use the badges daily. It can be inferred from this that it is the intent that each person issued a badge will wear the badge daily even though his work area for a given day would not under normal conditions result in excessive exposure. Information discussions indicate that actually this is a judgment matter and the daily wearing of the badge is not mandatory.*

Line management had the responsibility for ensuring individuals wore their dosimeters. The extent of issues that involved inappropriate wearing of dosimetry is unknown; however, radiological control staff, in response to this memo, established a program to spot check badge racks to determine whether individuals were wearing their badges.

5.6 FINDING 6: THE ASSUMPTION THAT THE USE OF A 95TH PERCENTILE NEUTRON-TO-PHOTON RATIO IS BOUNDING IS NOT CORRECT FOR SOME EXPOSURE SCENARIOS

The external dosimetry TBD indicates that all neutron dosimeters used prior to 1994 underestimate the neutron exposure received by workers. Furthermore, the TBD states that "neutron doses of record are unreliable and should not be used by dose reconstructors" (Fix et al. 2007). Due to the questionable sensitivity of Eastman Kodak Nuclear Track Film Type A (NTA) dosimeters to neutron energies below 1,000 keV, NIOSH has judged neutron monitoring data corresponding to NTA dosimeters to be unreliable. Neutron doses measured with the UD-802 TLD from 1980 to 1992 were not effective in reflecting neutron exposure and likely underestimated the dose (DOE 1989):

> *Dosimeters: The Pantex Dosimetry Program has used a Panasonic Model 802 dosimeter for approximately 8 years. The dosimeter package consists of 2-Ca_5O_4 elements, 2-LiB_4O_7 elements and the standard model 802 lead, plastic and open window filtration.*
>
> *Although Pantex uses the dosimeter in mixed neutron and photon fields and evaluates the dosimeter for neutron results, the 802 is not adequate for this use. Because the 802 uses natural lithium in the LiB4O7 elements, it is not possible to differentiate between the its* [sic] *TLD response differences due to photon energy dependence or neutrons.*
>
> *This inadequacy is borne out by the dosimeters performance in the most recent round of the DOELAP Performance Test. The dosimeter exceeded the mixed neutron and photon performance limits in the following categories:*

Cf-252 + Cs-137: Total performance error = 0.927
Cf-252 + Pu photons: Total performance error = 1.943

The performance criteria for these categories is 0.40.

To perform the necessary mixed photon and neutron dosimetry one alternative might be to replace the current dosimeter with one of the Panasonic units designed to perform mixed beta, photon, and neutron dosimetry. (pp. 15–16)

With the change in algorithm in 1992 to 1993, some questions were raised about the overestimation of neutron dose during this period (Fix et al. 2007). For this reason, the TBD proposes to employ neutron-to-photon ratios prior to 1994.

The TBD neutron-to-photon ratios are based on worker dosimeter measurements that were recorded using the Panasonic UD-809/UD-812 system and correspond to doses in which both the photon and neutron doses of the individual exceeded 50 mrem per year. From these data, a **median** neutron-to-photon ratio of 0.8 and a 95th percentile value of 1.7 were calculated. For dose reconstruction of monitored workers, NIOSH recommends the 95th percentile neutron-to-photon ratio of 1.7 unless actual recorded neutron doses exceed the calculated values.

NIOSH's assumption that the post-1993 neutron-to-photon ratio of 1.7 is a **bounding value** is based on the fact that post-1994 data reflect reduced photon doses associated with dosimeter readings under a lead apron, which heavily attenuated the 60 keV photon from Am-241 and, therefore, maximized the neutron-to-photon ratio. While the neutron-to-photon ratio is affected by the shielding present between the radioactive material and the person, it is also dependent on the weapon type and the distance of the individual from the source. SC&A reviewed radiation surveys taken with a Victoreen 440 and a Rem Ball on 12 units in various configurations to determine whether the value of 1.7 was bounding for exposure scenarios encountered by Pantex workers. In general, the neutron-to-photon ratio increased as the distance from the source term increased. Survey information also showed that work with units in stands or stored in containers also increased the neutron-to-photon ratio (Pantex 1992, Pantex 1993, Pantex 1994, Pantex 1995a, Pantex 1995b). The review indicates that the 95th percentile neutron-to-photon ratio does not provide an upper bound. Table 2 shows the weapons programs evaluated and whether the neutron-to-photon ratio is bounded by the ratio value of 1.7.

Measurements were taken at the surface, at 30 cm, and at 60 cm (sometimes 50 cm) from the surface of the object (e.g., bare pit, container, housing). Measurements for the 55 and 56 programs approach 1.7, but do not exceed this value (Drummond 1964). The use of bare pit measurements will not always reflect the most conservative neutron-to-photon ratio.

Empirical measurements made by **instruments** in 1979 suggest neutron-to-photon ratios for pits in shipping containers and pits in HE that exceed the 95th percentile value of 1.7 (DOE 1980). These higher neutron-to-photon ratios would apply to select workers associated with radiography, inspection, storage, and transportation of weapons.

Table 3: Comparison of the Neutron-to-Photon Ratios from Weapons Surveys to the TBD 95th Percentile Value

Weapons Program	Neutron-to-Photon Ratio Greater Than 1.7
48	Yes, in certain configurations
57	No
61	Yes, in certain configurations
62	No
68	Yes, in certain configurations
71	No
76	No
78	No
79	Yes, approximately 10:1 ratio*
80	Yes, in certain configurations
83	No
87	Yes, in certain configurations

* Survey data was limited for this unit.
Source: Pantex 1992, Pantex 1993, Pantex 1994, Pantex 1995a, Pantex 1995b

A neutron-to-photon ratio of about 8:1 was observed for workers monitored in 1960; when the inefficiency of NTA film is taken into consideration, the neutron-to-photon ratio for 1960 dosimetry data may exceed 30:1. For reasons that apparently involve classified information, the TBD (Fix et al. 2007) does not explain the extent to which the 1960 monitoring data reflect unusual work practices and source terms.

The assumption in the TBD that lead aprons reduce the photon contribution and therefore increase the neutron-to-photon ratio is correct. However, this is not the only factor that influences the ratio, and the relative reduction of the photon component of the ratio does not compensate for all factors. The 1.7 ratio can be exceeded through work with several weapon types and configurations. Ratios can range from less than one to as high as 30:1 based on information reviewed by SC&A to date. The external dosimetry TBD also fails to mention a ratio for operations in the Neutron Activation Analysis Facility, or with other nonweapons-related sources of neutrons.

5.7 WORKPLACE EXPOSURE CONDITIONS ARE NOT ADEQUATELY CONSIDERED IN THE EXTERNAL DOSE TBD

External radiation fields at Pantex arise from the handling of nuclear weapons components and components containing plutonium, thorium, EU, DU, and associated daughter products. The predominant source of external exposure is during the assembly, disassembly, and modification of weapons where radioactive material is unshielded and often held close to the body. The radiation characteristics vary in energy with the different weapons programs and radiation-generating devices used. A complicating factor related to the evaluation of external radiation fields is that much of the information existing is classified, including the source terms. Further complications exist as a result of the destruction of early field radiological control records in the 1980s (see Attachment 4).

Section 6.5.4 of ORAUT-TKBS-0013-6 (Fix et al. 2007) provides an overview of workplace radiation fields:

> *The highest dose rates are encountered when handling bare pits.* [Bare pits are defined as pits without high explosives.] (p. 24)

Section 6.5.4 also states the following:

> *The primary source of beta radiation are depleted uranium and thorium* (Pantex 2002a)…. *Pantex workers handled DU (primarily ^{238}U) during assembly and disassembly of weapon components, and during and following testing. ... DU components have ^{234m}Pa activities nearly equal to that of ^{238}U….[and] when it decays to ^{234}U with a maximum energy of 2.29 MeV and an average energy of 0.825 MeV. An additional source of exposure in the Pantex workplace is from... bremsstrahlung and characteristic X-rays in DU or ^{238}U (Shleien, Slaback, and Birky 1998). ...A bare slab source of DU contributes an Hp(0.07)dose of approximately 200 mrad/hr at the surface (BRH 1970) compared to an Hp(10) dose of approximately 2 mrad/hr (ORAUT 2004a).*

Dose rates surveys at the surface, at 30 cm, and at 60 cm from various pit types indicate that surface dose rates do exceed dose rates for bar units, units in containers, and units partially assembled (Pantex 1992, Pantex 1993, Pantex 1994, Pantex 1995a, Pantex 1995b).

The radiological characterization of workplace neutron fields for selected weapons programs is classified. Based on unclassified information, the external dose TBD (Fix et al. 2007) states the following:

> *Unclassified information on neutron spectra from fission and sealed plutonium sources is available." "...The average [neutron] energy is higher for unshielded plutonium and beryllium (α, n) interaction than for fission neutrons.* (p. 28)

It also states the following:

> *Each weapon program characterized was measured in each of four configurations: full weapon, physics package, bare pit, and pit in storage container. The data derived from these measurements is classified; however, some generalized unclassified conclusions can be stated.* (p. 25)

Other workplace radiation fields involve radiation-generating devices (x-rays, accelerators, flash x-ray), gamma sources, and neutron sources (Cf-252 exposure). Examples of these sources come from inventories by Ikenberry (1983) and Sievers (1981):

Diagnostic x-ray	12-2, Medical
Cabinet x-ray machines (2)	12-17, Bay 9
Van de Graaff Accelerator	12-21, East Bay
X-ray image intensifier	12-21, Bay 5
Gas Chromotograph	12-21, Bay 13
2.5 MeV x-ray	12-21, Bay 7
Linatron	12-40
Co-60 Source	12-40
Linatron	12-56
Portable x-ray unit	12-26, Bay 12
Portable x-ray unit	12-40
Source Room	12-2
Cs-137 Calibrator	12-5 (electronics), 12-26
SEM with x-ray spectrometer microprobe	11-17
X-ray diffraction unit	11-17
Neutron Activation Analysis Facility	11-17
Cooky Flash X-ray (3 heads) 600 keV	FS-10, Zone 4
X-ray spectrometer	11-51

N-rays (neutron rays) were used in lieu of x-rays for small metal and explosive parts (DOE 1995). Many of these units contributed to exposures from low-energy photons, which are difficult to detect with TLDs. These source exposures would be of more concern for skin exposures. For example, the scanning electron microscope surveys indicate exposure to very low energy photons.

> *Measurements made* a *30 kV, 225 μA beam current, two of three focusing magnets off using and aluminum-tungsten target, an exposure rate of 180–200 mr/hr was measured in the x-ray spectrometer at the window from the column. An assumption is made that at 30 kV, all the x-rays produced with a frequency of greater than 1% have x-ray energies less than 20 kV. Correction factors for this energy radiation would vary from 2–10. A more efficient dosimeter is suggested at this time. TLDs have a problem with detection of xray < 50* keV (Kouba 1978).

Worker geometry and proximity to radioactive material is also pertinent to dose reconstruction. An investigation into a possible radiation exposure conducted by Cassidy et al. (1979) describes the exposure distances typically required during weigh room activities:

> *Observation of Weigh Room activities show the operator of the balance and the Veeco leak detector was required to work within 6 to 24 inches of the surface of the pit in order to accurately perform measurements. Each different piece of equipment offers varying degrees of shielding from radiation. Inspectors unpacking and packing pits from shipping containers were generally an arm length from the surface of the pit (18 to 30 inches).*

The investigation report also states the following:

> *Prior to the leak test inspection, the pit surface must be absolutely clean to prevent interference in the determination of the helium leak rate. Every pit is wiped with alcohol and a Kimwipe prior to testing. It was observed that some inspectors hold pits within 2 inches of their chest during this nominal 2 minute cleaning period. The helium leak test takes approximately 6 to 7 minutes.*

The investigation report goes on to state the following:

> *Several pits (approximately one out of four) were received by Weigh Room personnel during the second quarter that were not sufficiently cleaned.* [Name} *and coworkers stated in interviews that the contaminated pits were placed in special fixtures on the top of waist high tables. The cleaning process required intimate contact (4 to 6 inches) of the pit surface with the upper torso of the body.* [p. 13]

Those involved in assembly and disassembly operations also reiterated during site expert interviews that radioactive material was at times held in their laps or worked with on equipment, placing the component at waist level rather than collar level where the badge was worn. With larger weapons, units were lowered into a hole in the floor and workers were positioned at floor level (See Attachment 4).

Film badges worn on the lapel or collar may not accurately represent organ doses. Site experts expressed concern related to the position of the source terms versus the badge. Workers reported manually handling pits adjacent to their person, working at tables where the pelvis was the highest area of exposure, or working on larger weapons from above. Dosimetry on the chest would not adequately reflect the exposure to lower organs. The external dose TBD refers the dose reconstructor to OCAS-TIB-0010 (OCAS 2005b) if the claim file provided information to suggest a geometry for which the dosimeter would receive appreciably less dose than the organ of interest (Fix et al. 2007, p. 32). The correction factors applied for glovebox workers may not be appropriate for situations encountered by Pantex workers where radioactive material is often handled directly against the body. The TBD should provide further basis for the application of the glovebox correction factor as an organ-specific correction factor for organ-versus-badge geometry issues.

Section 6.7.4 of the TBD (Fix et a1. 2007, p. 48) states the following:

> *In years before 1981, the skin dose records included beta doses only [99]. In 1981 and subsequent years, the skin dose has been calculated as the sum of the beta, gamma, and neutrons. In cases where no nonpenetrating dose was recorded, the skin dose is assumed to be equal to the whole-body penetrating dose [100].*

The assignment of whole-body penetrating dose as nonpenetrating dose may underestimate that actual nonpenetrating dose, particularly for those working with uranium. Depending on the

enrichment of the uranium, the nonpenetrating doses can be significantly higher than penetrating dose. Furthermore, dose from skin contamination has not been considered. There was a potential for skin contamination when working with weapons containing oxidized uranium and thorium.

In summary, the external dose TBD, in its analysis of workplace radiation fields, has not provided an adequate basis for assigning partial body exposures during the handling of weapons components. Dosimeters were worn at the collar as instructed by health physics staff. The highest exposures may have been at the waist or lower, resulting in an underestimate of dose to organs at waist level. The assignment of whole-body penetrating dose in situations where nonpenetrating dose is unavailable may underestimate the dose, particularly in situations where uranium is involved. Exposures from skin contamination were possible with weapons programs involving oxidized metal. External exposure from this route should be considered for skin cancers.

5.8 RADON DOSES ARE INAPPROPRIATELY ASSIGNED TO UNDERGROUND WORKERS AND NO RADON DOSE IS ASSIGNED TO ABOVEGROUND WORKERS

Section 5.3 of the TBD (Hickey et al. 2007) discusses enhanced radon levels associated with gravel gertie cells and bays. It presents data from two independent radon surveys. The first survey, conducted in 1969, was limited to Cells 1–6 and employed tracks imparted on film. A more comprehensive radon assessment was conducted in 1990 at 137 locations, including underground and aboveground buildings.

For dose reconstruction, NIOSH selected to use the more comprehensive 1990 survey data set and the following values:

- For workers with full-time assignments to gravel gerties (1958–present)
  - The median value of 1.5 pCi for underground buildings as a year-round value with a GSD of 3
  - An equilibrium fraction of 0.4 for radon and its short-lived daughters, which yields a yearly exposure of 0.072 working level month (WLM)
- For workers with occasional assignment/entries to gravel gerties (1958–present)
  - 0.0072 WLM/yr

SC&A reviewed the 1990 survey data in context with the model assumptions used to assign yearly radon exposures of 0.072 WLM and 0.0072 WLM to full-time and part-time workers assigned to underground “buildings.” SC&A identified the three issues described in the following sections.

5.8.1 The Use of 0.4 as the Equilibrium Fraction is Inappropriate and without Scientific Basis

Section 5.3.5 of the TBD (Hickey et al. 2007) states the following:

> *…the equilibrium factor F using an assumed value of **0.4** as recommended by the ICRP (1981) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993).* [Emphasis added]

A review of these references indicates that the value of 0.4 was intended to serve as a "typical" value for the indoor air of **residential** homes and not for unique facilities such as a gravel gertie or bay. With regard to the 0.4 equilibrium factor, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993, UNSCEAR 1994) provides the following information:

> *Recent determination of the equilibrium factor for radon indoors generally confirms the typical value of 0.4... Indoor measurements show a range from 0.1 to 0.9 but most are within the **typical value of 0.4.** A recent study in seven north American **houses** has shown that the equilibrium factor in any building shows a significant variation with time, typically of a few tens of percent.* [Emphasis added]

Given the unique function and design of gravel gerties and bays, an equilibrium factor should be based on building ventilation specifications that should be readily available.

5.8.2 The Use of the Median Radon Value for All Underground Buildings at Pantex is Inappropriate

Table 5-17 of the TBD (Hickey et al. 2007) shows that for **all** underground buildings at Pantex, measured radon levels varied between 0.8 pCi/l to 7.1 pCi/l, with a geometric mean of 1.5 pCi/l. It should be noted that for any given building, the estimated radon concentration was limited to a **single measurement.** Since it is unlikely that workers were periodically rotated among these buildings, the use of the geometric mean would severely underestimate radon exposures to those workers assigned to buildings with the highest levels.

In the absence of assigning building-specific radon values, a more justifiable approach would assign the highest building value of 7.1 pCi/l to all workers by assuming that this value represents the 95^{th} percentile value.

5.8.3 The TBD Does Not Assign Radon Exposure Doses to Workers/Personnel Assigned to Aboveground Buildings

Table 5-17 of the TBD (Hickey et al. 2007) shows that radon levels for aboveground buildings were comparable to underground buildings. In fact, the single highest radon measurement for **all** buildings at Pantex was the aboveground DOE Building with a radon level of **8.1 pCi/l.**

NIOSH notes that this building was constructed with bricks from the Texas panhandle area, which must reasonably be assumed to represent the radon source term. This "natural" source term is no different from the massive "gravel earth, and Gunite" concrete cap that defines the principal source term for gravel gerties or the massive concrete walls of a bay.

Related information is contained in Section 2 of the Pantex site description TBD (Martin 2007b), which states the following:

> *In this document the word "facility" is used as a general term for an area,* ***building,*** *or* ***group of buildings*** *that served a specific purpose at a site. … EEOICPA defines a DOE facility as* ***"any building,*** *structure, or premise, including the grounds upon which such building, structure, or premise is located ...* ***in which operations are, or have been, conducted by, or on behalf of, the Department of Energy. …*** *Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above,* ***any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.*** [Emphasis added]

Despite this all-encompassing definition of "facility," NIOSH further states the following:

> *NIOSH, however, does not consider the following exposures to be occupationally derived:*
>
> - *Radiation from naturally occurring radon present in conventional structures.*

SC&A considers this exclusion not only without basis but contradictory to the stated definition of "facility" and not consistent with practices in other DOE site profiles developed by NIOSH.

5.9 THE INTERNAL DOSE TBD FAILS TO CONSIDER EARLY TRITIUM EXPOSURES AND DOES NOT CONSIDER ALL CHEMICAL FORMS OF TRITIUM

Tritium was introduced into weapons systems in the 1950's (DOE 1997a). The internal dose TBD indicates reservoirs began arriving at Pantex in late 1956 or early 1957 (Hickey et al. 2007). The primary form of tritium used in the Pantex weapons programs was gas contained in pressured gas cylinders (reservoirs) (BWXT 2003). During certain programs, there were routine small releases of tritium to the work space during disassembly of tritium-containing parts. Portable tritium monitors were used to detect tritium offgassing, and local ventilation was available. With the pervasive nature of tritium, weapons components and waste contamination were a concern. For example, when Pantex took over smelter activities after Paducah shut down its smelter, older components were disposed of by smelting them. Tritium-contaminated components were identified as a source of potential internal exposure to Pantex workers (Alexander 1981):

> *Units which have had recycled reservoirs seem to be particularly troublesome. Contaminated components generally include the reservoir itself valves and the ends of the pit tubes. In some cases other parts can be contaminated.*

The document also stated the following (Alexander 1981):

> *Tritium contamination levels on some components are high enough to be a source of tritium exposure to Pantex employees. However, these levels do not represent an "imminent danger."*

Pantex verified that small amounts of tritium contamination were transferred to personal protective equipment, particularly gloves, during weapons operations (BWXT 2003).

The potential for metal tritide exposure existed at Pantex. Tritides were formed as a result of the tritium gas reacting with metal components of weapons and producing tritiated compounds or metal tritides. In addition, metal tritides were used in some weapons programs. The dates of potential exposure from use of metal tritides in weapons are classified.

5.9.1 Lack of Tritium Bioassay Monitoring Data Prior to 1972

The internal dose TBD has established that tritium monitoring occurred starting in 1972 but acknowledges that few bioassay results were found in worker dosimetry records (Hickey et al. 2007, p. 14):

> *From 1972 to the present, although tritium bioassay occurred, there are few routine monitoring data in individual worker dosimetry records.*

There was some indication that some tritium monitoring was conducted prior to this time (Hickey et al. 2007, p. 13):

> *The report further states that Pantex performed about 10 tritium urinalyses a month, and there was no indication of personnel exposure. There might have been a small routine tritium program, but the research for this analysis found no other information.*

Evaluation of Table 5-3 of the internal dose TBD indicates that the number of workers monitored for tritium uptakes was not constant, and only 0–4 workers were monitored per year from 1972–1975 (Hickey et al. 2007, p. 15). In the absence of bioassay data prior to 1972, NIOSH has proposed to assign twice the highest uptake from the 1970s for the years 1957 to 1971. For the period 1972 to present, unmonitored tritium exposures are assigned to production technicians, RSTs, and quality assurance technicians. The TBD uses a triangular distribution with a minimum of zero and a mode and maximum as defined in Table 5-6 to assign the missed dose (Hickey et al. 2007).

The TBD does not clearly define either the data used to derive values in Table 5-6 or the number of data points used for determining the mode. Many of the values are assumed without adequate

basis for the assumption. It is supposed that tritium bioassay occurred, yet few monitoring data were discovered in the dosimetry files. Unmonitored tritium exposures are also limited to three job classifications, which is not inclusive of all individuals handling reservoirs or tritium-contaminated components or those in the immediate vicinity when these activities are performed. For example, this would include those disposing of retired reservoirs and other tritium-contaminated equipment and materials and those receiving or preparing components for shipment, to name a few. The tritium monitoring program was not effective for metal tritides and other tritiated compounds. The TBD directs dose reconstructors to assume tritiated water unless otherwise noted in a worker's record. The lack of monitoring data in the files indicates that tritide uptakes would not be available in the claimant file for the dose reconstructor to make this decision. It is interesting to note from the site expert interviews that individuals currently involved with internal dosimetry had no knowledge of the existence of tritides on site, yet field radiological control personnel were knowledgeable.

In summary, the internal dose TBD must include further information on the completeness and adequacy of the tritium monitoring programs and a well-defined basis for assumptions. It is not reasonable to rely on data that may not exist in dosimetry files as a basis for establishing potential tritide uptakes, and alternate methods should be considered.

5.9.2 Assumptions Regarding the Chemical State for Tritium May Not Be Claimant Favorable

The default assumptions regarding the chemical state for tritium may not be claimant favorable or appropriate for all workers. Section 5.2.1 of the TBD (Hickey et al. 2007, p. 10) states the following:

> *Tritium sealed under high pressure in the reservoir units has the potential to leak during disassembly.…The tritium in the reservoirs is 99% gaseous molecular hydrogen (DT, HT, or T_2) and 1% tritiated water vapor (HTO or T_20).*

The TBD did not indicate if supporting evidence exists that the tritium from these aged units had not reacted with the metal reservoir and formed a tritide. **If tritides were present, they would not be detectable by the urine bioassay monitoring used at Pantex.**

Assigned tritium doses defined by bioassay data or assigned to unmonitored workers (defined in Table 5-6 of the TBD (Hickey et al. 2007)) for **all** years are based on the assumption that all bodily intakes and urine measurements reflect tritium in the form of water. This assumption conflicts with the following statement from the TBD:

> *Tritium gas interacts over time with moisture in the air, hydrogenated materials (e.g., hydrocarbons, organic compounds, and concrete), and some forms of metals to form tritiated compounds and metal tritides.* (Hickey et al. 2007, Section 5.2.1, p. 10)

SC&A raised the question of metal tritides with interviewees, who indicated that some metal components were contaminated with tritium and metal tritides were known to be present. Some

weapons systems did contain tritide components. SC&A's document review revealed that the dosimetry staff recognized the presence of metal tritides and addressed it in a March 2004 document (Jones and Levell 2004), which noted that "the current bioassay process will continue to be used for tritide operations." The document did recognize that no special swipe techniques had been identified to apply to metal tritide surveys and no special techniques had yet been identified. It should be noted that SC&A has made similar findings in other TBD reviews regarding monitoring limitations for tritides.

Compounds other than tritiated water would be expected to have substantially longer residence times in the body and, therefore, higher doses than what are assumed for tritiated water.

5.10 UNEXPLAINED AND UNREASONABLE EXTREME CHANGES IN SENSITIVITY VALUES FOR URANIUM URINALYSIS AND MINIMUM DETECTABLE ACTIVITY, AND SIGNIFICANT DATA GAPS IN TABLE 5-8

Table 4 (Hickey et al. 2007) shows an improvement in sensitivity of two orders of magnitude between 1960 and 1963, then jumps back by a factor of 50 between 1968 and 1978. Gaps appear in the data with no historical information on sensitivity from 1968 to 1978, 1978 to 1983, and 1983 through 1990.

Table 4. Uranium Urinalysis Sensitivity Values

Year	Laboratory	Sensitivity Value	Description
1959	Los Alamos Scientific Laboratory	0.5 µg[a]	
1960	Tracer Laboratory	10 µg/L[a]	Fluorometry sensitivity
1963	Controls for Radiation	0.10 µg/L[a]	Less-than value
1965	Controls for Radiation	0.10 µg/L[a]	Less-than value
1967	Controls for Radiation	0.15 µg/L[a]	Less-than value
1968	Isotopes, Inc.	0.10 µg/L[a]	
1978	Control for Environ. Pollution	5 µg/sample[a]	Less-than value
1983	Camp Dresser & McKee	1.4 pCi/L[a]	2σ counting error only; use 3.3 for MDA
1983	Los Alamos Scientific Laboratory	5 µg/L	Less-than value
1990–1992	Y-12 Bioassay Laboratory	0.03 pCi/sample	MDA[b]
1994	Y-12 Bioassay Laboratory	Approx. 0.15 dpm/ sample, U-238, U-234, U-235, 0.06 dpm/sample U-236	MDAs[a]
2001	Y-12 Bioassay Laboratory	U-238, U-234, U-235: 0.03 pCi/L	MDA[c]

a. From reports from the laboratories.
b. From BWXT Pantex (1992) and Ealy (1990).
c. From NWXT Pantex (2001).
Source: Hickey et al. 2007

The TBD recognizes these gaps (Hickey et al. 2007, Table 5-8, p. 22) and states the following:

> *Because uranium bioassays were generally not obtained routinely but usually from special bioassay samples obtained after events with potential for intake, it is*

> *not known if the gaps in the table occur because no bioassay was obtained in those years or if the bioassay sensitivities have not been found. If necessary, dose reconstructors should use the last previous MDA for years not covered in Table 5.8.*

This approach may not be appropriate or claimant favorable. There are a couple of orders of magnitude variation in sensitivity within the gaps between documented or assumed/less-than values. The TBD notes that the equations used to determine the less-than values are not known. It further assumes that the less-than values are more of a decision level than an MDA; it also assumes that the MDA is twice the less-than value. With these **inherent uncertainties and wide variations** in values, SC&A does not believe the TBD provides a technically valid basis for applying uranium bioassay analysis data spanning these gaps and years to coworker applications and intake calculations.

5.11 IMPROPER ADJUSTMENT FACTORS ASSOCIATED WITH LEAD APRON USE

According to the TBD, lead aprons were available to workers throughout the operation of Pantex, but their use was not proceduralized and mandated until the mid-1980s. Although workers were encouraged to wear their dosimeters under the lead apron "...in order to make the best estimate of the delivered dose equivalent to the major portion of the body," there was no enforcement to ensure that dosimeters were worn under the apron (Fix et al. 2007, Section 6.5.5.6).

The TBD (Fix et al. 2007) further notes the following:

> *In 1995, a series of studies were performed at Pantex on the effects of apron use on dosimeter readings. The studies were done by putting a dosimeter on the front of a phantom positioned in an **aisle way near the middle of an igloo in which plutonium pits were stored in cans.** The photon spectrum in this isotropic field was "hardened" by the steel cans and it included the 2.2-Me V photons generated when a thermal neutron is captured by hydrogen. This exposure scenario was chosen to represent the radiation fields where lead aprons were **least effective** in **reducing photon dose.** ... The results summarized in Table 6-14 are the percent reduction when wearing an apron in comparison with the measurement with no apron...* [Emphasis added]
>
> *An adjustment factor was derived from the largest relevant dose reduction data in Table 6-14 and applied to the location of cancer sites listed in Table 6-15.*

The TBD (Fix et al. 2007) provides the following guidance for dose reconstruction:

> 1. *If the cancer site is in an area protected by a lead apron, an adjustment factor of 1 applies to a worker who wore the dosimeter **under** the apron* [i.e., no adjustment is needed]. [Emphasis added]

2. *If a worker received dose while **not** wearing an apron, applying this factor of I to the measured dose is **still claimant favorable.*** [Emphasis added]

3. *If the cancer site is in an area not protected by a lead apron, an adjustment factor of 1.5 is applied, regardless of the location of the dosimeter.*

Each of these three guidance statements contains elements that are technically incorrect, misleading, and/or incomplete.

5.11.1 Regarding TBD (Fix et al. 2007) Statement #1

The NIOSH guidance states that when a dosimeter was worn under the apron, there is no need to adjust recorded dose for cancer sites protected by the apron. Given the failure to proceduralize the use of lead aprons and the failure to ensure that dosimeters were worn under the apron (as clearly acknowledged in the TBD), it is unclear what evidence exists in dosimetry records that would indicate that the dosimeter was, in fact, worn under the apron.

If evidence exists that the dosimeter was, in fact, worn under the apron, the following additional questions remain:

- Since the lead apron in itself contains 0.5 mm lead, which portion (i.e., open window or 1000 mg/shielded portion) of the recorded dosimeter reading would apply to specific tissues covered by the apron, such as skin or deep-lying tissues?

- What organ-specific dose conversion factors (DCFs) are to be used (e.g., Hp(10), 30–250 keV, anterior-posterior geometry)?

5.11.2 Regarding TBD Statement #2

In the second statement quoted above, the historical failure to proceduralize and/or enforce the use of lead aprons and the position of the dosimeter under the apron also raises the question regarding the existence of evidence to support the assumption that the dosimeter was worn in the absence of an apron (as opposed to with and underneath the apron).

5.11.3 Regarding TBD Statement #3

NIOSH (Fix et al. 2007) describes the adjustment factor of 1.5 for tissues not protected by the lead apron as follows:

> *An adjustment factor* [that] *was derived from the **largest relevant** dose reduction data in Table 6-14...* [Emphasis added]

This statement implies that the adjustment factor of 1.5 represents an upper bound value for converting the under-the-apron recorded dose to a dosimeter dose that would have been recorded in the absence of the apron. However, the dose reduction values cited in Table 6-14 (Fix et al. 2007) correspond to measurements, as cited below:

> *….on the front of a phantom positioned in an aisle way near the middle of an igloo in which plutonium pits were stored in cans… [and where] the photon spectrum in this* ***isotropic*** *field was* ***"hardened"*** *by the steel and included the 2.2 MeV photon generated when a thermal neutron is captured by hydrogen. This exposure scenario was chosen to represent the radiation fields where lead aprons were* ***least*** *effective in reducing photon dose.* [Emphasis added]

SC&A fully agrees with the last statement in the quote immediately above and would consider NIOSH's 1.5 adjustment factor appropriate for workers who were exclusively exposed inside igloos where the exposure geometry was isotropic and the photon spectrum was "hardened" by the steel containers.

SC&A concludes that for other locations and source terms where the radiation fields were dominated by low-energy photons (e.g., 60 keV) and an anterior-posterior geometry, adjustment factors considerably larger than 1.5 must be assumed.

5.12 ADEQUATE CONSIDERATION HAS NOT BEEN GIVEN TO THE POTENTIAL EXPOSURES AT THE FIRING SITES

Hydroshots were conducted at Firing Site 5 using DU as a surrogate material. The hydroshots at Pantex resulted in uranium contamination at the firing sites. Kilogram quantities of DU were used in test fire shots during the late 1960s and early 1970s. Approximately 83% of the uranium was recovered and approximately 95% could be accounted for at the firing site. The remaining 5% was vaporized and dispersed in the test fire cloud.

In a response to Goeckermann of Lawrence Livermore National Laboratory (LLNL), Drummand of the Pantex Plant provided the following information on hydroshot activities (Drummond 1961):

> *Some microscopic amounts of uranium are being dusted beyond the perimeter (2400' away) under certain moderately prevalent meteorological conditions. We have based this on the results of a "sticky pan" test performed on a typical unit.*
>
> *Recently it has been learned that in addition to particulate material, sizeable pieces of special case material are being propelled considerable distances. Pieces up to 58 grams have been collected at distances up to approximately 300'.*

Shots resulted in DU contamination at Firing Site 4, Firing Site 5, and Firing Site 10. In the early years, workers had to manually recover radioactive material with their bare hands. According to site experts, as the technician staff increased, part of their training was to survey for uranium shrapnel at the firing sites and clean it up if it was found. HE skid and wedge tests were also conducted at the firing sites.

5.12.1 Area Reentry Postshot

The TBD states on page 28 that the operators walked to ground zero to retrieve their instruments, which would have been clearly beyond the location of the air-monitoring stations. Section 5.2.2.6.1 of the TBD (Hickey et al. 2007) states the following:

> *After the detonation, the operators walked to ground zero to retrieve their instruments. A driver, who was outside the fenced area (approximately 2,000 ft from ground zero), drove to the detonation site to retrieve the operators. The total exposure time for the operators was less than 30 min. The cloud from the detonations was clearly visible and the operators and driver avoided direct exposure to the cloud.*

These comments (p. 31) suggest that the operators did not have respiratory protection and it is not certain whether the operators and drivers may have been in the shot-cloud at some time. If the driver was avoiding the cloud, then the approaching vehicle may have been upwind of the walking operators, and the operators would likely have been subjected to the dust cloud from the vehicle. Section 5.2.1 of the IAAP TBD, ORAUT-TKBS-0018 (ORAUT 2005, p. 26), states, "Neither the driver nor the control operators wore respirators." The IAAP hydroshots appear to have been conducted using procedures similar to those of Pantex. Interviews with workers conducted by SC&A staff as well as photographs obtained by SC&A that were taken at the burn pit appear to support this historic practice.

Section 5.2.2.6 of the Pantex TBD (Hickey et al. 2007) provides guidance for internal DU doses associated with the hydroshots. Based on a limited amount of air-sampling data, NIOSH developed **inhalation** dose models for site operators and drivers that are based on 95th percentile values and appear claimant favorable. SC&A reviewed available air-sampling data at Firing Station 4 starting October 27, 1959, and ending December 22, 1961, and compared these data with information presented in Figures 5-1 and 5-2 of the TBD (Hickey et al. 2007). The raw data appear to be consistent with data presented in the TBD. For example, the highest air concentration of 108 dpm/m^3 (or 49 pCi/m^3) inside the bunker was recorded on March 18, 1960, which matches the highest data point shown in Figure 5-1. However, the interpretation and verification of "outside the bunker" air-sampling data was considerably more difficult. For a large number of outside air samples, it was uncertain which number represented the total air volume drawn (i.e., m^3) or the activity in the sampled air (i.e., dpm/m^3).

Overall, the many questions that remain unanswered about the conditions to which these workers were exposed make it difficult to perform a dose reconstruction with the information given. For example, it is not known whether the operators and/or drivers were wearing respiratory protection, or whether the operators wore any other protective clothing while going to ground zero. The location of the "outside the bunker" air monitors is not known. Because these issues remain unanswered, SC&A does not agree that it is appropriate or claimant favorable to use the 95th percentile of 1960s outside air concentration of 24 pCi/m^3. The TBD (Hickey et al. 2007) indicates that intakes of DU by firing-site personnel were possible after every shot at Firing Site 5, not just after the hydroshots. A radio-controlled drone mounted with air samplers on each wing was used in the 1970s to monitor air concentrations in the cloud (Alexander and Phillips

1972). "The log-probability fit to the drone sampler results had a median concentration of 70 pCi/m^3 and a 95th percentile concentration of 944 pCi/m^3, so the median ground concentration outside the bunker in the 1960s was about 85 times less than the median cloud concentration measured in the 1970s" (Hickey et al. 2007) It is not clear why drone data were not considered when developing bounding doses for these workers, considering all of the unknowns and the additional resuspensions that may have been created by vehicle and personnel movement within the contamination areas.

5.12.2 Firing Site 5 Cleanup Exposure Assumptions

The use of 50 times 1 DAC-hour exposures per year for Firing Site 5 unmonitored workers during cleanup is inconsistent with other TBD intake assumptions. Firing Site 5 was decontaminated in the late 1990s. The work was done by a subcontractor under radiation work permits with monitoring by site RCTs, who provided for bioassays to be collected. The work was conducted during the time Pantex was using lapel air samplers and using 40 DAC-hours as the trigger for initiating bioassay. The TBD states the following:

> *Therefore, if it is determined that an energy employee was an unmonitored worker associated with the Firing Site 5 cleanup, an assumption of chronic intake of 5O DAC-hr per year of DU can be made.* [This assumes that intakes below] *DAC-hr on any given air sampler are disregarded and there might be 50 such results per year.] Fifty DAC-hr of type S uranium equates to an intake of 600 pCi, or 1.6 pCi/d.* (Hickey et al. 2007, Section 5.2.2.6.3, p. 32)

The use of 50 DAC-hours based on fifty 1-DAC-hour intakes seems very inconsistent with the fact that the trigger for initiating bioassay sampling is 40 DAC-hours and the TBD only considers missed doses below 1 DAC-hour for intakes. In Section 5.2.2.3.2 of the TBD (Hickey et al. 2007, p. 23), related to dose reconstruction for assembly/disassembly unmonitored workers, the value of 40 DAC-hours is considered claimant favorable and the calculated intake is 19 pCi/d for Type S inhalation. From the information given, it does appear that the worker wore lapel air samplers (but not whether all workers were wearing the lapel samplers) and bioassay sampling was done. However, the fact remains that the trigger for initiating bioassay was set at 40 DAC-hours, and the material was undoubtedly highly insoluble since this was a firing site where the HE and DU device underwent destruction in a contained system vented through a high-efficiency particulate air-filtered system involving high temperatures. SC&A questions the use of 1 DAC-hour in this case and finds it inconsistent with other calculated intakes for unmonitored workers, particularly considering the nature of the fired materials that were being remediated. In addition, the use of the 19 pCi/d intake factor is inconsistent with IAAP intake values.

5.12.3 Burn Area Exposures

Weapons components were in some cases recovered. To sanitize weapons components to render them unclassified, parts were removed and subjected to granulation, smelting, crushing, shredding, burning, incineration, and other processes. The average amount of hazardous material generated averaged about 75 pounds per weapon. This included DU as well as other metals and components (DOE 1995). In the early years, this material was handled with bare hands. In addition, burn pits were used to dispose of chemical wastes. The basis for determining exposure

to uranium from burning activities was air-sampling activity for the period of 1960–1967. The default intake rate of DU for the burning ground was 130 pCi/day for 1952 to present. No air-sampling data were available for 1952–1959 and 1963 (Hickey et al. 2007).

Furthermore, dose assignment from hydroshot and burning operations should adequately reflect potential internal and external exposures, particularly from cleanup activities and incidental entries into these areas. Based on a limited amount of air-sampling data, NIOSH developed **inhalation** dose models for site operators and drivers that are based on 95th percentile values and appear claimant favorable. SC&A reviewed available air-sampling data at Firing Station 4 starting October 27, 1959, and ending December 22, 1961, and compared these data with information presented in Figures 5-1 and 5-2 of the TBD (Hickey et al. 2007). The raw data SC&A reviewed does not support the determination that using the 95th percentile of 1960s outside air concentration of 24 pCi/m' is appropriate or claimant favorable. SC&A questions the use of 1 DAC-hour in this case and finds it inconsistent with other calculated intakes for unmonitored workers, particularly considering the nature of the fired materials that were being remediated. The 19 pCi/d intake factor at Pantex is inconsistent with that used for IAAP.

5.13 INCONSISTENCIES EXIST BETWEEN THE PRINCIPAL ASSUMPTIONS IN THE PANTEX PLANT TBDS AND VERSION 0 OF THE IAAP TBDS

The primary missions of Pantex included assembly, maintenance, and surveillance of nuclear warheads; disassembly of retired weapons; fabrication of chemical HE components; and storage of plutonium components from dismantled warheads. IAAP was also involved in the same activities while it was operating. In fact, these plants worked cooperatively with one another and sometimes worked on the same weapon. Both plants were also involved in conducting hydroshot tests and burning HE. In ORAUT-TKBS-0018 (ORAUT 2005), NIOSH assumed specific data to assign dose. These data were compared with the data assumed in the current Pantex TBDs. Although the operations at these plants were the same, contradictions exist in the parameters assumed for the Pantex plant and IAAP (ORAUT-TKBS-0018) site profiles for external and internal dose. The assumptions for Pantex were not as conservative as those for IAAP.

5.13.1 Differences in the Interpretation of Early Recorded Film Dosimeter Measurements

Section 1.0 of the IAAP TBD (ORAUT 2005) provides the following summary description of principal activities performed at IAAP:

> *The Iowa Army Ammunition Plant (IAAP) was responsible for high explosive (HE) fabrication, assembly of non-nuclear and nuclear components, retrofits, modifications, surveillance, and disassembly of nuclear weapons.*

The same company, Silas Mason Company, operated both IAAP and Pantex. Both facilities were involved in weapons assembly, disassembly, and modification. Each of the facilities conducted hydroshot tests and burning operations. The principal radionuclides of concern are uranium, plutonium, thorium, and tritium. IAAP conducted operations on returned Pantex weapons and vice versa. Activities involved essentially the same physical structures, such as

bays and gravel gerties, as acknowledged in Section 5.3 of ORAUT-TKBS-0018, Revision 0 (ORAUT 2005), as demonstrated by the following statement (which erroneously assumed that in the absence of IAAP-specific radon data, Pantex data could serve as surrogate information):

> *Weapons assembly/disassembly was conducted in **bays** and special cells called **Gravel Gerties** … without additional information, it was deemed claimant-favorable to use **Pantex** data. …* [Emphasis added]

Pantex radon measurements and dose calculations were assumed to be the best indicators of radon exposure at IAAP and were used as discussed below.

Not surprisingly, most descriptions, information, data, and references cited in the IAAP TBD are either identical to or closely parallel those cited in the Pantex site profile, including those involving external radiation exposure. For example, Section 6.2 of the IAAP TBD (ORAUT 2005, pp. 34–35) states the following:

> *The main contribution to external radiation at **IAAP** was due to processes involving the handling or working around the nuclear components (pits) which contained plutonium and/or highly enriched uranium (HEU). In addition, radiography of explosive components at various stages of assembly also results in some potential for external exposure…*
>
> *The generic pit spectrum clearly indicates that the **external dose** contribution is predominately from 30–250 keV photons, with approximately **70%** of the total dose rate coming from the 60 kV photopeak from Am-241.* [Emphasis added]

Section 6.5.4 of the Pantex TBD (Fix et al. 2007, pp. 24–25) describes workplace radiation fields similarly, as given by the following:

> *The **main** workplace radiation fields at **Pantex** arise from the handling of nuclear weapon components containing plutonium, thorium, and highly enriched uranium (HEU) and their radioactive progeny, as well as DU. The **highest** dose rates are encountered when handling bare pits…*
>
> *The predominant source of radiation dose at Pantex is photons and the main source is ^{241}Am, with the 60-keV photon being the **most significant energy....*** [Emphasis added]

In brief, both TBDs emphatically state that work activities associated with pits represent the principal source for external exposure and that the 60 keV Am-241 photon contributes the majority of dose. However, the TBDs differ in how early recorded film dosimeter measurements are viewed and employed for dose reconstruction, as explained in the following statements.

Section 6.4 of the IAAP TBD states the following (ORAUT 2005, pp. 43–44):

> *Specific designs of the Landauer film dosimeters used at IAAP have not been located, and no records of the mentioned earlier use of TracerLab dosimeters have been found. However, from the content of IAAP-submitted AEC termination reports and personal testimony (Fix and Bihl 2003), it is likely that the film dosimeter was, at least, a two-region design (i.e., non-penetrating dose calculated from film response to* ***open window*** *or generally unfiltered region of the film and* ***penetrating dose calculated*** *from film response under a selected, usually metallic, filter). …*
>
> *The AEC conducted performance testing of several commercial and in-house film dosimeter services during 1954 with exposures provided by the National Bureau of Standards* ***(AEC 1955).*** *Specific dosimeter design specifications are included in the documentation. The testing included* ***40-, 70-, and 210-keV*** *narrow spectral beam X-ray techniques, ^{60}Co gamma radiation, and selected mixtures of these beams. Measured response data are provided in the report for each of the respective dosimeter open-window and filtered regions of the film. This information exhibits the significant over response of the open-window and lightly filtered regions of the film at lower (i.e., 40 and 70 keV) photon energies and an* ***under response*** *of the heavily filtered portions of the film dosimeters to photon energies less than 70 keV.*
>
> ***There is considerable uncertainty as to whether the IAAP dosimeter badge could reliably measure a penetrating dose from the 60 keV photons from Am-241.*** *As illustrated in Figure 6.1, the Am-241 60 keV photopeak contributes approximately 70% of the total photon dose. ... dosimetry measurements conducted at Hanford (Larson and Roesch, 1954) using a two element film badge similar to the early IAAP dosimeter, photons less than 70 keV were severely attenuated. Based on the Hanford report, at 60 keV, only 37% of the penetrating dose would be measured.*
>
> *Based on the Hanford information and professional judgment,* ***a claimant favorable fraction of 30% of the Am-241 photopeak is assumed to have been measured by the IAAP film badge.*** *This value is likely to be slightly lower than reality, and since multiple filters were used throughout the DOE complex from the early 1960s, this is likely a considerable overestimate for the later years (1970s).* [Emphasis added]

However, Section 6.5.5 of the Pantex TBD states the following (Fix et al. 2007, p. 29):

> *The Pantex Plant used film for beta and photon dosimetry from* ***1952 to 1973.*** ***Three*** *companies provided dosimetry services during this period; the services and dosimeters were essentially the same. The dosimeters provided an open window with little filtration, a lower energy window for allowing beta particles and lower energy photons to enter a film area with a plastic filter, and a film area with a metal (usually aluminum) filter. The open window enabled measurement of beta particles and lower energy photons. The plastic filter enabled measurement of*

> *intermediate energy photons, and the metal filter enabled measurement of higher energy photons (1-cm depth).*
>
> *The **AEC** tested film badges provided by **TracerLab** (AEC 1955) with exposures to 40-, 70-, and 210-KeV X-rays and ^{60}Co gamma rays, and mixed-energy exposures of all four radiations. The film badges generally responded well "with a tendency to interpret most exposures too high." The over response (in the 100- to 200-keV region) tended to yield conservatively high results. **This testing,** combined with the data from Figure 6-2 and the pattern in recorded doses with progressively more sophisticated dosimetry systems, **leads to the conclusion that photon doses measured at Pantex by film badges were reliable. Moreover, photon exposures from 60-keV ^{24l}Am photons were not underestimated and the total photon dose was probably slightly overestimated because of the over response to photons in the 100- to 200-keV energy region.*** [Emphasis added]

Section 6.5.4.2 of the Pantex TBD also states the following (Fix et al. 2007, p. 26):

> *Photon radiation in the workplace would have been **readily** measured at Pantex, with available dosimeter technology, during **all** years of operation.* [Emphasis added]

SC&A finds these contradictory conclusions hard to understand given that identical references were cited and at least one subject matter expert is common to both TBDs.

5.13.2 Inconsistency in Dose Assessment for Depleted Uranium

Section 5.2.4 of the original IAAP TBD (ORAUT-TKBS-0018) (ORAUT 2005) gave intake values for DU from disassembly of weapons. This TBD stated, "Experience at Pantex indicated that 'about half of a cup' (118 cm) of oxidized DU (Depleted Uranium) was available for resuspension," and further stated, "The estimated intake of DU per disassembly is then: 815 pCi." This value of 815 pCi per disassembly, with an average of 100 disassemblies per year, provided a modeled chronic annual intake of 81,500 pCi of DU per year as a constant upper bound. The revised TBD for IAAP, OCAS-TKBS-0001 (OCAS 2005b), goes on to state, "it was determined that internal exposures cannot be estimated with sufficient accuracy to complete dose reconstructions (USDOL 2005); thus, no internal dose should be assigned for Iowa Army Ammunition Plant employment." On the other hand, for Pantex, the internal TBD (Hickey et al. 2007) states that the dose reconstructors should assume median chronic DU inhalation intake of 1.3 pCi/d for Type M or 19 pCi/d for Ttype S. There is a huge disparity between the original intake estimates, which IAAP TBD referenced back to Pantex per disassembly, and the values the Pantex TBD, ORAUT-TKBS-0013-5 (Hickey et al. 2007), instructs the dose reconstructors to use. The Pantex TBD values, likewise, do not agree with statements given by workers at Pantex who stated that 90 units were disassembled in a work bay in approximately 2 weeks and that DU oxide flaked off and was swept up and bagged at the end of the day and given to safety personnel. If the estimated intake of 815 pCi per disassembly, which the IAAP TBD stated came from Pantex, is correct, there is a serious inconsistency between the estimated intakes for the two sites.

The use of an intake of 19 pCi per day for internal exposure from DU for Pantex is inconsistent with the like parameter indicated by the IAAP TBD (ORAUT 2005) for the same work under the same conditions. IAAP's modeled intake of 81,500 pCi/yr is nearly 200 times higher than the recommended intake values for the two periods (i.e., 1980–1993 and 1961–1979) and is more than 800 times higher than the recommended value for Pantex for 1994 to the present. Beyond the gross inconsistency is the paradox that the 81,500 pCi/yr value for **IAAP** was derived from **Pantex** data, but these data were not used in the corresponding Pantex TBD.

5.13.3 Inconsistencies in Determining Tritium Dose

Section 5.1 of the IAAP TBD, ORAUT-TKBS-0018 (ORAUT 2005), provides the following information:

> *Tritium intakes could have occurred and probably did occur to a certain extent during weapons assembly and disassembly procedures. The tritium reservoirs came from the Savannah River Site (SRS), so the earliest possible date for tritium exposure at IAAP would be 1954….*
>
> *…No tritium bioassay results for IAAP workers have been located.* ***However, material and procedures at IAAP were almost certainly the same as those at Pantex because the same company operated both plants, and the materials and tasks were the same.***
>
> *…Tritium reservoirs were shipped to the Iowa Ordnance Plant in pressurized metal vessels known as JP containers. Prior to the opening of the JP container, which contained the tritium reservoir, the pressurized air was vented. . .* [and]*. . . surveyed… to ensure that the tritium air concentrations were less than 90 pCi/m*^{3} *before the container was released to production* [i.e., assembly].

The TBD (Hickey et al. 2007) contains apparent inconsistencies regarding the tritium bioassay monitoring program at Pantex. In Section 5.2.1.1, the TBD states that the extent of a routine tritium bioassay program before 1972 is **unclear,** although there are indications of sampling of about 10 workers per month in the 1960s. Then, the TBD goes on to say that there is "no evidence that workers were monitored for tritium before 1972.…" In a memorandum dated October 1, 2003, by J.B. Martin (ORAUT) from a personal communication with Mark Prather (Pantex Radiation Safety Department), Mr. Prather states that monitoring (urine bioassay) for tritium exposures was started in 1972 for a few individuals (Martin 2003). It appears that not only is there little or no information upon which to base exposures, but information conflicts as to whether any personnel monitoring took place before 1972. In reference to unmonitored workers for 1956 to 1971, Section 5.2.1.15 of the TBD (Hickey et al. 2007) states the following:

> *Because tritium uptakes before 1972 were unknown but unlikely to be greater than the post-1972 uptakes, this analysis assumed that twice the highest uptake from the 1970s was to apply to all the years from 1957 to 1971 (Table 5-6).*

This sweeping assumption is without any foundation or scientific support. Further exacerbating the issue, Table 5-6 of the Pantex TBD gives a default maximum uptake of 5.8 pCi during the

1970s, whereas Section 5.1 of the IAAP TBD, ORAUT-TKBS-0018 (ORAUT 2005), gives an upper bound chronic tritium intake of 4,902 μCi/year or 13.4 μCi/day (331 mrem/yr).

Despite the stated similarity between IAAP and Pantex, the Pantex TBD never mentioned the transfer of the H-3 reservoir from the container as one of the key steps associated with weapon assembly during the early years of Pantex operations. In fact, the potential for H-3 exposure in the early years at Pantex was largely dismissed (Hickey et al. 2007, p. 17):

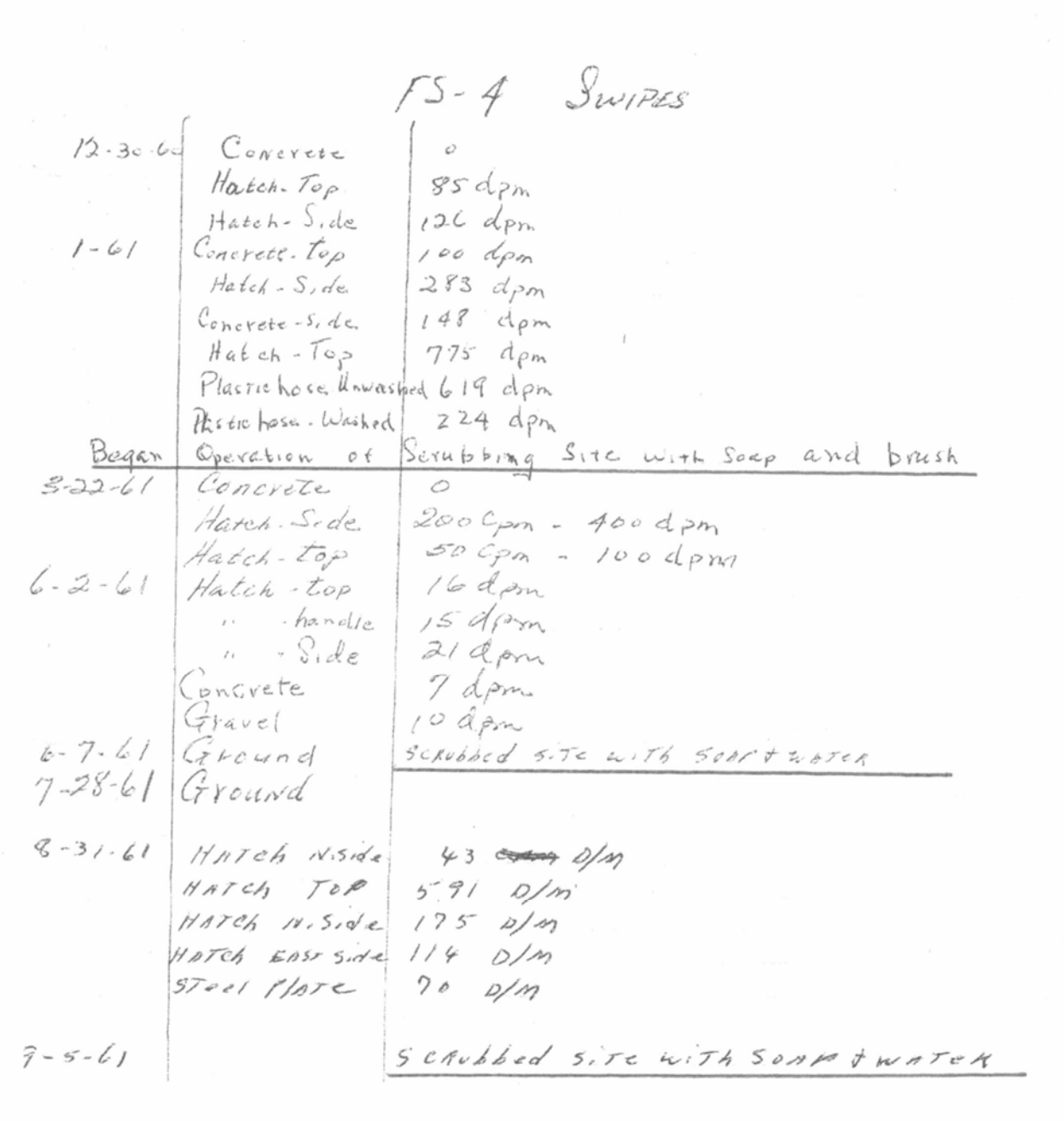
> *During weapons assembly, there was little chance that tritium could leak because workers did not manipulate the valves on the tritium reservoir. ... Around 1980, disassembly of weapons became more frequent than assembly, and releases were more likely to occur.*

In short, the modeled tritium dose of 331 mrem per year for IAAP workers should be compared to doses identified in Table 5-6 of the Pantex TBD (Hickey et al. 2007) for Pantex workers.

5.13.4 Hydroshot Inconsistencies

A comparison of respective hydroshot dose models cited in the IAAP TBD (ORAUT 2005) with those of the Pantex TBD reveals notable, unexplained discrepancies. The IAAP hydroshot dose models include **ingestion** intakes for cleanup crews, as given in Table 5-5 of ORAUT-TKBS-0018 and chronic onsite **environmental** inhalation exposures to downwind personnel as given in Table 5.4 (OCAS 2005b). Despite the commonalities between the two sites, the Pantex TBD neither includes ingestion exposure to cleanup crews nor environmental exposures to other workers. Handwritten records verify routine cleanup efforts at Pantex Firing Site 4, as shown in Exhibit 3.

EXHIBIT 3



FS-4 Swipes

Began	Operation of	
12-30-60	Concrete	0
	Hatch-Top	85 dpm
	Hatch-Side	126 dpm
1-61	Concrete-Top	100 dpm
	Hatch-Side	283 dpm
	Concrete-Side	148 dpm
	Hatch-Top	775 dpm
	Plastic hose Unwashed	619 dpm
	Plastic hose-Washed	224 dpm
	Scrubbing Site with Soap and brush	
3-22-61	Concrete	0
	Hatch-Side	200 cpm - 400 dpm
	Hatch-Top	50 cpm - 100 dpm
6-2-61	Hatch-top	16 dpm
	" -handle	15 dpm
	" -Side	21 dpm
	Concrete	7 dpm
	Gravel	10 dpm
6-7-61	Ground	Scrubbed site with soap & water
7-28-61	Ground	
8-31-61	HATCH N.SIDE	43 ~~cpm~~ D/M
	HATCH TOP	5.91 D/M
	HATCH N.SIDE	175 D/M
	HATCH EAST SIDE	114 D/M
	STEEL PLATE	70 D/M
9-5-61		SCRUBBED SITE WITH SOAP & WATER

In conclusion, since operations at the Pantex plant and IAAP were similar, it is unclear why assumptions presented in ORAUT-TKBS-0018, Revision 0 (ORAUT 2005) differ from those in the Pantex site profile. SC&A finds it difficult to understand these contradictory conclusions regarding the interpretation of film badge information between the IAAP and Pantex site profiles, given that they cite identical references and at least one subject matter expert is common to both TBDs. A disparity exists between the assumed uptake for DU at Pantex and that at IAAP. A 19 pCi intake per day was used for Pantex while at IAAP an intake of 81,500 pCi/yr

was assumed for some time periods. Beyond the inconsistency is the paradox that the value of 81,500 pCi/yr for **IAAP** was derived from **Pantex** data, but these data were not used in the corresponding Pantex TBD. Potential missed tritium dose is also higher for IAAP than in the Pantex site profile. When the Pantex site profile is compared to Revision 1 of the IAAP TBD, it is unclear why internal dose cannot be calculated at IAAP, but calculation of internal dose is possible at Pantex. The limitations in monitoring data are similar between the sites in many cases.

5.14 INTERNAL INCIDENTAL EXPOSURES ARE NOT SUFFICIENTLY DISCUSSED IN THE TBD

SC&A conducted a search of NIOSH's Site Query Research Database and was unable to find any documentation regarding many of the incidents that were found during SC&A's search of classified and unclassified documents. Several boxes contained incidents, including one complete box of summary reports of accidents, occupational injuries, and illnesses for the period 1961–1989. As a result, SC&A is unable to assess the potential usability of these data for dose reconstruction.

SC&A is also concerned about other radiological incidents not identified in the TBD and for which bioassay data are not included in personnel files.

Furthermore, there was inadequate documentation of accidents and incidents, as noted in a letter to Secretary of Energy James D. Watkins, December 15, 1989, from the Advisory Committee on Nuclear Facilities Safety, stating the following (Ahearne 1989):

> *The plant procedures for handling accidents do not include adequate procedures for follow-up to identify exactly what happened and what were the root causes. For example, after the tritium accident, no records were kept of the early debriefing of the operators involved or of health physics (HP) technicians.*

The internal dose reconstruction assumptions for plutonium and thorium indicate that a single acute intake should be assumed. These are usually the result of incidental exposure to radionuclides rather than continuous exposures. The TBD should outline incidents resulting in exposure to workers to inform the dose reconstructor of potential exposure situations. In addition, records for cleanup workers from these incidents should be carefully evaluated to determine the completeness and adequacy of monitoring data available.

5.14.1 Plutonium Exposure for the 1961 Incident

Section 5.2.4.2 of the TBD (Hickey et al. 2007) provides a separate analysis of a plutonium **contamination** event that occurred on November 6, 1961, in building 12-44-6. The TBD states that "… the details of this event are **classified.**" [Emphasis added]

Even in the absence of additional information, available data, as given in the **unclassified** report *Decontamination of Building 12-44-6 Following Radiation Accident on November 6, 1961*

(MHSMC 1962), strongly suggest that worker exposure to plutonium may have involved source term other than "encapsulated plutonium pits," as stated in the TBD.

From air-sampling data contained in the unclassified report, NIOSH reconstructed potential internal exposure to three people who were in the **cell** at the time of the incident. Two operators were wearing respirators, but the supervisor "**standing approximately 6 ft from the release point was not."** [Emphasis added]

Exhibit 5 is taken directly from the TBD (Hickey et al. 2007) and identifies air-sampling data and assumptions used to drive intakes of plutonium for three workers.

SC&A reviewed the data contained in Exhibit 4, as well as the original 1961 incident report that contains the air-sampling data used by NIOSH. Exhibit 4 contains the relevant air-sampling data collected in the first two hours following the incident for the Equipment Room, Cell 6, and the A cubicle.

SC&A concurs with the assigned intakes for the two workers with respirators and regards NIOSH's higher air concentration of 1,900 dpm/m^3 in the assembly cell as claimant favorable. However, SC&A disagrees with the fourth bullet in Exhibit 4, which states that the "…supervisor was not as close to the release, so the second highest air concentration (1,030 dpm/m^3) was used for him." The three individuals involved in the incident were in the assembly cell, and the air concentration value of 1,030 dpm/m^3 was taken in the equipment room. SC&A does not believe that using an air concentration value from another room is justified or appropriate.

5.14.2 Inappropriate Assumption Used for Deriving Supervisor's Intake of Plutonium

The air-sample value of 1,030 dpm/m^3 corresponds to the equipment room and is inconsistent with the statement that "...the two operators were wearing respirators, but the **supervisor** standing approximately **6 ft** from the release was not."

EXHIBIT 4

5.2.4.2 1961 Cell Incident

An incident of plutonium exposure occurred in 1961. The details of the event are classified, but some data were available that dose reconstructors can use to estimate intakes. The appropriate intake should be applied to all workers known either to have been involved in this event or to have worked in the cells or bays in 1961 even if it is not clear that they were involved.

Some individuals were in the cell at the time of the incident, and all were contaminated. The problem was recognized as soon as the incident happened, and these individuals immediately left the cell. The operators were wearing respirators, but one individual standing approximately 6 ft from the release point was not. Initial contamination readings were as high as 450,000 dpm, but there was no contamination outside the cell. There was a statement that an initial urinalysis performed immediately after the incident showed no internal deposition of plutonium, but there is no information on exactly how long after the incident the urinalysis occurred. A urinalysis within a few hours would be unlikely to find anything. In addition, because the material was most likely type S, urinalysis would not have been a particularly sensitive indicator of intake. The air-sample data in Table 5-15 were obtained from reports.

Table 5-15. Plutonium incident air sample counts (dpm/m^3), 1961.

Location	0-2 hr	+ 3 d	+ 4 d
Assembly cell	1,900	1.03	0.43
A cubicle	880	0.55	0.156
B cubicle	---	28	0.185
Equipment room	1,030	Filter paper damage	0.156

Analysis of this incident made the following assumptions:

- The breathing rate of the some of the workers was 3 m^3/hr (ICRP 1994) or 0.05 m^3/min (heavy exercise, adult male).
- The workers were exposed for 5 min (assumes time in the cell and immediately following while they removed contaminated clothing).
- The workers closest to the pit were exposed to the highest air concentration (1,900 dpm/m^3).
- One individual was not as close to the release, so the second highest air concentration (1,030 dpm/m3) was used for that worker.
- The air samples were removed for counting 2 hr after the incident, but essentially all activity on the filters was obtained in the first 5 min. Therefore, the air concentration breathed by the workers in those 5 min was 120/5 min, or 24 times greater than as reported.
- The material was aged weapons-grade plutonium mixture, absorption type S.
- Assuming the plutonium was produced 10 yrs before the incident, isotopic ratios can be obtained from Table 5-14.
- A protection factor of 5 (0.2) was allowed for the two workers in respirators. This factor underestimates the protection of most respirators when worn properly with a good fit. However, the quality of the respiratory protection program at that time was not known, and some intake could have occurred during undressing.

Using these assumptions, an estimation of the intake can be made as follows:

- For the workers wearing respirators:
  Total alpha = 0.05 m^3/min × 5 min × 1,900 dpm/m^3 × 24 × 0.2 = 2,280 dpm = 1,027 pCi
- For worker(s) without a respirator:
  Total alpha = 0.05 m^3/min × 5 min × 1,030 dpm/m^3 × 24 = 6,180 dpm = 2,784 pCi

For the 55 other individuals for whom plutonium urinalyses were performed (and who are assumed to have participated in the subsequent cleanup), 42 had bioassay results that were reported as 0.000 dpm/sample; 13 had positive values; and 3 had values corresponding to 0.04, 0.16, and 0.20 dpm/sample. Based on the IMBA (James 2003) calculated equivalency of 66,000 pCi for 0.04 dpm/sample, these three individuals may have had alpha intakes of 66,000 pCi, 264,000 pCi, and 330,000 pCi.

The TBD (Hickey et al. 2007) provides no specific recommendations/guidance to dose reconstructors for cleanup workers despite its acknowledgment that workers' personal records are unlikely to contain information regarding bioassay results and/or their involvement in the cleanup.

Applying the more reasonable assumption that the air concentrations for all three workers were, in fact, the same, the intake for the supervisor would have been 5 times that of the other two workers, since he was **not** wearing a respirator. A more realistic and claimant-favorable assigned intake for the supervisor would correspond to 11,400 dpm or 5,135 pCi alpha.

5.14.3 Failure to Address Potential Intakes for Cleanup Workers Associated with the 1961 Incident

A potentially more serious concern involves plutonium intakes that may have involved workers assigned to the cleanup of the 1961 incident. NIOSH acknowledged the potential for exposure among cleanup workers, as given in the following statements (Hickey et al. 2007, Section 5.2.4):

> *In addition to the incident itself there was decontamination of the cell following the accident. Decontamination of Building 12-44-6 Following Radiation Accident on November 6, 1961 (MHSMC 1962) contains information on decontamination activities. Exhibit 3 of that report provides urinalysis data for the workers who participated in cleanup operations. Only* [number redacted] *samples were 0.04 dpm or higher. These workers wore full-face respirators and full protective clothing during decontamination activities. The first* [number redacted] *individuals listed in Exhibit 3 of the accident report are the workers involved in the incident.*

A review of the decontamination report (MHSMC 1962) shows that 58 workers, including the those individuals identified above, were evaluated for plutonium intake by urinalysis at various time intervals that ranged from 8 days to 44 days after the November 6, 1961, incident.

For the workers associated with the incident, urinalysis at 8 days showed activity levels of 0, 0.01, and 0.03 dpm/sample. NIOSH regarded these values as consistent with the expected daily urine excretion values (based on the assigned intakes as described above) and below the MDA value of 0.04 dpm per sample. Using IMBA (James 2003), NIOSH calculated that a urinalysis MDA value of 0.04 dpm per 24-hour urine sample would correspond to an acute intake of 66,000 pCi (which is about one order of magnitude higher than the assigned intakes for the workers involved).

SC&A is also concerned about other radiological incidents not identified in the TBD and for which bioassay data are not included in personnel files. For example, Section 5.2.4.3 of the Pantex TBD (Hickey et al. 2007) cites an incident in 1978 involving a storage cylinder:

> *Sometime just before November 14, 1978, a nuclear materials inventory of a Nuclear Weapons Accident Residue (NWAR) storage cylinder.., was attempted…. A subsequent survey on November 14 found alpha contamination associated with a small hole in one 11-M can that contained mostly plutonium waste... Potentially exposed workers were given bioassay on or about November 17.*
>
> *…Cleanup began on January 23, 1979, and concluded by February 8.*
>
> *Details are provided in (MHSMC 1979), which includes the decontamination procedure, results of surveys, pictures, notes associated with the original movement of the cans from the cylinder and with cleanup of the igloo, and* ***results of bioassay samples. It is possible that claims files for energy employees associated with this work do not have these bioassay results;*** *if an energy employee was employed at Pantex in 1978 or 1979, the bioassay results in this file should be checked.* [Emphasis added]

In conclusion, the internal dose reconstruction assumptions for plutonium and thorium indicate that a single acute intake should be assumed. These are usually the result of incidental exposure to radionuclides rather than continuous exposures. The TBD should outline incidents resulting in exposure to workers to inform the dose reconstructor of potential exposure situations. In addition, cleanup workers from these incidents should be carefully evaluated to determine the completeness and adequacy of monitoring data available.

5.15 THE TBD FAILS TO ADEQUATELY DEFINE AND ASSESS THE OCCUPATIONAL MEDICAL DOSE TO WORKERS

Section 3 of the Pantex TBD for occupational medical dose, ORAUT-TKBS-0013-3 (Winslow and Thomas 2007), refers to occupational dose guidelines in ORAUT-OTIB-0006, Revision 3 PC-1 (Kathren 2005) as its basis for estimating medical dose. This ORAUT technical information bulletin (OTIB) provides a reasonable basis for some assumptions regarding estimation of worker medical exposures at Pantex. The SC&A review notes the TBD's recognition of a total lack of exposure data and protocols that existed prior to 1967. Table 3.2 of the TBD states that technique factors for x-rays at Pantex before 1967 are based solely on assumptions, and the TBD provides no documentation or reference.

Specific dose estimations in the TBD for occupational x-rays are also derived for the period prior to 1967 solely by using ICRP 34 (ICRP 1982) and National Council on Radiation Protection and Measurements (NCRP) 102 (NCRP 1989). This issue is important in that estimated medical doses, based upon these reports, are not due to an actual measurement of dose from any of the Pantex x-ray units. For the period of 1967–1971, the medical TBD states (Winslow and Thomas 2007) that measurements were made by the Pantex staff and the Food and Drug Administration

(FDA); however, no actual survey documentation was provided. There is reasonable evidence in the TBD that Pantex x-ray units were actually surveyed routinely after 1971.

The TBD states that there is no physical evidence to show if photofluorography (PFG) was used for chest screenings at Pantex. Based on the finding that only 14x17 films were used and based on employee statements taken in the course of writing the TBD, the TBD concludes that dose assessors should not include the use of PFGs in their dose estimations for Pantex.

Additionally, the TBD states that all medical x-rays administered, in conjunction with routine, physical, or screening exams are to be considered as part of occupational exposure; however, only pre-employment and routine annual chest exams are mentioned to be used by dose assessors in estimating medical dose. SC&A's review of the TBD has resulted in a number of issues that are important for NIOSH to consider and clarify to avoid underestimating medical doses and to ensure that considerations are claimant favorable. These issues are discussed below.

5.15.1 The TBD Fails to Adequately Define and Assess the Occupational Medical Dose to Workers

The current guidelines, as presented in ORAUT-OTIB-0006, Revision 3 PC-1 (Kathren 2005), seek to ensure that all occupational medical exposures are reasonably included in determining the overall dose estimations for claimants. However, some NIOSH interpretations to date have not been applied in a manner that would ensure the most claimant-favorable estimate of medical dose. The occupational medical dose TBD (Winslow and Thomas 2007) assumes an interpretation that has been also considered and applied at other sites, such as the Mound Plant, LANL, Paducah, and Pinellas. The assumption that medical procedures are limited to only one pre-employment chest x-ray and chest x-rays that are part of routine physical exams may substantially underestimate worker medical exposure when evaluating occupational medical dose.

The basis documentation (Kathren 2005) concludes that other examinations should be included, such as special screening exams (e.g., respiratory protection, beryllium workers, and asbestos workers) and termination exams. The occupational medical TBD does not acknowledge this possibility and assumes that no additional screening x-rays for respirator certification, beryllium and asbestos workers, and food handlers occurred at Pantex. The assumption is not well documented in the medical TBD. The TBD also does not discuss the potential impact of x-ray procedures used by medical authorities for special screenings that are performed outside the frequency suggested in the TBD

The TBD (Winslow and Thomas 2007) concludes that chest examinations are often quite limited after 1981. After 1981, kidney, ureter, and bladder x-rays were no longer taken and chest x-rays were taken only every 5 years. It is stated that there was a policy of an x-ray every 5 years, but nothing is documented in the TBD. However, there is ample evidence that chest x-rays were often provided on a voluntary basis to nearly all workers, usually on an annual basis. The majority of contractor workers at DOE sites had chest x-rays as a routine until the mid-1980s, when federal guidelines warning against routine screening were first being implemented.

After discussion with NIOSH personnel, NIOSH decided to limit occupational medical exposure considerations to those chest exams described above and to assume that all other x-ray exposure was a part of worker background and not a condition of employment. SC&A believes such an interpretation is not claimant favorable to those most at risk. Specified "high-risk" workers, those most likely exposed to radiation and beryllium, would be at risk of having an incomplete medical dose assessment, if not all radiation associated with medical screening for job-related activities were included. Given that all radiation provides some risk and, arguably, is cumulative, all forms of work-related x-ray exposure warrant consideration to be claimant favorable. SC&A believes that NIOSH should review its interpretation of included medical exposures as a condition of employment and should adopt a broader interpretation of occupational medical dose, as provided for in its guidance (Kathren 2005).

5.15.2 Frequency and Type of X-ray Exposure is Uncertain

The occupational medical TBD (Winslow and Thomas 2007) relies on a very limited review of archived medical records to establish frequency assumptions. The assumption of one chest radiograph (posterior-anterior) every 5 years is not reasonably conservative, in that workers could essentially request an x-ray or be subject to special screening exams. The frequency of screenings and number and type of workers receiving x-rays do vary from site to site.

Section 3.2 of the occupational medical TBD (Winslow and Thomas 2007) provides no documentation or references to support the assumption that only a limited group of workers received x-ray exams more frequently than every 5 years after 1982. To the contrary, up until about 1985, most DOE sites performed chest x-rays almost on a voluntary basis. DOE medical program reviews documented during the early 1990s showed that many sites still used chest radiography as a general screening exam. Most workers accepted chest x-rays, even though the job did not require it. In addition, the assumption that workers in special exposure categories, such as beryllium workers, were given chest x-rays only as part of their routine physical or more than once every 5 years is not well documented and not consistent with special screening guidelines. The TBD applies no conservative assumption to cover such screening exams.

Section 3.3 of the occupational medical TBD (Winslow and Thomas 2007) states that PFG units, although generally available up to the late 1950s at most DOE sites, were not documented as being in use at Pantex. The undocumented absence of PFG units at Pantex clearly has significant dose implications to workers who may have received much higher doses from PFG units. The PFG unit provides a dose to the worker that is a factor of 5–6 greater than that delivered by conventional radiography. The TBD does not provide documentation for the types of equipment in use at Pantex prior to 1967. SC&A believes it is not claimant favorable to instruct dose assessors to assume no PFG unit use at Pantex. To be fully claimant favorable, it would be appropriate to instruct dose assessors to use an annual dose of 3.0 rem per year for chest radiographs, in accordance with guidelines set forth Kathren (2005).

5.16 THE TBD DOES NOT ADDRESS INTERNAL AND EXTERNAL EXPOSURE FROM OFFSITE AND NONROUTINE OPERATIONS CONDUCTED BY PANTEX WORKERS AS EMPLOYEES OF PANTEX

Pantex workers were involved in operations that potentially exposed them to radioactive material at locations other than the Pantex site. For example, representatives from the Amarillo Area Office (AAO) and Pantex were involved in the Tweezer Project located at NTS from 1962 through at least 1966 (NVOO 1966):

> *AAO, under the jurisdiction of ALOO* [Albuquerque Operations Office], *is responsible for administering the conduct of Tweezer test operations in accordance with ALOO/AAO and NVOO* [Nevada Operations Office] *approved procedures.*
>
> 1. *Mason & Hanger—Silas Mason Co., Inc. (M&H—SM Co., Inc.)*
>
>   *The technical program will be executed under the direction of M&H-SM Co., Inc.'s Test Group Director, who is responsible to the Test Manager, NVOO, for the safety conduct of the Tweezer tests, including radiological and industrial safety within the Tweezer Facility compound.*

Drummond indicated that Pantex personnel worked at the Component Testing Facility in Area 11 (Drummond 1966):

> *Mason & Hanger—Silas Mason Co., Inc., Pantex Plant personnel have been doing work for the USAEC approximately two times a year at the Component Testing Facility, Area 11, NTS, and you have been providing these persons with film badges and furnishing the company film badge reports.*

The Tweezer facility was designed to conduct special surveillance activities to test the proper operation of "safing" systems on warheads from the stockpile (NVOO 1966). Testing involved weapons programs with DU, EU, thorium and plutonium. Rosters are available for individuals from Pantex involved in this program. Details of the operations are classified. Site experts involved in the Tweezer activities at NTS indicated that exposures received at NTS were higher than those typically received at Pantex, and that the Pantex dosimetry file did not reflect this dose (see Attachment 4). The TBD does not address potential internal or external exposures that may have been received during these operations and how other NTS operations may have contributed to worker dose. It is prudent for NIOSH to investigate whether dosimetry documentation includes these doses and doses received from other offsite activities. If these doses are absent from the database, further dosimetry information should be requested from the monitoring site (e.g., NTS for Tweezer).

Pantex workers were involved in nonroutine work with Joint Test Assemblies (JTAs) and Joint Test Evaluations. The particular responsibility of Pantex workers was to evaluate the JTA after the test:

> *Units built for flight tests are composed of components derived from the dismantlement and inspection program, post flight units and new components. The resulting assembly, known as a joint test assembly (JTA), which contains no nuclear material, is sent to the military where it is deployed in a manner similar to the actual nuclear explosives. The JTA is flown (airplane, missile, etc.) and the various weapons systems are actuated to determine if the systems will function as designed in an actual deployment environment. Where possible, the JTA is returned to Pantex Plant for further evaluation.* [Pantex 1995]

Although these units did not contain the pit, they did contain radioactive material. This post-mortum evaluation at Pantex may be a potential source of exposure to Pantex workers. Further research is necessary to determine the condition of radioactive material from JTAs upon return to Pantex.

According to site experts, Pantex workers traveled to other DOE sites (e.g., LANL, Rocky Flats) and in some cases internationally. Some individuals traveled to Russia for training in 1993. Several weapons program modifications and retrofits required that the work be done in the field and in some cases at the deployment location. A portion of the modifications required manipulation of radioactive material. It is unclear how and by whom these individuals were monitored. Presumably Pantex would provide the monitoring; however, this assumption should be verified. Site experts were not aware of Pantex working with weapons from other countries at the Pantex Plant itself.

Personnel were sent from Pantex to assist in recovery from nuclear weapons accidents. For example, on January 21, 1968, a B-52 carrying four nuclear weapons crashed and burned in Thule, Greenland. The weapons were destroyed and radioactive contamination was spread. Pantex workers traveled to Thule to assist after the nuclear weapons accident occurred. Pantex also received debris from accidents for evaluation. For example, on September 19, 1980, a warhead was lost from an aircraft. The weapon was recovered and sent to Pantex for evaluation and disassembly. In this case, the unit caught fire and melted the HE between the pit and the outside of the unit. The exact nature of the exposure as a result of worker involvement in evaluating damaged weapons should be investigated to ensure that potential internal exposure was adequately monitored.

Such offsite and nonroutine operations potentially exposed Pantex workers to different source terms and damaged weapons components. The details of personnel monitoring and its adequacy should be evaluated and unique exposure conditions included in the TBD. Some verification that Pantex claimant files include exposures from these activities is necessary.

5.17 SECONDARY FINDINGS

5.17.1 The Most Significant Contributor to Environmental Dose is Not Due to Natural Radiation

The TBD (Strom and Winslow 2007) draws upon a sampling of air-monitoring data to conclude that the majority of estimated environmental dose is due to naturally occurring radioactivity. An

attempt to establish the U-234 to U-238 ratios was accomplished using a few air samples collected in 2000. The TBD does not address or identify the actual location of these air samples or whether they reasonably compare with the highest known soil contamination areas. For example, there would likely be differences in resuspension factors alone when comparing uranium deposited from episodic releases and historic burn events to naturally occurring uranium and sources resulting from worldwide fallout. Likewise, the level of Th-232 released from Pantex activities over the years is essentially indistinguishable from naturally occurring thorium. In addition, the ratios determined in 2000 are not compared with offsite and upwind area environmental samples, which would be a better indicator of expected activity variations and concentrations in determining background estimates for the Pantex site. SC&A believes that the argument presented in the TBD that most, if not all, environmental dose is attributable to natural isotopes has not been reasonably demonstrated in this assessment.

5.17.2 Other Potential Medical Exposures Have Not Been Identified

The occupational medical TBD (Winslow and Thomas 2007) does not address the potential use of other forms of radiation exposure other than x-ray units on workers to support medical diagnosis. This may involve use of isotopes, sealed sources, or other implements. The TBD also deficient does little to catalog the number and types of x-ray equipment, frequency of use, and other pertinent data, as discussed above in Section 5.15.

There was limited performance of routine and preventive maintenance of medical x-ray equipment at Pantex in the 1967–1982 timeframe, unless it had been performed by an unknown outside contractor and not documented. Unfortunately, no substantial records exist to document routine equipment maintenance, calibrations, and other standard procedures. The lack of defined protocols and a basis for approval of radiography procedures suggests that the use of radiography was not closely controlled. The occupational medical TBD does not discuss the use of portable radiography to perform screenings and the potential for exposure of medical personnel or other workers who were not monitored. This issue would be relevant for the PFG unit that was often van-mounted and moved from site to site and therefore considered a portable unit. Additionally, the TBD fails to document that available x-ray units were not operated at greater than 80–90 kVp prior to 1981.

SC&A finds that the TBD does not include sufficient documentation regarding the variety of medical occupational exposures that may have been associated with medical x-ray equipment. The type of equipment in use and the available maintenance records do little to ensure that a conservative and claimant-favorable estimation of dose would be likely under the circumstances.

5.17.3 Techniques and Protocols Increase Uncertainty of DCFs Listed in the TBD

Section 3.3 of the TBD (Winslow and Thomas 2007) fails to describe adequately all the information upon which to establish beam quality for x-ray units in use before 1967. In 1972, the site documented the survey of a full-phase Picker unit. There is only limited documentation to show that the Picker unit, in use through 1984, had significant added filtration. In the absence of definitive tube output measurements, the TBD directs the use of default values and DCFs derived from ICRP 34 (ICRP 1982). These values are then applied to determine organ doses

using Tables A.2 through A.8 of ICRP 34. An issue of concern is that the DCFs are derived using a default Half Value Layer (HVL) of 2.5 mm Al for Type 1 units, in use from 1946–1980.

The occupational medical TBD (Winslow and Thomas 2007) provides little documentation to support the assumed techniques and protocols applied to calculate the dose, which is mainly derived from NCRP 102 (NCRP 1989). The TBD states that a posterior-anterior chest x-ray was typically the only view taken. SC&A has inquired whether definitive protocols existed to validate that chest exams included posterior-anterior views and a lateral view, and only on a limited basis (every 5 years) after 1982. NIOSH has acknowledged in other TBD reviews that the lack of verifiable protocols is a generic problem at many sites, has planned to search all available records, and will include pertinent records and references in any future revision of this section of the TBD.

The occupational medical TBD is also deficient in that little documentation exists to validate x-ray protocols, equipment maintenance, and upkeep records prior to 1967.

5.17.4 Additional Factors Contribute to Uncertainties in Medical Exposures

The occupational medical TBD (Winslow and Thomas 2007) does not consider dose impacts due to less than optimal use of technology, such as using screens, grids, or bucky systems. The TBD does not consider these elements as potential contributions to uncertainty.

The TBD does consider the potential contribution to dose that may have resulted in less than optimal use of collimation prior to 1981. Unresolved is the concern that the DCFs are basically derived from ICRP reports (circa 1982) and therefore are not comparable in terms of beam quality, which varies from unit to unit and over time. These additional uncertainty factors can contribute greatly to the medical dose to the chest (lung) and other organs and is further complicated because there is no documentation prior to 1993. NIOSH has indicated in other TBDs that it will continue to search for other available records to better define equipment use and beam quality, and it will address this information in an updated version of the TBD.

The TBD (Winslow and Thomas 2007) defines uncertainty as being due to measurement error and variation in kilovoltage, tube current, timers, and the source-to-skin distance. This approach is quite similar to the uncertainty analyses documented in other DOE site profiles. The conclusion in this TBD, and others, is that dose reconstructors should use an uncertainty factor of +30% for exposure estimation. SC&A believes that a higher correction factor of up to 2.0, applied at some other sites for environmental dose, is more appropriate for use.

SC&A agrees that the TBD may conservatively estimate these essential aspects of an uncertainty review; however, unresolved is the contribution to uncertainty in dose due to other types of errors which are introduced by the lack of quality controls in processing equipment and the lack of adherence to established standard operating procedures. A reasonable estimate of these contributions to uncertainty would be an evaluation of retake rates for each examination type. As part of future revisions of this TBD, NIOSH should revisit the potential for significant retake rates and evaluate the potential effect on dose, from these retakes, especially dose prior to 1982.

The occupational medical TBD (Winslow and Thomas 2007) does not address whether Pantex applied dose minimization principles to effectively reduce medical dose. The document also does not assess or consider the likely exposure to workers who are referred to offsite medical facilities for followup. The TBD states that review of selected medical records and files did not reasonably show or match expected x-ray exam frequency and type of exam as shown in Table 3.1.1. Little evidence exists to document the number of x-ray exams provided to the average worker or for special exposure needs.

5.17.5 No Site-wide Atmospheric Model is in Use at Pantex to Ensure an Accurate and Integrated Environmental Dose

The current version of ORAUT-TKBS-0013-4 (Strom and Winslow 2007) was published with significant data gaps in the environmental data before 1973. Therefore, the current TBD version already warrants a future revision due to these existing data gaps, especially regarding historical data prior to 1970. Any revisions should include additional information pertaining to environmental monitoring and effluent data collected through data capture.

Most of the environmental dose to Pantex workers is attributed to tritium, uranium, plutonium, and thorium. Internal dose from exposure outside the facilities is mainly due to facility releases, releases from outside burning events, and resuspension from contaminated soils. Source terms are derived from very limited process knowledge and calculated or estimated maximum releases from stacks and vents. However, few actual environmental measurements exist for the early years of operation. Most effluent data used in the TBD were derived from several annual environmental reports for the years 1973 to 2002, inclusive. Other airborne releases are derived from radiation safety incident reports and various plant vent measurements.

Most releases and subsequent doses are presumed to be primarily from DU and natural uranium (mostly U-238). Lesser contributors to environmental dose are thorium-232, plutonium, and tritium. Notably, the Th-232 was not monitored routinely, as it was believed to be a minor contributor to dose. The TBD (Strom and Winslow 2007) concludes that estimates of environmental dose can be derived strictly from uranium air-monitoring data, as these data should account for any potential resuspension of radionuclides (mostly DU) in soil.

The current TBD (Strom and Winslow 2007) recognizes this deficiency (the lack of a site-wide atmospheric model), which Pantex has purposely chosen not to put in place. SC&A has questioned the need for such a site-wide atmospheric model at this site as well as others and whether Pantex could reasonably assess environmental dose using only limited environmental data, as presented in the TBD. NIOSH has relied upon the use of dose estimates for the public, derived from the U.S. Environmental Protection Agency-approved CAP88-PC computer model to estimate the onsite environmental dose. To offset this lack of data, the TBD (Strom and Winslow 2007) relies upon any available emissions data to estimate maximum intakes of workers in environmental areas outside of restricted areas (areas where radiation workers were resident). This is problematic, in that (1) raw emissions data are not easily converted to environmental dose when several emission points have to be considered, and (2) knowledge is lacking that could place workers at specific locations during exposure events. The TBD also indicates that effluent data before 1981 have not been identified and validated, and therefore, the

TBD has relied solely on incomplete air-monitoring data as its basis. NIOSH should therefore consider the need to revise the TBD.

The TBD (Strom and Winslow 2007) describes the predominant operation of Pantex up to 1980 as basically an assembly facility with very little activity devoted to research or disassembly of weapons. It is further argued that newly formed metals used in assembly were not prone to oxidation and would release minimal environmental contaminants. The TBD also concludes that only minimal releases of tritium occurred up to 1972. Although plutonium was monitored in recent years, the TBD states that significant quantities of Pu-238 were never introduced at Pantex and, accordingly, present no dose hazard. Based upon these conclusions, NIOSH believes an atmospheric dispersion model for Pantex is not warranted. The TBD further concludes, based solely upon limited air-monitoring data after 1980, that environmental doses to all workers would be negligible (i.e., less than 1 mrem per year). SC&A believes that the limited data on meteorology presented in the TBD and the lack of environmental surveys of onsite locations over time do not support these suppositions and conclusions regarding negligible dose.

5.17.6 The TBD Lacks Sufficient Environmental Data to Accurately Estimate the Cumulative Environmental Dose Resulting from Exposures to Varied Source Terms at Differing Locations and Zones at Pantex

In the current TBD (Strom and Winslow 2007), NIOSH has stated that even though existing air-monitoring data does not enable it to distinguish the source of emissions, they believe it is a reasonable approach to evaluate cumulative environmental dose. Their approach was used to estimate dose, however, it does not fully address cumulative dose to workers who were not routinely monitored across the entire site. Until 1989, as many as 60% of the site workers at Pantex were not routinely badged or monitored for radiation.

SC&A believes that the lack of an adequate number of air-monitoring stations, in general, and the overall positioning of stations within a particular zone at Pantex of known higher releases of DU do not readily enable a dose assessor to accurately estimate environmental dose, using only the very limited existing air-monitoring data. It will be difficult for any dose assessor to accurately estimate a claimant's overall environmental dose without more comprehensive air-monitoring data, more environmental survey data, and substantial knowledge of the location of workers during such episodic and acute releases.

In addition, the TBD does not attribute any significant environmental dose to preexisting contamination of the environs. In fact, very limited environmental analyses of only a few soil samples are used to suggest that nearly all uranium contamination is attributable to natural causes and worldwide fallout. SC&A believes it is erroneous to suggest that less than 1 mrem per year of environmental dose is attributable to releases from Pantex operations, given that the plant has operated continuously for over 50 years and has experienced numerous incidents and episodes of environmental releases. For monitored workers prior to 1989 (nearly 40% of the population), it is assumed that the dosimeters were provided and worn, and would reasonably include an environmental dose component. This approach tends to discount any potential dose that resulted from inhaled materials and the dose from tritiated water that was absorbed, which would not be assessed by dosimetry badges that monitored only ambient gamma radiation. In addition,

workers were not included in routine bioassay programs to assess internal dose. For unmonitored workers (nearly 60% of the population), their environmental dose is attributed to only ambient (gamma) radiation levels, based on a regression analysis of ambient radiation data from 2002. Similarly, this approach does not consider internal deposition or variations, due to workers varying locations on the site.

NIOSH has recently conceded, based on prior experience with other DOE sites, that using limited source term emissions data alone to estimate air concentrations for the entire Pantex site may not be appropriate. There is need for more historic emissions data to fill the gaps for sampling and air-monitoring data for a larger group of radionuclides, as it relates to worker locations at a large site such as Pantex.

5.17.7 The TBD Does Not have Sufficient Emission Data for the Years Prior to 1973 to Support Estimation of Early Year Environmental Doses

To the extent possible, the TBD (Strom and Winslow 2007) relies on current emissions data derived from known source terms, yet the validation of that data remains somewhat in question. NIOSH/ORAUT needs to further investigate the possibility of recovering more historic emission data or reports for the 1942–1973 timeframe.

NIOSH has indicated that an obstacle to its evaluation is that effluent and emissions data back to the 1940s and 1950s had not been found at the time this TBD was written and approved for dose assessor use. Another source of ongoing controversy involves the development of coworker data that could possibly be used in some instances to address unaccounted-for doses from environmental releases. This is particularly important due to the very large numbers of unmonitored workers at Pantex.

The lack of environmental data is also significant in terms of the lack of any early tritium effluent data because there is no basis to estimate tritium releases prior to 1972, even though tritium was first stored and used at Pantex as far back as 1956. In addition, significant quantities of thorium and lesser amounts of plutonium did exist at Pantex, but they were not routinely sampled until 1998. It would be important to locate any early (1950s and 1960s) air-monitoring or soils analyses data to validate the presence or absence of plutonium or thorium nuclides in the environs at Pantex.

SC&A believes that the lack of substantial environmental data before 1973 warrants closer scrutiny to effectively assess all doses from environmental sources such that they are claimant favorable.

5.17.8 The TBD Details Some Known Episodic Releases, but does Not Provide Substantial or Accurate Estimates of Dose for Those Episodes or Consider Doses for Unknown Incidents

The TBD (Strom and Winslow 2007) notes a paucity of information regarding episodic releases that may result in potential environmental contamination and subsequent environmental dose to workers. NIOSH states that the purpose of the TBD is not to provide direct estimates of dose,

but rather to offer estimates of source terms from releases to be used by dose assessors to estimate the dose to the individual claimant. Environmental monitoring data used by dose assessors would necessarily often include the measurements for both routine and episodic releases; however, NIOSH recognizes that significant gaps exist in this information.

Episodic releases detailed in the TBD are limited to two cited events. The most significant event was a tritium release of approximately 40,000 curies that occurred on May 17, 1989. Estimated fence line doses were estimated to be 1.43 mrem to the nearest member of the public, and unmonitored (unbadged) onsite workers are estimated to have received at least 10 times that level (~14.3 mrem). Since no environmental measurements for either during or after the event are available, it is not possible to validate the level indicated by NIOSH of 15 mrem as a maximum exposure, which is being suggested for use in claimant dose reconstruction.

The other event described is a reported release of DU on January 10, 1986. This event was also not monitored, and, reportedly, soil samples taken shortly after the event could not distinguish this release from other previous uncontained test shots. SC&A believes that the minimal doses attributed to these two events, as well as other statements made in the TBD regarding U-234 to U-238 ratios found in the soils, do not seem to support the supposition that environmental doses are negligible at Pantex and can be largely attributed to both natural radioactivity and worldwide fallout. To the contrary, the lack of adequate environmental monitoring data, as discussed in Section 6.2 above, would indicate the need for alternative and more conservative approaches to estimate environmental dose contributions to workers. SC&A believes that NIOSH needs to reassess its chosen methodology to ensure the use of a worst-case scenario to more accurately estimate a claimant-favorable environmental dose.

6.0 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 in terms of the adequacy and completeness of each particular element of the profile as well as a "horizontal" assessment of the extent to which the profile as a whole satisfies its intended purpose and scope. This section addresses the latter objective by evaluating (1) how, and to what extent, the site profile satisfies the five objectives defined by the Advisory Board for determining adequacy; (2) the usability of the site profile for its intended purpose (i.e., to provide a generalized technical resource for the dose reconstructor when individual dose records are unavailable); and (3) generic technical or policy issues that transcend any single site profile that need to be addressed by the Advisory Board and NIOSH.

6.1 SATISFYING THE FIVE OBJECTIVES

The SC&A review procedures, as approved by the Advisory Board, require that each site profile be evaluated against five measures of adequacy—completeness of data sources, technical accuracy, adequacy of data, site profile consistency, and regulatory compliance.

6.1.1 Objective 1: Completeness of Data Sources

Given the highly classified operational mission of Pantex, SC&A spent considerable time reviewing classified documents related to operations, radiation protection, and special projects. As a part of the review, pertinent information was retrieved on both external and internal exposures. SC&A found that the Pantex site profile appears to be based on a limited review of unclassified data, supplemented by a minimal review of classified sources. For the site profile, only limited routine internal dosimetry monitoring information was obtained and characterized for tritium, with little routine bioassay monitoring program information presented for the other radionuclides handled on the site with the exception of those handled during 1991–1992. No significant historical air monitoring or contamination survey data are provided as a default to support dose reconstructions.

The Pantex Occupational Medicine Department does possess the entire historical employee record of x-rays and the log books of x-rays taken. It can provide progress reports and statistical reports from early as 1968, which are available in the document control archives.

6.1.2 Objective 2: Technical Accuracy

For occupational medical exposures, SC&A concludes that, like other TBDs, this site profile fails to adequately define and fully assess occupational medical dose because, under current practice, not all forms of work-related x-ray exposures are included. These would include additional screening x-rays for respirator certification, beryllium and asbestos workers, and food handlers, as well as special screenings that may be performed outside the frequency suggested in the TBD.

With respect to occupational environmental dose, SC&A believes that the limited data on meteorology presented in the TBD and the lack of environmental surveys of onsite locations over

time do not support these suppositions and conclusions regarding negligible dose. The TBD details some known episodic releases; however, it does not provide substantial or accurate estimates of dose for those episodes, and the TBD does not consider doses for unknown incidents. The lack of adequate environmental monitoring data indicates the need for alternative and more conservative approaches to estimate environmental dose contributions to workers. SC&A believes that NIOSH needs to reassess its chosen methodology to ensure the use of an upper-bound scenario to more accurately estimate a claimant-favorable environmental dose.

The site profile acknowledges data insufficiency in the case of bioassay and air-sampling data for early worker dose reconstruction. However, it is SC&A's assessment that NIOSH did not do a sufficiently thorough search of the records to identify the appropriate exposure timeframes for some of the major radioisotopes involved in incidents and in use at Pantex.

For external doses, SC&A found that the TBD (Fix et al. 2007) does not recognize the likely unreliability of early recorded deep doses at Pantex. This discrepancy stems from the historic use of Cs-137 and Co-60 calibration sources for film dosimeters at Pantex, when in fact the dominant photon energy at the plant was due to the 60 keV photon of Am-241 (from the plutonium pits), which is a factor of 10 lower, leading to an over-response for the open window of the film badge for deep dose. SC&A also found that key assumptions regarding the use of the 95th percentile neutron-to-photon ratio as bounding may not be correct and that derived estimates of the photon and neutron doses for unmonitored workers may be too low. As was found with other site profiles, this TBD does not adequately acknowledge programmatic deficiencies in the Pantex personnel monitoring program, particularly the results of a 1980 DOE investigation, that raise questions regarding the reliability of dose data generated by that program.

6.1.3 Objective 3: Adequacy of Data

The TBD noted questions regarding data adequacy, and the lack of bioassay and air-monitoring data suitable for dose reconstruction led NIOSH to adopt an alternate approach. However, SC&A questions this alternative approach.

The internal dosimetry records of workers contain only very limited routine bioassay records and in many cases contain no bioassay data for any radioisotopes. The alternate model data are not adequate or claimant favorable.

Occupational medical records for the individual employees may not contain information regarding all of the x-rays that were taken over the years. The only record would be listed in the logbooks by date, thus making the data almost impossible to retrieve by employee. Thus, the TBD does not appear to bound medical radiation doses adequately.

6.1.4 Objective 4: Consistency among Site Profiles

SC&A performed an extensive analysis to compare and contrast the methodologies used in the Pantex and IAAP site profiles and, where appropriate, other site profiles reviewed to date. These comparisons focused on the methodologies and assumptions associated with dose assessments and the derivation of values used to obtain a POC for individual claimants. Attachment 4 to this report provides a detailed analysis.

Since operations at Pantex and IAAP were similar, it is unclear based on the assumptions presented in ORAUT-TKBS-0018, Revision 0 (ORAUT 2005), why a clear difference exists between the two characterizations. SC&A finds it difficult to understand these contradictory conclusions between IAAP and Pantex site profiles regarding the interpretation of film badge information, given that identical references were cited and at least one subject matter expert is common to both TBDs. A disparity exists between the assumed uptake for DU at Pantex and IAAP. An intake of 19 pCi per day was used for Pantex, while at IAAP an intake of 81,500 pCi/yr was assumed for some time periods. Beyond the gross inconsistency is the paradox that the value of 81,500 pCi/yr for **IAAP** was derived from **Pantex** data, which are not used in the corresponding Pantex TBD. Potential missed tritium dose is also higher in the IAAP site profile than in the Pantex site profile. When the Pantex site profile is compared to Revision 1 of the IAAP TBD, it is unclear why internal dose cannot be calculated at IAAP, but calculation of internal dose is possible at Pantex. The limitations in monitoring data are similar between the sites in many cases.

6.1.5 Objective 5: Regulatory Compliance

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 Part 82. In addition, SC&A evaluated the TBDs for adherence to general quality assurance policies and procedures used for the performance of dose reconstructions. The dose reconstruction process employs a hierarchy of data, beginning with the use of individual monitoring data as a priority. When possible given the availability of data, NIOSH has complied with the hierarchy of data required under 42 CFR Part 82 and its implementation guides. Quality assurance with respect to claimant-specific information is lacking, and further consideration should be given to evaluating records provided by sites and how the requests for these records are communicated to the sites. In essence, if something is not explicitly requested, it will not be provided.

For each of the four annual assigned intakes of thorium, NIOSH employed a DAC value of 1×10^{-12} µCi/ml. This value corresponds to the ICRP 30 (ICRP 1979) value, which has been significantly increased in ICRP 68 (ICRP 1994). Thus, all annual thorium intakes derived in Section 5.3 are a factor of **three too low** if the more current DAC value applies. The requirements under 42 CFR Part 82 require NIOSH to use the most current international or national models available. The use of ICRP 30 is inconsistent with this requirement.

6.2 USABILITY OF SITE PROFILE FOR INTENDED PURPOSES

SC&A has identified seven criteria that reflect the intent of the final rule implementing EEOICPA and the regulatory requirements of 42 CFR Part 82 for dose reconstruction. Because the purpose of a site profile is to support the dose reconstruction process, it is critical that the site profile assumptions, analytic approaches, and procedural directions be clear, accurate, complete, and auditable (i.e., sufficiently documented). SC&A used the following seven objectives to guide its review of the Pantex site profile to determine whether it meets these criteria:

Objective 1 — Determine the degree to which procedures support a process that is expeditious and timely for dose reconstruction.

Objective 2 — Determine whether procedures provide adequate guidance to be efficient in select instances where a more detailed approach to dose reconstruction would not affect the outcome.

Objective 3 — Assess the extent to which procedures account for all potential exposures and ensure that resultant doses are complete and are based on adequate data.

Objective 4 — Assess procedures for providing a consistent approach to dose reconstruction, regardless of claimants' exposures by time and employment locations.

Objective 5 — Evaluate procedures with regard to fairness and the extent to which the claimant is given the benefit of the doubt when there are unknowns and uncertainties concerning radiation exposures.

Objective 6 — Evaluate procedures for their approach to quantifying the uncertainty distribution of annual dose estimates that is consistent with and supports a U.S. Department of Labor POC estimate at the upper 99% confidence level.

Objective 7 — Assess the scientific and technical quality of methods and guidance contained in procedures to ensure that they reflect the proper balance between current/consensus scientific methods and dose reconstruction efficiency.

6.2.1 Ambiguous Dose Reconstruction Direction

The conditions for application of environmental dose to Pantex employees are not clearly defined in the introduction of the environmental dose TBD, as is usually the case with other TBDs. There are recommendations for usage throughout the TBD, but concrete direction for determining which workers receive environmental dose is lacking.

6.2.2 Inconsistencies and Editorial Errors in the Site Profiles

Several editorial errors and inconsistencies existed in the Pantex site profile. These are listed below and should be corrected in the next revision of the site profile:

- Section 5.2.2.3.2 of ORAUT-TKBS-0013-5, Revision 01 (Hickey et al. 2007), references Section 5.2.3.3.1. The TBD contains no such section.
- Section 5.2.3 of ORAUT-TKS-0013-5, Revision 01, states that, "There is no record of disassembly of thorium weapons before 1980." Documents were found that state otherwise as noted in Section 5.3 of this report.
- The TBD (Hickey et al. 2007) states in Section 5.2.2.1 that, "No data are available to indicate that EU was ever a contaminant in the workplace." Survey results indicate alpha contamination was found on components which may have contained EU. Although missed internal dose is assigned for plutonium, it is not for EU. These metals were used in a similar manner.

- The environmental dose TBD references early revisions of the site description, although a revision was made to this document prior to the release of the environmental dose TBD.

6.3 UNRESOLVED POLICY OR GENERIC TECHNICAL ISSUES

A number of issues were identified that are common in the Pantex TBDs and other site profiles reviewed to date; in some cases, they represent potential generic policy issues that transcend any individual site profile. These issues may involve the interpretation of existing standards (e.g., oro-nasal breathing), how certain critical worker populations should be profiled for historic radiation exposure (e.g., construction workers and early workers), and how exposure itself should be analyzed (e.g., treatment of incidents and statistical treatment of dose distributions). NIOSH indicates that it may develop separate TIBs in order to address these more generic issues. The following represents those issues identified in the Pantex and previous site profile reviews that in SC&A's view represent transcendent issues that need to be considered by NIOSH as unresolved policy or generic technical issues:

- Direction on the applicability of the TBD and/or TIBs to individual dose reconstructions is absent.

- The mobility of the work force between different areas of the site should be addressed. Site expert testimony that many workers moved from one plant to the next is a complicating factor. Establishment of an accurate worker history is crucial in such cases. This will be especially difficult for family member claimants.

- Statistical techniques used in the application of the data to individual workers should be further considered and substantiated.

- Dose from impurities and/or daughter products in radioactive material received and processed at sites should be assessed as a contributory exposure source.

- The significance of various exposure pathways and the assumptions made that influence dose contributions need to be considered (most notably) for solubility, oro-nasal breathing, and ingestion.

- Analysis needs to be performed regarding how frequent or routine incidents should be addressed, given the possibility that such "spike" exposures may be often missed by routine monitoring depending on how often and in what manner it was conducted.

- The availability of monitoring records for transient or outside workers (e.g., subcontractors, construction workers, and visitors) who may have potential exposure while working on or visiting a facility should be ascertained.

- Dose to decontamination and decommissioning workers should be assessed. Many facilities have large-scale decontamination and decommissioning operations that extend back many years. Decontamination and decommissioning operations often require working in unknown situations, which may provide unique exposure events.

- Dose reconstruction for occupational medical exposures remains incomplete. NIOSH needs to reconsider the definition of occupational medical exposure to include all forms of radiation medical exposure to ensure that its considerations are claimant favorable.

- NIOSH should consider dose reconstruction for workers involved in nuclear weapons testing who were employed by a facility other than the testing site itself.

- Quality assurance reviews of records provided by the site to NIOSH/ORAUT are necessary to determine whether complete information has been provided.

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ATTACHMENT 1: NIOSH TECHNICAL DOCUMENTS CONSIDERED DURING THE REVIEW PROCESS

Technical Basis Documents

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ORAUT-OTIB-0023, Revision 0, 2005, *Technical Information Bulletin – Assignment of Missed Neutron Doses Based on Dosimeter Records,* Oak Ridge Associated Universities, Cincinnati, Ohio. March 7, 2005.

ATTACHMENT 2: NIOSH/ORAUT REGARDING SITE PROFILE DOCUMENTS

On January 22, 2007, SC&A submitted preliminary questions to NIOSH related to the Pantex Plant Site Profile Documents.

SC&A QUESTIONS REGARDING PANTEX TBD

Questions on Pantex External Dosimetry TBD (ORAUT-TKBS-0013-6)

[No questions at this time]

Questions on Pantex Internal Dosimetry TBD (ORAUT-TKBS-0013-5)

(1) On what basis does NIOSH believe the approach of using a single acute exposure of 40 DAC-hr per year is acceptable and claimant favorable for dose reconstruction for transuranics (plutonium in particular, but also for americium) considering there was no routine bioassay monitoring program at Pantex?

(2) How does NIOSH justify using the air-sampling limit (p. 26) of 2 pCi/m³ for calculating exposure when the workplace indicator trigger for bioassay was 40 DAC-hr (p. 21, DAC for U-238 is 6×10^{-11} µCi/ml)?

(3) Was area air monitoring used for tracking the 40 DAC-hour annual exposures during this time period, or was lapel monitoring used for tracking?

(4) Were any lapel monitors used prior to the mid-1990s?

(5) After the mid-1990s, did all workers wear lapel monitors, or were representative individuals wearing them and exposures assigned to others in the group?

(6) How can the statistical analysis of a small number of U-238 urine samples compare to a small dataset of less than 300 in 1990, and be used to justify the use of 0.2 times the '1980 to 1993' data for assigning dose for unmonitored workers from 1994 to the present?

(7) Do the 299 samples used in the 1990 uranium bioassay sampling represent all the workers, as affirmed by Pantex management (p. 23)?

(8) What is the basis for the stated claim that the midpoint of the 10-year chronic intake assumption is the most claimant favorable?

(9) On what basis were the intake values used for 1980–1993 exposures applied to 1961–1979 exposures, given the uncertainties expressed for the former?

(10) How can any faith be placed in the uranium bioassay analytical results when there is such disparity in the sensitivity values (probably decision-level values) jumping by as much as 2 orders of magnitude and gaps in the data?

(11) During the hydroshots, were the operators and/or drivers wearing respiratory protection?

(12) Did the operators wear any other protective clothing when moving to ground zero?

(13) Where were the "outside the bunker" air monitors located?

(14) In reference to paragraph 5.2.2.6.3 (p. 33), in the 1990s, were the air-sampler devices limit of detection at 1 DAC-hour?

(15) In the cleanup of firing site 5, the entire exposure for unmonitored workers is based on the assumption of fifty 1 DAC-hour exposures per year. At the same time, the triggering level to do bioassay sampling for workers wearing lapel air samplers was a single acute exposure of 40 DAC-hours per year. Can you explain this seeming inconsistency?

(16) What is the basis for NIOSH's use of a single acute exposure of 40 DAC-hours per year as an acceptable and claimant-favorable approach for thorium dose reconstruction considering there was no routine bioassay monitoring program for thorium at Pantex?

(17) In Table 5-19 (p. 48), what are the definition codes for "i" and "b" in rows 12 and 13?

(18) Is there supporting evidence that the tritium from the aged units was in gaseous molecular form or tritiated water vapor, and that no tritides were formed within the reservoirs over the years, or was this just assumed to be the case?

(19) How will NIOSH handle the issue that Pantex had and still has no lung-counting capabilities for in-vivo measurements of plutonium in the lungs? (Thus, no way of knowing if there has been a build-up with time to chronic low-level exposures of insoluble plutonium in workers exposed in disassembly or deposition in the lungs of those exposed in the 1961 Cell incident.)

(20) How will the issue of highly insoluble components of plutonium (Type Super S) be handled?

Questions for NIOSH on Occupational Medical Dose (ORAUT-TKBS-0013-3)

(21) The current version of the TBD (Revision 1, dated December 23, 2005) references OCAS-IG-001 and OTIB-0006 Revision 2 (Kathren and Shockley 2003) as the substantial basis upon which it defines occupational medical doses. Should Section 3.1 (Introduction) be clarified to indicate that routine and periodic diagnostic screening x-ray exams also contribute to medical doses, as shown in other site profiles?

(22) The TBD states that little, if any, early information was found regarding equipment manufacturers, models, examination techniques, and exposure rates. The TBD states that assumptions derived from Kathren and Shockley (2003) are used as being claimant favorable. Since Kathren and Shockley (2003) (OTIB-0006 Revision 2) is actually derived from basis documents from 1982 and 1989 and uses an assumed HVL of 2.5 mm Al, should it not be clarified further how NIOSH established this as being favorable, as there is no evidence on equipment use prior to 1967 and no demonstrated equipment surveys for that period seem to exist?

(23) Section 3.3.1 of the TBD states that no direct evidence of use of photofluorography (PFG) was found up through the year 1982. The TBD states that 14 × 17 films were found for all years. The TBD also suggests that employees mentioned that PFG units were not used (not documented or referenced). The ORAUT-OTIB-0006 Revision 2 and Revision 3 suggest that in the absence of data to the contrary, the use of PFG should be assumed to be claimant favorable. The dose contributor should use a value of 3 Rem per year up through 1958. Should the intent of this guideline be clarified and whether the premise of no PFG use at Pantex is justified?

(24) The TBD does not document any x-ray equipment in use prior to 1967. After 1967, several units are documented; however, little if any physical measurements on beam quality and exposure rates were made prior to 1995. Can NIOSH provide the physical measurement data from the PHS surveys of 1967 and 1970? The one survey on the Continental unit in 1995 states that exposures were measured in air at 30 inches and extrapolated to 62 inches. Since most chest radiography occurs at 72 inches, why did they estimate air doses at 62 inches?

(25) The TBD indicates there is evidence of ongoing reviews of the x-ray equipment (Gidley 1970; Alexander 1972a and 1972b), but states it is difficult to evaluate that data. Can NIOSH provide that data for review and any substantial information on equipment being surveyed?

(26) Section 3.3.3 of the TBD states that some kVp and filtration data were found and are listed in Tables 3-2 through 3-4, yet no references are provided. Can NIOSH provide copies of the actual data relied upon and the appropriate references?

(27) Section 3.4 of the TBD indicates that all organ dose estimates presented for use in Tables 3-5 through 3-9 are based only on a chest x-ray for physicals and a single lumbar spine series in men only. Prior to 1995, default doses taken from Kathren and Shockley (2003) were used. Without evidence of any beam exposure measurements prior to 1995, how can NIOSH substantiate that the tables and estimated organ doses are claimant favorable?

(28) The TBD indicates that lumbar spine x-rays occurred as a pre-employment exam only one time. Can NIOSH document that no other lumbar spine x-rays were taken? Can NIOSH document any knowledge of the unit and techniques used to do pre-employment exams up to 1967? Were all pre-employment and annual exams always taken at onsite

medical facilities? Is there any documentation in medical records that any onsite x-rays were prescribed?

(29) The TBD states that uncertainty as described in Kathren and Shockley (2003) should be applied as a positive 30% when estimating doses to Pantex workers. Kathren and Shockley (2003) does not discuss other factors in detail that may contribute to dose, such as poor techniques, retakes, faulty processing equipment, etc. Has NIOSH attempted to determine the additional contribution those factors may add?

(30) The TBD suggests that only some workers received x-ray exams, as presented in Table 3.1. Other sections of the site profile indicate that only workers in Zones 4 and 12 were considered radiation workers and were monitored. Were non-monitored workers as a class provided physicals including x-rays or excluded? If not, please clarify those workers who did not receive routine chest radiography.

Questions for NIOSH on Occupational Environmental Dose (ORAUT-TKBS-0013-4)

(31) Section 4.2 of the TBD states that an EPA computer code was used to evaluate offsite doses and that an isotopic contribution to dose is represented in Figure 4.2. The TBD seems to suggest that onsite environmental doses would follow the same distribution. How does NIOSH intend to validate this assumption, given the meteorology for the site would suggest that deposition of nuclides from stacks and incidents should fall out readily onsite?

(32) Section 4.2 of the TBD in suggests that estimated releases and monitoring data are available, but not specific source terms. Could NIOSH clarify why source terms, normally used to validate the models, are not available?

(33) Section 4.2.1 of the TBD in states that environmental releases were identified from 1973 to date. Was NIOSH able to identify any data from individual stations prior to 1973 and can that can be provided?

(34) Section 4.2.1 of the TBD in indicates it was concluded that atmospheric dispersion modeling was deemed unnecessary. Given that no monitoring data are apparent prior to 1973 and atmospheric releases are only tabulated after 1980 (Table 4-1), does NIOSH believe that a site-wide dispersion model is warranted? If so, could such a model be applied to data that does exist after 1973?

(35) The TBD authors conclude that environmental doses prior to 1980 were negligible, yet no data from the early years seems available to support this assumption. The conclusion seems to be that prior to 1980, environmental dose was attributable solely to fallout, cosmic, and natural radioactivity. Does NIOSH believe this approach is sufficiently claimant favorable to assign occupational environmental dose?

(36) The TBD only discusses one uncontrolled release of uranium occurring on January 10, 1986. The TBD states that the dose estimation was not possible from the event, due to

prior contamination from controlled burns and firing events. How does NIOSH intend to validate that little environmental dose is possible from site activities, given the statement that extensive soil contamination does exist?

(37) The TBD concludes that organ doses due to environmental intakes are negligible and due to naturally occurring nuclides. This assumption is based upon isolated air samples and an isotopic ratio analysis of U-234 to U-238. Assuming the air concentrations are due to resuspended soil concentrations, has NIOSH evaluated whether soil analyses bears out the same ratios?

(38) The TBD states that before 1989, only radiation workers were monitored. Also, no environmental gamma doses were recorded before 1986. The authors suggest that a linear regression analysis using post-1990 data is appropriate to estimate the ambient dose to unmonitored workers. Given that the use of the site varied significantly over the decades, has NIOSH tried to validate this approach by comparison to results from long-term monitored workers in Zone 4 and Zone 12?

ATTACHMENT 3: CONSISTENCY BETWEEN SITE PROFILES

The default site profile assumptions and methodologies for the Pantex Plant are summarized below and were compared primarily to those of the current Iowa Army Ammunition Plant (IAAP) site profile (OCAS 2005b). Where applicable, comparisons were made with other site profiles reviewed to date or in current review. The primary missions of Pantex included assembly, maintenance, and surveillance of nuclear warheads; disassembly of retired weapons; fabrication of chemical high-explosive components; and storage of plutonium components from dismantled warheads. IAAP was also involved in the same activities while it was operating. In fact, these plants worked cooperatively with one another and sometimes worked on the same weapons. Both plants were also involved in conducting hydroshot tests and burning high explosives. When IAAP closed in 1976, its work was transferred to Pantex.

To ascertain the differences in assumptions between the Pantex and IAAP site profiles, the assumptions for occupational medical, occupational environmental, occupational external and occupational internal dose were evaluated. In the case of medical and external exposures, this was completed in a tabular form. Internal and environmental occupational dose were not effectively addressed in the IAAP site profile (OCAS 2005b), so this approach was not feasible. Note that internal and environmental dose were discussed in the original IAAP site profile (ORAUT 2005); however, after the SEC was granted, these sections were removed or substantially shortened. The comparison provided here is based on unclassified TBDs and supporting documents. The core assumptions for each TBD, where available, have been outlined below.

Dose Reconstruction Assumptions for Occupational Medical Exposure

Occupational Medical Exposure Default Assumptions for Pantex and IAAP are outlined in Table A.3-1 below. Assumptions for Pantex are derived from ORAUT-TKBS-0013-3 (Winslow and Thomas 2007) and ORAUT-OTIB-0006, Revision 3 PC-1 (Kathren and Shockley 2005). Assumptions for IAAP are derived from OCAS-TIB-0001 (OCAS 2005b), ORAUT-OTIB-0006 Revision 0 (NIOSH 2003), and Lincoln and Gupton (1958).

Table A.3-1: Occupational Medical Exposure Default Assumptions

Description of Assumption	Iowa Army Ammunition Plant (IAAP)	Pantex
Chest X-rays		
Frequency of Chest X-rays (Default)	1947–1975 General Worker – Annual Assembly Worker – Semiannual Radiography Workers – Quarterly (OCAS 2005b)	1952–1981: Pre-employment and annually thereafter. 1982–2004: Pre-employment and every 5 years thereafter (Winslow and Thomas 2007)
Chest X-ray Technique	20 mAs 85 kVp	Pre-1967: 200 mA, 70 kVp 1967–1994: 100 mA, 70 kVp 1995–2004: 80 kVp, 62 in TSD; Used 0.1 sec and 100 mAs in calculation of entrance kerma (Winslow and Thomas, 2007)
Total Filtration	Not listed in the TBD.	Pre-1967: 1.5 mm Al 1967–1990: 1.5 mm Al

Table A.3-1: Occupational Medical Exposure Default Assumptions

Description of Assumption	Iowa Army Ammunition Plant (IAAP)	Pantex
		1991–2004: 4.0 mm Al (Winslow and Thomas 2007)
ESE	Pre-1970: 270 mrad 1970–1975: 135 mrad (NIOSH 2003)	Pre-1967: 256 mrad 1967–1990: 256 mrad 1991–2004: 44 mrad (Winslow and Thomas 2007)
Frequency of Lumber Spine X-rays (default)	1947–1975 (View not specified) Assigned to males in the year of hire (OCAS 2005b)	Prior to 1/1/82: Lat Lumbar Spine: Pre-employment for men AP Lumbar Spine: Pre-employment for men (Winslow and Thomas 2007)
AP Lumbar Technique	Not listed in the TBD	Pre-1967–1981: 100 mAs, 70 kVp (Winslow and Thomas, 2007)
AP Lumber ESE (mrad)	1,800 (OCAS 2005b)	1,340 (Winslow and Thomas 2007)
LAT Lumber Technique	Not listed in the TBD	Pre-1967–1981: 200 mAs, 86 kVp (Winslow and Thomas 2007)
LAT Lumber ESE (mrad)	5,800 (OCAS 2005b)	3,710 (Winslow and Thomas 2007)
Organs Not Listed in ICRP 34	The dose is assigned based on the proximity of the organs to organs listed in Table 3.2 (OCAS 2005b)	Not specifically listed in the TBD
Skin and Testes Dose	Calculated based on Lincoln and Gupton (1958), RFP TBD (ORAUT 2007).	Measured values not referenced.
Photofluorography (PFG)	PFG was not mentioned in the TBD	TBD concluded there was no use of PFG at Pantex (Winslow and Thomas 2007)
Comments	Additional organs were added to the ovary category for the determination of organ dose for lumbar spine exams. These included the stomach, kidneys, adrenals, and pancreas (OCAS 2005b).	
Organ Dose Conversion		
Dose Conversion Coefficient for Organs	Obtained from ICRP 34, Tables A2–A9 (1982) (OCAS 2005b).	Obtained from ICRP 34, Tables A2–A9
Substitute DCFs for Uncollimated Beam (General)	Doses for organs not listed in ICRP 34 but specified in IREP code are based on proximity to the ICRP organs. Surrogate organs are used (OCAS 2005b).	Doses for organs not listed in ICRP 34 but specified in IREP code are determined by analogy and anatomical location per ORAUT-OTIB-0006 (ORAUT 2005)
Skin dose	Not specifically listed in the TBD. ORAUT-OTIB-0006, Rev. 0 references NCRP 102, Table B8. A backscatter factor of 1.35 is multiplied by the value.	Reference to NCRP 102, Table B8 Backscatter multiplier: 1.35 w/ HVL 2.5 mm Al (Winslow and Thomas 2007)
IREP Input Parameters (default)		
IREP Radiation Rate	Acute	Acute
IREP Radiation Type	Photons, 30–250 keV	Photons, 30–250 keV
IREP Dose Distribution Type	Chest X-ray: Constant Lumbar Spine: Lognormal	Chest X-ray: Constant Lumbar Spine: Lognormal
Total Uncertainty	30% (x-ray dose multiplied by 1.3 and entered as a constant)	30% (x-ray dose multiplied by 1.3 and entered as a constant) (Winslow and Thomas 2007)
Technical Information Bulletin Reference	ORAUT-OTIB-0006, Revision 0; Lincoln and Gupton (1958)	ORAUT-OTIB-0006, Revision 3 PC-1

PA = posterior-anterior; LAT = lateral; kVp = kilovolt potential; mAs = milliampere-second; ESE = entrance skin exposure.

One noticeable difference between the TBDs was the basis for the medical dose assumptions. In the IAAP TBD, the author referenced Revision 0 of ORAUT-OTIB-0006 (NIOSH 2003) whereas the Pantex TBD referenced Revision 3 of the ORAUT-OTIB-0006 (Kathren 2005). Overall, the default assumptions appear to be consistent between the TBDs. Future revisions should reference the latest version of ORAUT-OTIB-0006, which incorporates guidance on the assignment of dose from lumbar spine exams. Other deviations from the standard assumptions are based on site-specific information.

Dose Reconstruction Assumptions for Occupational Environmental Exposure at Pantex (Strom and Winslow 2007)

- Application: Applied to employees not monitored who did not receive potential exposure.
- Radionuclides Considered: Tritium, uranium, plutonium, and thorium (p. 8).
- Sources of Environmental Dose Considered: Airborne releases from facilities, ground-level releases (e.g., burning activities), and resuspension of radioactive material from soil (p. 8).
- No air-monitoring data available to substantiate releases of tritium prior to 1972 (p. 12).
- Thorium, plutonium, and uranium were primarily in metal form (p.11).
- Air-monitoring data considered appropriate for determining dose from airborne releases and resuspension of soil (p. 11).
- For the May 17, 1989, tritium release, assign 15 mrem to the whole body for workers in the area during the time. For 1990, assign 1 mrem, due to slow release from the walls (pp. 12–13).
- Assume 100% U-234 for uranium (p. 15).
- Breathing rate assumed to demonstrate negligible dose was 1.2 m^3 per hour. Exposure time was 2,000 hours in a work year (p. 17).
- Solubility classes included Types M and S for thorium, Ttype S for U-234, and Type M for Pu-239/240 (p. 19).
- There is no need to reconstruct dose for internal exposure from environmental sources, since the simultaneous exposure to all environmental radionuclides results in less than 10 µSv (p. 20).
- Dose from resuspension of soil was determined to be negligible. No missed or unmonitored dose from resuspension of radionuclides was assigned (p. 22).

- Dose of record for monitored workers included occupational environmental doses and no adjustments are required (p. 23).

- An external environmental dose of 100 mrem/year is assigned for 1951–1974, based on a linear regression analysis of data from 1986–2000. A dose of 50 mrem/year is assigned for 1975–2000 (p. 25).

- No attempt was made to quantify uncertainties other than those associated with dosimeters (p. 27).

No guidance was provided on the assignment of occupational environmental dose in the IAAP TBD. Dose reconstruction reports indicate onsite ambient doses were not assigned, because the occupational external dose took into account any doses that may have been received from environmental or onsite ambient doses (Strom and Winslow 2007, Fix et al. 2007). This made a comparison of environmental dose factors difficult. Earlier dose reconstructions for IAAP indicate environmental dose was assigned in the past.

In their assessment of environmental dose for Pantex workers, NIOSH considered potential exposure from airborne releases, ground-level releases, resuspension of soil, and external exposure. The Pantex site profile authors have gone to great lengths to show that internal environmental dose is negligible and, therefore, does not need to be assigned. External environmental dose was assigned based on extrapolation of measurement data from 1986 to 2002. The assigned external environmental doses for Pantex were in the same range as other site profiles.

Dose Reconstruction Assumptions for Occupational Internal Exposure

Default assumptions for the calculation of internal dose were dependent on work categories or assignments. The radionuclides considered in the analysis were plutonium, uranium, tritium, thorium, and radon, although not all workers were assigned dose from each of these radionuclides (Hickey et al. 2007).

Category 1 (Production Technicians, Quality Assurance Technicians, Radiation Safety Technicians, Assemblers, and Disassemblers):

- Radionuclides: Plutonium, uranium, or depleted uranium (1961–present), tritium (1956–present), Th-232 (1980–present), Th-228 (1980–present), and Radon (1958–present)
- Chronic inhalation/absorption of tritium oxide
- Chronic inhalation or ingestion of depleted uranium or uranium for 1961–1993; 20% of the 1961–1993 intake for the years 1994–present
- Inhalation Types M or S uranium, whichever is more claimant favorable
- Insoluble or soluble for ingestion, whichever is more claimant favorable
- One acute intake of Th-228 and Th-232 for 1980–present of Type S material (Note that the intake quantity is reduced in 2001)

- One acute intake of plutonium per year for 1958–present of Type S plutonium (Note that the intake quantity changes in 1980 and 2001)
- 20-year old weapons grade plutonium
- Chronic inhalation of radon
- IREP Distribution: Triangular distribution for tritium, thorium, and plutonium; lognormal distribution with a GSD of 3 for uranium and radon

Category 2 Workers (Material Handlers, Operations Managers, Production Supervision, Quality Control Inspectors/Auditors, Security, and Engineering):

- Radionuclides: Plutonium, uranium or depleted uranium (1961–present), Th-232 (1980–present), Th-228 (1980–present), and Radon (1958–present)
- Chronic inhalation or ingestion of depleted uranium or uranium for 1961–1993 at 10% of the Category 1 worker value; chronic inhalation or ingestion of depleted uranium or uranium for 1994–present at 2% of the Category 1 worker value
- Inhalation Types M or S uranium, whichever is more claimant favorable
- Insoluble or soluble for ingestion, whichever is more claimant favorable
- One acute intake of Th-228 and Th-232 for 1980–present at 10% of the Category 1 worker value (Note that the intake quantity is reduced in 2001)
- Type S thorium assumed
- One acute intake of plutonium per year for 1958 resent at 10% of the Category 1 worker value. Note that the intake quantity changes in 1980 and 2001
- Type S plutonium assumed
- 20-year old weapons grade plutonium
- Chronic inhalation of radon at 10% of the Category 1 worker value
- IREP Distribution: Triangular distribution for tritium, thorium, and plutonium; lognormal distribution with a GSD of 3 for uranium and radon

Machinists

- Radionuclides: Depleted uranium (1960–1965)
- Chronic inhalation and ingestion
- Inhalation Types M or S uranium, whichever is more claimant favorable
- Insoluble or soluble for ingestion, whichever is more claimant favorable
- IREP Exposure Rate: Chronic
- IREP Distribution: Lognormal distribution with a GSD of 3

Burning Ground Technicians/Operators

- Radionuclides: Depleted uranium (1952–present)
- Chronic inhalation of depleted uranium
- Types M or S uranium, whichever is more claimant favorable
- IREP Distribution: Constant

Firing Site Technician/Operations

- Radionuclides: Depleted uranium (1952–1986) and Th-232 in equilibrium
- Chronic inhalation of depleted uranium
- Types M or S uranium, whichever is more claimant favorable
- Single acute intake of Th-232
- Types M or S thorium, whichever is more claimant favorable
- IREP Distribution: Constant

Firing Site 23 Clean-up

- Radionuclides: Depleted uranium
- Chronic intake of Type S material from 1994–1999.
- IREP Exposure Rate: Chronic
- IREP Distribution: Triangular distribution

Firing Site 5 Clean-up

- Radionuclides: Depleted uranium
- Acute intakes occurring November 10, 1983; January 2, 1984; July 1, 1984; and 1988, and two acute intakes for each year from 1985–1987.
- Type S uranium
- IREP Exposure Rate: Acute
- IREP Distribution: Lognormal distribution with a GSD of 3

1961 Bay Accident

- Radionuclides: Plutonium (November 1961)
- 10-year old weapons grade plutonium (Activity Ratios: 0.796 Pu-239+240, 0.0883 Pu-238, 5.68 Pu-241, 0.116 Am-241)
- Single acute intake of Type S material
- IREP Exposure Rate: Acute
- IREP Distribution: Constant

The particle size assumed for dose reconstruction was 5 micron AMAD. Calculation of internal dose from firing sites and burn areas is based on air-sampling data. It is assumed that workers at the firing site were exposed for 30 minutes during each shot, with a breathing rate of 1.2 m^3/hour. Workers involved in burning of contaminated high explosives were assumed to be exposed for 2 hours once per week. Again, a breathing rate of 1.2 m^3/hour was used. The quantity of tritium assumed for uptake is based on two times the highest recorded tritium dose at Pantex.

External Exposure

Occupational External Exposure Default Assumptions for Pantex and IAAP are outlined in Table A.3-2 below. Many external dosimetry assumptions depend on information that is classified. Information falling into this category includes radionuclide constituents of weapons components and numbers of weapons handled or stored at the facilities.

Table A.3-2: Occupational External Exposure Default Assumptions

Description of Assumption	Iowa Army Ammunition Plant (IAAP)	Pantex
Photon Exposure		
Source	OCAS 2005a	Fix et al. 2007
IREP Exposure Rate	Acute	Acute
IREP Radiation Type	100% 30–250 keV photons	100% 30–250 keV photons
IREP Dose Distribution	Missed Dose: Lognormal Recorded Dose: Point Estimate	Missed Dose: Lognormal Recorded Dose: Point Estimate
Exposure Geometry	100% Anterior-Posterior	100% Anterior-Posterior
Missed Dose Application	Assigned for each reported non-positive dosimetry result (represented by 0 or M) in the employee's exposure record (p. 9).	Assigned for situations where the dose of record is zero or there is no dose of record for the assigned badge for the monitoring period (p. 43)
Missed Dose Method	Missed doses are calculated using the nLOD/2 method where nLOD/2 is the median value of the distribution and nLOD is the 95th percentile. A GSD of 1.52 is assigned.	The missed dose for photon exposure is based on MDL/2 times the number of exchange periods (p. 43)
Unmonitored Beta/Gamma Dose	Not distinguished from missed dose	For years before 1959, when gamma dose is less than or equal to 40 mrem, assign the median dose for 1960 for each year of employment (p. 43)
Limit of Detection	1955–1069: 20 mrem 1962–1974: 10 mrem (p. 9)	1952–1976: 40 mrem 1976–present: 30 mrem (p. 47)
Photon Dose Adjustments for Activities Involving Handling Weapons Components	N/A	For cancer sites outside lead aprons, multiply the dosimeter measurement by 1.5 (p. 43)
Unmonitored workers who should have been monitored (not handling weapons)	N/A	Use the median photon dose for radiation workers for each year (Table 6-17). Adjust the dose for dosimeter response uncertainty (p. 43).
Dosimetry Uncertainty	None for positive recorded dose. (LOD)/2 method for missed dose using a lognormal distribution.	Film Badge: 30% TLD Before 1994: 20% TLD After 1994: 10% (pp. 50–51)

Table A.3-2: Occupational External Exposure Default Assumptions

Description of Assumption	Iowa Army Ammunition Plant (IAAP)	Pantex
Neutron Dose		
IREP Exposure Rate	Chronic	Chronic
IREP Radiation Type (default)	100% 100 keV to 2 MeV (fission spectrum) (p. 9)	100% 100 keV to 2 MeV (fission spectrum) (p. 29)
IREP Dose Distribution Type	Missed Dose: Lognormal Recorded Dose: Point Estimate	Missed Dose: Lognormal Recorded Dose: Point Estimate
Adjustment for ICRP 60 Weighting Factor	1.91 (p. 9)	1.91 (p. 36)
Organ dose conversion factor	Deep Dose Equivalent to Organ Dose Equivalent Factors from the *External Dosimetry Implementation Guidelines* (NIOSH 2002).	Deep Dose Equivalent to Organ Dose Equivalent Factors from the *External Dosimetry Implementation Guidelines* (NIOSH 2002).
Missed Dose or Unmonitored Neutron Dose Application	Missed neutron dose is assigned for neutron badge cycles where a zero or "M" dose is documented in the employee's exposure record (p. 9).	Unmonitored workers with evidence of potential neutron exposure (p. 42).
Unmonitored Neutron Dose	Not differentiated from missed dose.	Use the median photon doses for Radiation Workers by applying a median photon neutron-to-photon dose ratio (p. 43).
Exposure geometry	100% Anterior-Posterior	100% Anterior-Posterior
Limit of Detection	50 mrem (p. 9)	1994–present: 50 mrem (p. 47)
Neutron Dose Adjustments for Activities Involving Handling Weapons Components	None	(1) Prior to 1994, assign a neutron dose by multiplying the adjusted photon dose and missed photon dose by a neutron-to-photon ratio of 1.7, unless the recorded neutron dose is greater (p. 45). (2) For best-estimate claims, if an individual was exposed to a non-uniform field, use the glovebox correction factors in OCAS-TIB-0010 (OCAS 2005b). (3) For cancer sites outside lead aprons, multiply the dosimeter measurement by 1.5 (p. 43)
Unmonitored workers who should have been monitored (not handling weapons)	None	Apply a neutron-to-photon ratio of 0.8 to the adjusted total photon dose (p. 48).
Uncertainty	None for positive recorded dose. nLOD/2 method for missed dose using a lognormal distribution.	Beginning in 1994: 30% (p. 51)
Electron Dose		
IREP Exposure Rate	Acute	Acute
IREP Radiation Type	100% >15 keV electrons	100% >15 keV electrons
IREP Dose Distribution	Missed Dose: Lognormal Recorded Dose: Point Estimate	Missed/Unmonitored Dose: Point Estimate
Exposure Geometry	100% Anterior-Posterior	100% Anterior-Posterior
Limit of Detection	40 mrem (p. 10)	1952–1973: 40 mrem 1973–present: 30 mrem (p. 15)

Table A.3-2: Occupational External Exposure Default Assumptions

Description of Assumption	Iowa Army Ammunition Plant (IAAP)	Pantex
Assignment of Nonpenetrating Dose in the Absence of Recorded Dose	Missed doses are calculated using the nLOD/2 method where nLOD/2 is the median value of the distribution and nLOD is the 95th percentile.	In cases where nonpenetrating dose is unavailable, the skin dose is assumed equal to the whole-body dose. Refer to ORAUT-OTIB-0017 for further guidance (Merwin 2005)
Application of Missed Dose	Assigned for each reported zero dose in the employee's exposure history record (p. 10)	Not specified in the TBD.
Dose Conversion Factor	1.0 (p. 9)	Not specified in the TBD.
Uncertainty	None for positive recorded dose. nLOD/2 method for missed dose using a lognormal distribution.	Not specified in the TBD.
Extremity Dose		
Application	Only applicable to target organs of the extremity (p. 10)	Cancer site involves hands, forearms, feet, or legs below the knee (p. 49).
IREP Radiation Type	> 15 keV electrons or 30–250 keV photons, whichever is more claimant favorable (p. 10)	Not specified in the TBD.
Extremity Adjustment Factors	None	Prior to 1994, measured wrist doses should be multiplied by 2.5 to obtain the maximum extremity dose (p. 49).
Unmonitored Extremity Dose	Assigned using the missed dose for each reported non-positive dosimetry result. Whole-body badge limit of detection is used (p. 10).	For any periods when the extremity dose of record is missing, the whole body dose can be multiplied by 10 to obtain an extremity dose (p. 49).

An improvement in both the IAAP and Pantex TBDs over other TBDs is the inclusion of discussions on electron and extremity dose. The Pantex TBD also provides references to TIBs used as part of the analysis. The Pantex TBD also encourages dose reconstructors to consider non-uniform exposures.

Inconsistencies between Site Profiles

The occupational medical dose TBDs for Los Alamos National Laboratory (LANL), Mound, Pinellas, Paducah, and IAAP generally only apply consideration of limited x-ray views (typically chest and lumbar spine) and accept some limited use of PFG exams. The IAAP and the Pantex occupational medical dose TBDs choose to default to 100% Posterior/Anterior (PA) chest exposure and Pantex extended the frequency to every 5 years after 1981. Some of the inconsistencies in assumptions for medical x-ray exposure may be the result of different TBDs references to different versions of OTIB-0006 (Revisions 1–3). NIOSH/ORAUT should consider development of a consistent default assumption for exposure types and frequency between all site profiles.

There is no consideration of potential exposure from liquid effluents or drinking water. Drinking water was addressed in the LLNL environmental TBD as a potential exposure pathway (Thomas 2005). This deserves some consideration, given the burning and hydroshot operations that occurred at Pantex.

Guidance of the assignment of internal dose to IAAP workers is limited to the following statement:

> *No actual internal exposure data could be located for any given individual worker involved in Line 1 operations. Based upon the recommendations of the Secretary of Health and Human Services, it was determined that internal exposures cannot be estimated with sufficient accuracy to complete dose reconstructions (USDOL 2005); thus no internal dose should be assigned for Iowa Army Ammunition Plant employment (Rolfes and Taulbee 2005, pg. 8).*

Previous versions of the IAAP TBD assigned hypothetical electron doses for tritium and alpha doses for DU exposures. When the SEC was established, internal dose was no longer calculated. Pantex has a similar situation, where internal exposure data is lacking in the early years. Routine tritium bioassay data are unavailable prior to 1972, although tritium was present at the facility prior to this date. Routine monitoring for plutonium, uranium, and thorium started at Pantex in 1991, 1991, and 1992, respectively. Again, these radionuclides were present prior to the initiation of a routine bioassay program. Pantex did employ an event-based bioassay program prior to the establishment of routine bioassay programs; however, the comprehensiveness of this program is not clearly defined. TBD authors also indicate that claimant files may be incomplete with respect to bioassay data. Pantex had similar circumstances in the early years as IAAP, yet an internal dose assignment was possible for Pantex. The approach to dealing with internal dose from these sites is inconsistent and deserves further consideration.

The Pantex internal dose TBD defaults to the use of weapons-grade plutonium aged 20 years, except in the case of the 1961 incident. SRS assumes a 10-year old 12% plutonium mixture (Scalsky 2005). The Hanford TBD (Bihl 2004) defaults to 10-year aged fuel-grade plutonium prior to 1996 and 20-year aged fuel grade plutonium for 1996–present. Activity fractions for plutonium provide critical information for the assessment of dose from americium as an impurity. When developing default values, there should be some consistency between the types of materials assumed for internal dose calculations.

The Pantex TBD is silent about exposures from EU, although some weapons contained this material. The RFP (Flack and Meyer 2007) and Y-12 Plant (Jessen 2006) site descriptions indicate that EU weapons operations were conducted in the complex. Further consideration should be given to whether Pantex was involved in disassembly of weapons containing EU.

The LANL, Hanford, SRS, RFP, and other site profiles have gone to great lengths to determine neutron energy spectra for various source terms. A single neutron-to-photon ratio of 1.7 is provided at Pantex, regardless of the acknowledgment in the TBD that neutron-to-photon ratios were highly variable prior to the mid-1980s. With the various weapons designs handled by Pantex and the different exposure scenarios, it is unclear whether the single neutron-to-photon ratio is adequate to provide an upper bound.

In general, the Integrated Radio Epidemiology Program (IREP) input criteria for Radiation Rate, Radiation Type, and Dose Distribution Type are the same for Pantex, as for other site profiles. External dose assumptions for Pantex were consistent with those used in other site profiles. The default energies for beta, photon, and neutron exposure were >15 keV, 30–250 keV, and 0.1–

2.0 MeV, respectively. The missed external dose is calculated using the MDL/2 calculation times the number of monitoring periods. This is consistent with other site profiles.

ATTACHMENT 4: SUMMARY OF SITE EXPERT INTERVIEWS

Interviews were conducted with some approximately 20 current and former Pantex workers from production, maintenance and crafts, environmental monitoring, medical, and health physics departments. Personnel represent experience at the site ranging from 1953 to the present. The interviews were conducted by Robert Bistline and Kathryn Robertson-DeMers (SC&A) from February 22, 2007, through March 9, 2007. Onsite interviews were conducted in a secure location, while offsite interviewees were directed not to disclose classified information. All interview notes (onsite and offsite) were reviewed by a Pantex classification officer. The purpose of these interviews was to receive firsthand accounts of past radiological control and personnel monitoring practices at Pantex, and to better understand how operations were conducted. Interviewees were selected in conjunction with the local union and the EEOICPA site coordinator based on guidance provided by SC&A. Site experts selected represented a reasonable cross-section of production areas and job categories.

Workers were briefed on the purpose of the interviews and background on the EEOICPA dose reconstruction program and site profiles, and asked to provide their names in case there were follow-up questions. Participants were reminded that participation was strictly voluntary and that all interviewer notes would be reviewed for classification following the interview.

Pantex Plant facilities represented by the site experts interviewed included the following:

- Burning Grounds
- Firing Sites
- Area 4
- Area 12 (Bays)
- 56 Residues
- Seawater Recovery
- JTA Program
- Tweezer (NTS)
- Warehouse

Also included were support personnel who worked throughout the site.

The job categories represented included the following:

- Assembly Operations
- Disassembly Operations
- Dosimetry
- Environmental Monitoring
- Fire Protection
- Radiation Safety Maintenance
- Medical Records
- Nurse
- Quality Control Inspector Production Technician
- Security

- Training
- Warehouse Operations
- X-ray Technician

Individuals interviewed were given the opportunity to review their respective portions of the interview summary for accuracy and completeness. This is an important safeguard against missing key issues or misinterpreting some vital piece of information.

During the course of the interview, one individual indicated that he participated in a classified Computer-Assisted Telephone Interview (CATI). Another individual's claim input was reviewed as it was deemed to be classified. In the first case, Pantex no longer had possession of the classified interview. A review of the second individual's claim input indicated that pertinent information to dose reconstruction was contained in the information.

Notes generated as a result of the site expert interviews were submitted to the Pantex Classification office for review. Two sets of notes were provided to SC&A. The first set requested was redacted prior to shipment to SC&A. The second set included interview notes as documented during the interviews, including classified information. A comparison of the two sets assisted SC&A in identifying areas of classification concern.

The information the workers provided to SC&A has been invaluable in providing us with a working knowledge of the site operations and the radiation protection program. All interviews have been documented and summarized below. The information provided is not a verbatim discussion, but is a summary of information from multiple interviews with multiple individuals. Individuals have provided this information based on their personal experience. It is recognized that these former worker recollections and statements may need to be further substantiated before adoption in the TBD, however, they stand as critical operational feedback. These interview notes are provided in that context. Former worker input is similarly reflected in our discussion and, with the preceding qualifications in mind, has contributed to our findings and observations.

Medical

The medical department reported to the Plant Manager until 1991. The department now reports to the Environmental Safety and Health Division Manager. Progress reports and statistical reports have been submitted monthly by the department since 1968. These reports are archived in Document Control.

Annual and pre-employment exams included urinalysis, blood work, pulmonary function tests, x-rays, a general physical, and a Briggs-Meyer Test (every 5 years). Pre-employment chest x-rays were given until the early 1970s. Later, the frequency of physicals was dependent on the materials with which an employee worked. In the case of the beryllium program, individuals received an x-ray, Lymphocyte Proliferation Test, and other blood tests every 3 years. For the asbestos program, physicals were given every 3 years. Department of Transportation workers were also given more frequent physicals. Firefighters recall receiving a few back x-rays at Pantex. General employees received physicals with x-rays every 5 years. A single posterior-anterior chest x-ray was given during physicals, which were sent offsite for reading. The history

of x-ray machines in the medical department that the medical staff could identify were a Picker (only by hearsay), Continental, and Universal models.

It was noted in the interview session with the occupational medicine staff that not all x-ray results were logged into the individual's medical file; complete x-ray information was entered into the logbooks. Since these logbooks are organized by date and not by employee, it would be difficult to gather x-ray data for a particular individual.

The FDA came by and checked the x-ray units in the early years and in the mid-1990s, and a Health Physicist from Dallas was contracted to calibrate and check the shielding, filters, aprons, drapes, etc., every 24 months. The interviewers were told that everyone was given pre-placement chest x-rays until early 1970s, at which time the frequency was changed to every 5 years, except for surveillance x-rays such as for beryllium, asbestos, and Department of Transportation workers.

A National Institute of Health grant was awarded to West Texas A & M University to conduct studies on granulomas in the lungs of Pantex workers. This program was separate from the former worker program presently in place. Volunteers received physical exams, including a PA and lateral chest x-ray at a facility offsite. Exams also included evaluation of mucous, a pulmonary function test, and a complete medical history.

Note: This is a partial site expert summary. As additional worker comments are provided and cleared through the Pantex classification office, a new revision will be released.