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Review of 2019–2020 Revisions to Rocky Flats Plant Technical Basis Documents

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Abbreviations and Acronyms

ABRWH, Board	Advisory Board on Radiation and Worker Health
Am	americium
AMAD	activity median aerodynamic diameter
Bq	becquerel
CDPHE	Colorado Department of Public Health and Environment
CEDR	Comprehensive Epidemiologic Data Resource
CFR	Code of Federal Regulations
Ci	curie
CML	Critical Mass Laboratory
Co	cobalt
Cs	cesium
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DR	dose reconstruction
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
FBI	Federal Bureau of Investigation
ICRP	International Commission on Radiological Protection
INEEL	Idaho National Environmental and Engineering Laboratory
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron volt
LANL	Los Alamos National Laboratory
LOD	limit of detection
m	meter
m^3	cubic meter
MDA	minimum detectable activity
MeV	mega-electron volt
MFAP	mixed fission and activation product
Mg-Th	magnesium-thorium
MOD	Transportation Modification
mrem	millirem

NCRP	National Council on Radiation Protection and Measurements
NDRP	neutron dose reconstruction project
NIOSH	National Institute for Occupational Safety and Health
Np	neptunium
NTA	nuclear track emulsion, type A (film)
NUREG	Nuclear Regulatory Report (U.S. Nuclear Regulatory Commission)
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
ORNL	Oak Ridge National Laboratory
pCi/m^3	picocurie per cubic meter
PFG	photofluorography
ppm	parts per million
Pu	plutonium
R&D	research and development
RATCHET	Regional Atmospheric Transport Code for Hanford Environmental Tracking
RFETS	Rocky Flats Environmental Technology Site
RFP	Rocky Flats Plant
SEC	Special Exposure Cohort
SRDB	Site Research Database
TBD	technical basis document
Th	thorium
TLD	thermoluminescent dosimeter
TLLα	total long-lived alpha
TRU	transuranic
U	uranium
UNH	uranyl nitrate
yr	year

1 Executive Summary

SC&A reviewed all five Rocky Flats Plant (RFP) technical basis documents (TBDs) that have been revised as of January 2021 to determine if previous issues identified by its original 2005 site profile review (SC&A, 2005), as well as by the work group in its proceedings, were resolved and addressed by SC&A and the National Institute for Occupational Safety and Health (NIOSH). SC&A also performed a general review of the five revised TBDs:

- Site description (TBD-2): ORAUT-TKBS-0011-2, revision 02, "Rocky Flats Plant – Site Description" (NIOSH, 2020a)
- Occupational medical dose (TBD-3): ORAUT-TKBS-0011-3, revision 03, "Rocky Flats Plant – Occupational Medical Dose" (NIOSH, 2019a)
- Occupational environmental dose (TBD-4): ORAUT-TKBS-0011-4, revision 03, "Rocky Flats Plant – Occupational Environmental Dose" (NIOSH, 2020b)
- Occupational internal dose (TBD-5): ORAUT-TKBS-0011-5, revision 04, "Rocky Flats Plant – Occupational Internal Dose" (NIOSH, 2020c)
- Occupational external dose (TBD-6): ORAUT-TKBS-0011-6, revision 03, "Rocky Flats Plant – Occupational External Dose" (NIOSH, 2019b)

SC&A found that for TBD-2, the site description, all previous issues have been addressed in revision 02 (NIOSH, 2020a). A general review found revision 02 to be more comprehensive in scope and depth and to include more details on site closure and decommissioning, as well as specific information about operations involving recycled uranium and uranium (U)-233. SC&A recommends closure of finding 8 (inadequate information regarding recycled uranium) from its original review (SC&A, 2005), based on updated treatment of the issue in the internal dose TBD (TBD-5). However, no such updated assessment was noted in TBD-2, and SC&A recommends that TBD-2 be revised to be consistent with TBD-5. SC&A considers all other identified issues resolved.

For TBD-3 on occupational medical dose, SC&A similarly found that all previous issues expressed in finding 5 (which was concerned with radiation exposure from occupationally necessitated medical x-rays) have been addressed and resolved in revision 03 of TBD-3 (NIOSH, 2019a), and recommends closure. A general review of this most recent revision did not identify any findings, although some incorrect tables were listed in the "Publication Record" and on page 2 of the TBD.

SC&A's review of TBD-4, revision 03 (NIOSH, 2020b), on occupational environmental dose, found that the revised TBD addressed and resolved SC&A's finding 9 from its original 2005 site profile review regarding inadequacies in addressing potential environmental exposure from routine and ambient airborne releases and resuspension of contaminated soil at RFP. SC&A found that more specific information and guidance has been added about the contribution of resuspension of soil contaminants for occupational environmental exposures and that NIOSH provides better justification of its basis in available site monitoring data. Therefore, SC&A recommends closure of this finding. SC&A finds that the potential impact of the 1989 Federal

Bureau of Investigation (FBI) investigation on environmental dose reconstruction (DR) has been addressed, resolved, and previously closed.

For TBD-5, SC&A's (2005) original site profile review had three findings and one observation; later work group proceedings identified additional concerns for internal exposures related to the Critical Mass Laboratory (CML), neptunium, magnesium-thorium (Mg-Th), and tritium. For these later concerns, the work group, SC&A, and NIOSH addressed and resolved them during work group deliberations. SC&A finds that they are adequately reflected in TBD-5, revision 04 (NIOSH, 2020c), as appendices.

For finding 1 of its 2005 review ("Suggested use of urine bioassay MDA values for plutonium and americium appear low") and finding 2 ("TBD lacks definitive direction in some instances") (SC&A, 2005, p. 15), SC&A now finds that NIOSH has addressed and resolved them in TBD-5, revision 04 (NIOSH, 2020c), and recommends closure.

For finding 7 ("The internal TBD does not consider potential contribution of ingestion pathway"; SC&A, 2005, p. 17), SC&A continues to find a lack of clarity about how ingestion intakes would be handled by dose reconstructors. TBD-5, revision 04 (NIOSH, 2020c), only refers to ORAUT-OTIB-0060, revision 02, "Internal Dose Reconstruction" (NIOSH, 2018b), on page 22 in reference to selecting solubility type. ORAUT-OTIB-0060 addresses ingestion intakes on pages 16 and 38, which refer to OCAS-TIB-009, revision 0, "Estimation of Ingestion Intakes" (NIOSH, 2004f). For clarity, SC&A believes that TBD-5 should include recommendations for ingestion intakes or direct reference to the appropriate ingestion intake-related document. Although SC&A understands that this issue has been resolved in practice, ingestion intakes should be addressed by specific guidance in TBD-5 with reference to OCAS-TIB-009. Therefore, SC&A recommends that this issue remain open until appropriate revisions are made in TBD-5.

For TBD-6, the external dose TBD, SC&A reviewed revision 03 (NIOSH, 2019b) and compared it with the 2005 site profile review (SC&A, 2005). SC&A determined that the issues identified the five 2005 findings have been addressed and resolved. Therefore, SC&A recommends closure of all findings and issues. The five findings were as follows:

- Finding 3 was concerned with the interpretation of nuclear track emulsion, type A (NTA) film data for workers who were not included in the neutron dose reconstruction project (NDRP). The revised TBD-6 addressed this finding.
- Finding 4 was concerned with the treatment of personal dosimeter placement and angular dependence. The revised TBD-6 resolved this finding by analysis of angular dependence of the monitoring devices.
- Finding 6 was concerned with potential calibration errors, technology deficiencies, and possible data integrity issues that could have contributed to missed dose. The revised TBD-6 addressed and resolved these issues.
- Finding 10 was concerned with hand and wrist doses. The revised TBD-6 addressed these extremity doses.

- Finding 11 was concerned with the potentially significant doses from industrial x-ray and neutron generators for research and development (R&D) and nondestructive work. The revised TBD-6 addressed these issues.

The issue of the Gammacell 220 irradiator and cobalt (Co)-60 orphan source was previously discussed, resolved, and closed during the RFP work group meeting of October 28, 2015 (ABRWH, 2015, pp. 23–31).

SC&A's general review of the TBD found no further issues but did result in three observations:

1. Use of different neutron dose multiplier factors needs clarification.
2. Limit of detection (LOD) values for 1962 and 1963 need clarification.
3. References for LOD values for 2004 and 2005 are needed.

Additionally, several other references need to be added, and the attachment C list of tables on page 93 incorrectly substitutes "plutonium" for "uranium" in the table C-8 caption (NIOSH, 2019b).

2 Introduction and Background

The Rocky Flats Plant Work Group tasked SC&A with a review of the revised RFP TBDs on January 22, 2021, to determine if previous issues were addressed and resolved by the revised TBDs. The following sections summarize SC&A's (1) evaluation of the revised TBDs in view of previously identified issues and (2) general review of the documents.

3 Review of TBD-2 Site Description, ORAUT-TKBS-0011-2, Rev. 02

The following sections summarize SC&A's evaluation of the revised TBD-2 site description, ORAUT-TKBS-0011-2, revision 02 (NIOSH, 2020a), in view of previously identified issues and a general review of the document.

3.1 Previously identified issues

In its 2005 original site profile review (SC&A, 2005), SC&A identified several gaps in the site description in ORAUT-TKBS-0011-2, revision 00 (NIOSH, 2004a). SC&A reviewed revision 02 of TBD-2 (NIOSH, 2020a) to determine if those identified gaps and others identified during work group reviews had been addressed and resolved. The following documents are relevant to this review:

- ORAUT-TKBS-0011-2, revision 00 (NIOSH, 2004a)
- SC&A's December 2005 SCA-TR-TASK1-0008, revision 0, "Rocky Flats Plants Site Profile Review" (SC&A, 2005)
- ORAUT-TKBS-0011-2, revision 02 (NIOSH, 2020a)

The issues that need further consideration, as identified in SC&A's site profile review (SC&A, 2005), were as follows:

- Finding 8: "TBDs do not adequately address potential exposure contribution of recycled uranium and other radiation sources shipped onsite" (SC&A, 2005, p. 17). Addressed in SC&A (2005) section 5.4.1, "Inadequate Information Regarding Recycled Uranium." Also, the TBD "makes only a passing reference to the processing of ^{233}U" (SC&A, 2005, p. 17). Addressed in SC&A (2005), section 5.4.3, "Inadequate Information Regarding the Processing of Uranium-233."
- Observation 1: "The RFP site profile does not address post-production (post-1992) decontamination and decommissioning activities and worker exposures" (SC&A, 2005, p. 18). Discussed in SC&A (2005), section 5.8.3, "Inadequate Description of Post-Production Mission at Rocky Flats," section 5.4.2, "Inadequate Information Regarding Highly-Enriched Uranium Storage Vulnerabilities," and section 5.8.4, "Inadequate Description of Nuclear Plutonium Storage Activities and the Absence of Related Dose Reconstruction Guidance."

SC&A (2005) originally presented these issues in both narrative form in the sections given in the preceding list and in a specific finding or observation. The following subsections summarize SC&A's evaluation of the status of this finding, observation, and other issues in view of the information in TBD-2, revision 02 (NIOSH, 2020a), and documents, procedures, and accepted practices that have been developed since SC&A's review of TBD-2, revision 00, in 2005.

3.1.1 SC&A (2005) finding 8, section 5.4.1 – inadequate information regarding recycled uranium

SC&A's 2005 review of the RFP site profile led to finding 8:

> The RFP site description TBD (Flack and Meyer 2004) does not provide an accurate assessment of the potential risks associated with recycled uranium. According to a U.S. Department of Energy report (DOE 2000), the DOE's Idaho National Environmental and Engineering Laboratory (INEEL) shipped quantities of ^{236}U recovered from previously irradiated reactor fuel in 1955 to the RFP. This represents a potential for significant gamma fields and a potential source of missed dose for RFP workers. [SC&A, 2005, p. 17]

TBD-2, revision 02 (NIOSH, 2020a), makes the following statement, which is nearly identical to that in revision 01 (NIOSH, 2007a, p. 11):

> While Paducah was processing recycled uranium beginning in 1953, available RFP records do not indicate whether fission product or transuranic (TRU)-contaminated uranium was processed at RFP. [NIOSH, 2020a, p. 11]

However, NIOSH's 2014 RFP internal dose TBD (TBD-5, revision 03)[1] indicated a substantive revision to accommodate assessment of potential recycled uranium exposure at Rocky Flats:

> Revision initiated to incorporate Advisory Board comments, the approval of SEC-00192, and new dose reconstruction approaches in assessing tritium, ^{233}U, and recycled uranium. [NIOSH, 2014a, p. 2]

In TBD-5, revision 03, NIOSH provided guidance for DR:

> For all DOE uranium after 1952, this analysis assumed the possibility that uranium from refineries was recycled uranium or contained recycled uranium. Table 5-5 provides the activity fractions that should be applied to all uranium intakes after 1952. [NIOSH, 2014a, p. 18]

This guidance is consistent with work group discussions on March 27, 2006 (ABRWH, 2006a), which acknowledged the likely presence of recycled uranium at RFP (after 1952) and indicated that programwide guidelines would be applied for assessment of recycled uranium contributions to exposure.

On the basis of its acknowledgement and treatment in TBD-5, SC&A recommends closure of this issue from a substantive standpoint. However, SC&A also recommends that, for consistency, TBD-2, revision 02, be revised to reflect this understanding.

3.1.2 SC&A (2005) section 5.4.3 – inadequate information regarding the processing of uranium-233

In its 2005 site profile review, SC&A found that:

> The TBD makes only a passing reference to the processing of ^{233}U. From 1945 to the early 1980s, a considerable amount of effort involving several sites in the Federal nuclear complex was made by the Atomic Energy Commission and its successor agencies to produce ^{233}U and to develop military and civilian applications for this fissile material. Between 1965 and the mid 1980s, DOE records indicate that the RFP routinely handled kilogram quantities of ^{233}U. [SC&A, 2005, p. 68]

NIOSH acknowledged the need to address U-233 and other radionuclides, such as neptunium (Np)-237 and thorium, from a DR feasibility standpoint and addressed them in its Special Exposure Cohort (SEC) Petition-00192 evaluation report. NIOSH's September 30, 2013, evaluation report found that:

> Uranium-233 and associated progeny exposure was related to receipt and processing of U-233 residues. Processing involved thorium strikes to extract Th-228, which was containerized and shipped to Idaho National Laboratory. The uranium was then converted to a peroxide and ultimately reduced to U-233 metal.

[1] Where substantive changes were made in earlier TBD versions, SC&A has chosen to reference those changes in terms of resolutions or clarifications achieved for findings and observations.

> In its review of available bioassay records for individuals identified as having worked in U-233 processing areas, NIOSH has determined that uranium bioassay data may not be available for all potentially-affected individuals. In additional, these same workers were also potentially exposed to Th-228. NIOSH lacks thorium bioassay data for Rocky Flats personnel. Furthermore, NIOSH has determined that workplace air monitoring and contamination surveys for U-233 processes are insufficient for dose reconstruction purposes. Without uranium and thorium bioassay results, NIOSH has concluded that it cannot estimate with sufficient accuracy the potential internal exposures to U-233, U-232, and Th-228 which the proposed class may have received from 1964 through 1983. [NIOSH, 2013, p. 5]

Based on its treatment and inclusion in the SEC evaluation and later acknowledgment in TBD-2, revision 02, SC&A recommends closure of this issue.

3.1.3 Inadequate description of post-production mission at Rocky Flats

Observation 1 is based, in part, on information about highly enriched uranium storage vulnerabilities (section 5.4.2) and nuclear plutonium storage activities (section 5.8.4).

In observation 1, SC&A noted:

> The RFP site profile does not address post-production (post-1992) decontamination and decommissioning activities and worker exposures. This period involved nuclear material storage, nuclear material stabilization and packaging, waste management, and decontamination and decommissioning, for which records show a history of contamination incidents and personnel exposure. [SC&A, 2005, p. 18]

SC&A further addressed this issue in terms of long-term storage activities involving highly enriched uranium and plutonium after RFP production activities ceased in 1989:

> Similarly, the environmental, safety, and health vulnerabilities associated with the storage of plutonium and high enriched uranium at RFP during these and previous time periods are not addressed. For example, in the 1990s, RFP held over metric tons of highly enriched uranium (HEU) consisting mostly of metals in the form of pits, part samples, and scrap. [SC&A, 2005, p. 18]

TBD-2, revision 01 (NIOSH, 2007a), included a new section (2.5, "Site Closure and Decommissioning"), which is carried over to TBD-2, revision 02 (NIOSH, 2020a). This section describes the post-production mission of RFP and the timeline and operations involved in specific building closure and decommissioning. This includes operations involving stored uranium and plutonium.

Based on the addition of this new section to TBD-2, SC&A recommends closure of this observation and related issues.

3.2 Summary and conclusions for TBD-2

SC&A summarized the issues previously presented in SC&A's (2005) review of TBD-2, revision 00 (NIOSH, 2004a), to determine if the issues were addressed in TBD-2, revision 02 (NIOSH, 2020a). SC&A found that the finding, observation, and issues have been addressed and resolved and recommends closure. However, to avoid confusion, it is recommended that TBD-2 be revised to be consistent with TBD-5 on the treatment of recycled uranium.

SC&A performed a general review of TBD-2, revision 02, and did not identify any findings or concerns. The 2020 revised TBD is considerably expanded in detail and scope from the 2004 first version and includes information about historical facilities, operations, and potential exposure sources that were not included in previous versions of TBD-2.

4 Review of TBD-3 Occupational Medical Dose, ORAUT-TKBS-0011-3, Rev. 03

The following sections summarize SC&A's evaluation of the revised TBD-3 for occupational medical dose, ORAUT-TKBS-0011-3, revision 03 (NIOSH, 2019a), in view of previously identified issues and a general review of the document.

4.1 Previously identified issues

In its 2005 site profile review (SC&A, 2005), SC&A identified several potential DR issues in ORAUT-TKBS-0011-3, revision 00 (NIOSH, 2004b), for RFP energy employees. SC&A reviewed revision 03 of TBD-3 (NIOSH, 2019a) to determine if the potential DR issues had been addressed and resolved. The following documents are relevant to this review:

- ORAUT-TKBS-0011-3, revision 00 (NIOSH, 2004b)
- SCA-TR-TASK1-0008, revision 0 (SC&A, 2005)
- ORAUT-TKBS-0011-3, revision 03 (NIOSH, 2019a)

Finding 5 of SC&A's 2005 report was that "The RFP occupational medical dose TBD does not adequately address the contribution of historic radiation exposure from occupationally necessitated medical x-ray exposure of workers at Rocky Flats" (p. 16). SC&A (2005) discussed the potential DR issues needing further consideration under finding 5 in the following sections (pp. 97–101):

- Section 5.10.1, "Guidelines Needed on What Constitutes Occupational Medical Exposure"
- Section 5.10.2, "Potential for Other Types of X-ray Exposures"
- Section 5.10.3, "Frequency and Types of X-ray Exposure Is Derived from Other Sites"
- Section 5.10.4, "The Determination of Machine and Technician Uncertainties"
- Section 5.10.5, "Use of Screens, Grids, and Impact of Off-site Medical X-rays Are Not Considered"

SC&A (2005) presented these five issues in a narrative form, unlike the present practice of developing a topic and then stating a concluding finding (or observation). Therefore, this report summarizes the issues from the SC&A (2005) narrative to present the important points to be addressed.

The following subsections summarize SC&A's evaluation of the status of these five issues in view of the information in TBD-3, revision 03 (NIOSH, 2019a), and documents, procedures, and accepted practices that have been developed since SC&A's 2005 review of TBD-3, revision 00.

4.1.1 SC&A (2005) section 5.10.1 – guidelines needed on what constitutes occupational medical exposure

In this section, SC&A had concerns that it is not claimant favorable to limit occupational medical examinations to one or two chest x-rays annually, unless medical records and protocols clearly limit the use of radiography to a small fraction of workers, which was not the case up to the mid-1980s.

SC&A reviewed the revised TBD-3, revision 03 (NIOSH, 2019a), to determine if this issue was addressed and resolved. SC&A found that NIOSH addressed the issue as follows in revision 03:

- Section 3.2 (p. 8) states:

  > Only medical exposures that were required as a condition of employment are included; diagnostic and therapeutic procedures that were not required for employment are excluded (e.g., exposures that were received in the treatment of work-related injuries).

- Table 3-5 (p. 12) summarizes the recommended default x-ray examination frequencies for all RFP workers for 1952–2005.

These recommend x-ray examination frequencies and views are compatible with those recommended at the major U.S. Department of Energy (DOE) sites.

SC&A finds that this issue has been addressed and recommends closure.

4.1.2 SC&A (2005) section 5.10.2 – potential for other types of x-ray exposures

In this section, SC&A (2005) had concerns that TBD-3, revision 00 (NIOSH, 2004b):

- Did not address the potential use of other forms of diagnostic radiography to support medical injury diagnosis. This may involve use of isotopes, sealed sources, etc.

- Did little to catalog the number, types of x-ray equipment, frequency of use, etc. Little information exists about protocols to govern the utilization of x-ray units.

- Failed to document that available x-ray units were not operated at greater than 80–90 kilovolt-peak. In light of this, there is a need to reconsider the approach for reconstructing medical radiation exposures.

SC&A reviewed the revised TBD-3, revision 03 (NIOSH, 2019a), to determine if these items were addressed and resolved. SC&A found that these items were addressed as follows in revision 03 of TBD-3:

- Section 3.2 (p. 8) states:

  > Only medical exposures that were required as a condition of employment are included; diagnostic and therapeutic procedures that were not required for employment are **excluded (e.g., exposures that were received in the treatment of work-related injuries)**. [Emphasis added.]

- Section 3.2 (p. 8) recommends the use of ORAUT-OTIB-0006, revision 05, "Dose Reconstruction from Occupational Medical X-Ray Procedures" (NIOSH, 2018a), for x-ray equipment parameters because the details of the RFP x-ray equipment are not complete. The available RFP x-ray equipment information is summarized in table 3-1 and table 3-2 (NIOSH, 2019a, p. 8).

- Section 3.4.2 (p.10) recommends assigning the x-ray dose as 30–250 kiloelectron volt (keV) photons. The RFP x-ray units were operated at a maximum of 125 kilovolt-peak (Kaiser Hill, 2003).

SC&A finds that these items have been addressed and recommends closure of this issue.

4.1.3 SC&A (2005) section 5.10.3 – frequency and types of x-ray exposure is derived from other sites

In section 5.10.3, SC&A (2005) had concerns that TBD-3, revision 00 (NIOSH, 2004b):

- Relies on assumptions of x-ray frequency derived from other DOE sites. The assumption of one to two chest radiographs per year is not reasonably conservative, in that workers could essentially request an x-ray. The frequency of screenings and the number and types of workers receiving x-rays varied from site to site.

- Relies on retake rates (3 percent) derived from other DOE sites. A comparison review of Federal facilities, such as by the U.S. Department of Defense during the 1970s using less-trained technicians (Federal regulations did not require technician certification), showed that retakes sometimes ran up to 30 percent for abdominal examinations and often over 15 percent for chest radiography.

- Does not address the issue that there were photofluorography (PFG) units at RFP for 20 years, suggesting their potential heavy use, far more than at any other DOE site.

SC&A reviewed the revised TBD-3, revision 03 (NIOSH, 2019a), and related documents to determine if these items were addressed and resolved. SC&A found that these items were addressed as follows in revision 03 of TBD-3:

- Table 3-5 (NIOSH, 2019a, p. 12) summarizes the recommended default x-ray examination frequencies for all RFP workers for 1952–2005.

These recommended x-ray examination frequencies and views are comparable to those recommended at the major DOE sites.

- The retake rate at RFP has not been documented, but ORAUT-OTIB-0006 (NIOSH, 2018a, p. 25) states:

> In the DOE complex, Los Alamos National Laboratory reported a retake rate of 2.2% in 1998 . . .; Lawrence Berkeley National Laboratory reported a retake rate of 0% in 1991 . . . ; no retake program was in place at Lawrence Livermore National Laboratory in 1991 . . . or at Brookhaven National Laboratory in 1994 . . . . These do not support the automatic inclusion of retakes as an additional source of exposure to each worker, but if dose reconstructors encounter records of retakes in individual claim file records, the dose from them should be included.

- Section 3.3 of TBD-3, revision 03 (NIOSH, 2019a, p. 9), states:

> Based on X-ray inventory records provided after February 2009, photofluorography (PFG) examinations were performed at RFP. A note in the available documentation indicates that the fluoroscope was removed from the plant in 1968 [MFG, 2003]. There is not enough information about the machine and settings to derive site-specific doses; therefore, default PFG doses from [NIOSH, 2018a] are assigned.

The recommended PFG examinations for 1952–1968 are provided in tables 3-4 and 3-5 of TBD-3, revision 03 (NIOSH, 2019a).

SC&A finds that these items have been addressed and recommends closure of this issue.

4.1.4 SC&A (2005) section 5.10.4 – determination of machine and technician uncertainties

In this section, SC&A (2005) had concerns that TBD-3, revision 00 (NIOSH, 2004b):

- Provides little documentation to support the assumed techniques and protocols applied to calculate the dose.

- Does not address the potential impact of associated uncertainties nor provide documentation to warrant its assumption that multiplication of estimated doses by a factor of 1.3 is claimant favorable.

SC&A reviewed the revised TBD-3, revision 03 (NIOSH, 2019a), and other x-ray-related documents to determine if these items were addressed and resolved and found:

- TBD-3, revision 03 (NIOSH, 2019a), provides some information concerning lumbar views in table 3-4. However, since the details of some of the RFP x-ray parameters are not available for most of the RFP operating period, the operating parameters in ORAUT-OTIB-0006 (NIOSH, 2018a) are recommended as reasonable default values.

- ORAUT-OTIB-0006, revision 05 (NIOSH, 2018a, p. 38), states:

> However, a more reasonable approach is to assume that the uncertainties are in fact random, and therefore to compute the combined statistical uncertainty as the square root of the sum of the squares of all the uncertainties, which is ±28.9%. Rounding this up to ±30% provides an adequate and suitably conservative indication of uncertainty. Therefore, for a derived dose equivalent to an individual organ, a total combined standard uncertainty of ±30% can be assumed. Dose reconstructors should, therefore, input the organ dose equivalent as the mean of a normal distribution, with a standard uncertainty of ±30%.

- The present default value of 30 percent uncertainty is used throughout the DOE complex for occupational medical DR. Since some of the details of the RFP x-ray characteristics are not available for most of the RFP operating period, 30 percent uncertainty is a reasonable default value to use for RFP occupational medical DR.

SC&A finds that these items have been addressed and recommends closure of this issue.

4.1.5 SC&A (2005) section 5.10.5 – use of screens, grids, and impact of offsite medical x-rays are not considered

In this section, SC&A (2005) had concerns that TBD-3, revision 00 (NIOSH, 2004b):

- Does not consider the dose impact due to less than optimal use of technology, such as using screens, grids, or bucky systems.

- Does not consider offsite medical exposure as part of worker exposure.

SC&A reviewed the revised TBD-3, revision 03 (NIOSH, 2019a), and related x-ray documents to determine if these items were addressed and resolved.

- SC&A finds that since the details of some of the RFP x-ray parameters are not available for most of the RFP operating period, the operating parameters in ORAUT-OTIB-0006 (NIOSH, 2018a) are recommended as reasonable default values. These parameters have been applied to other DOE facilities where specific information about the x-ray examination parameters is not available.

- Since the 2005 SC&A review, NIOSH has developed ORAUT-OTIB-0079, revision 02, "Guidance on Assigning Occupational X-Ray Dose Under EEOICPA for X-Rays Administered Off Site" (NIOSH, 2017a). In table 3-2 (p. 11) of ORAUT-OTIB-0079, RFP is listed as a DOE site where onsite occupational medical x-rays were performed on site for all years of DR.

SC&A finds that these items have been addressed and recommends closure of this issue.

SC&A finds that the issues outlined in finding 5 have been sufficiently addressed, resolved, and included in the revised TBD-3. SC&A recommends closure of finding 5.

4.2 General review of ORAUT-TKBS-0011-3, revision 03

SC&A had not performed a general review of the RFP occupational medical dose TBD since 2005; therefore, SC&A performed a general review of TBD-3, revision 03 (NIOSH, 2019a), to determine its technical accuracy and applicability to the RFP DR process. The following summarizes the results of SC&A's review:

- Revisions – The RFP occupational medical dose TBD has been revised three times (2007, 2017, and 2019) since its initial issue in 2004 (NIOSH, 2004b, 2007d, 2017b, 2019a). These revisions revised and updated information and dose values in the tables.

- Current revision – TBD-3, revision 03 (NIOSH, 2019a), divides occupational medical dose at RFP into two time periods: (1) April 1, 1952–June 10, 2001, and (2) June 11, 2001–March 31, 2005. TBD-3, revision 03, states (p. 9):

  > Section 3.4.1 describes the method used to estimate the doses post-June 11, 2001, when there is enough information to calculate site-specific organ doses. As discussed in Section 3.3, not all equipment or settings information about what was in use at RFP before 2001 has been located. Therefore, site-specific organ doses cannot be calculated for the time period prior to June 11, 2001, and default dose values are assigned from [NIOSH, 2018a].

- Two time periods – Because of the two time periods defined in the previous item, TBD-3, revision 03, refers all pre-June 11, 2001, occupational medical x-ray doses for DR to ORAUT-OTIB-0006 (NIOSH, 2018a). For the latter period, June 11, 2001–March 31, 2005, TBD-3, revision 03, provides the standard occupational medical x-ray dose information (e.g., table 3-3 and table A-1). This specific RFP medical x-ray information is based on information recorded in a 2003 RFP x-ray machine shielding calculation summary (Kaiser Hill, 2003), a 2002 performance summary (Dyn Corp, 2002, PDF p. 5), and International Commission on Radiological Protection (ICRP) Publication 34 (ICRP, 1982).

SC&A's review of TBD-3, revision 03, indicated that NIOSH used the information available to provide reasonable occupational medical x-ray DR considering the limited information and data available, especially for the early years. SC&A reviewed the references used in TBD-3, revision 03, to support the conclusions and recommendations and found them to be applicable. SC&A reviewed the dose values recommended in tables 3-3 and A-1, verified their derivation, and found them to be correct. The factor of 1.8 for three-phase x-ray units is accounted for in TBD-3, revision 03, page 9.

SC&A does note that the "Publication Record" on page 2 of revision 03 contains incorrect table references for revision 03 (table 3-7 and table A-2 are no longer used in this version). Also, the reference to table 3-4 in at the end of the second paragraph in section 3.4.2 (p. 10), should be corrected to table 3-3, which has the organ dose estimates.

4.3 Summary and conclusions for TBD-3

SC&A summarized the issues previously presented in a narrative form in SC&A's (2005) review of TBD-3, revision 00 (NIOSH, 2004b), to determine if the issues were addressed in TBD-3, revision 03 (NIOSH, 2019a), other x-ray-related documents, or currently accepted practices. SC&A found that the issues have been addressed and resolved and recommends closure of the five issues identified in finding 5 of SC&A's 2005 review.

SC&A performed a general review of TBD-3, revision 03, and did not identify any additional issues. SC&A did locate some incorrect tables listed in the Publication Record (p. 2) and on page 10 of revision 03.

5 Review of TBD-4 Occupational Environmental Dose, ORAUT-TKBS-0011-4, Rev. 03

SC&A reviewed the revised occupational environmental dose TBD, ORAUT-TKBS-0011-4, revision 03 (NIOSH, 2020b), and compared it with TBD-4, revision 01 (NIOSH, 2004e), issued June 29, 2004, which SC&A (2005) reviewed and found one finding, one observation, and other issues. The following documents are relevant to this review:

- ORAUT-TKBS-0011-4, revision 01 (NIOSH, 2004e)
- SCA-TR-TASK1-0008, revision 0 (SC&A, 2005)
- ORAUT-TKBS-0011-4, revision 03 (NIOSH, 2020b)

In that review, SC&A determined that the environmental dose TBD (NIOSH, 2004e) had several deficiencies, including the following (SC&A, 2005, p. 88):

(1) Need for source term and exposure pathways re-examination
(2) Need for a timeline for phases of operations, and data availability and types
(3) Data adequacy and completeness
(4) Ambiguous recommendations for particle size
(5) Uncertainty with the RATCHET model

These deficiencies were cited in finding 9 and observation 2 of SC&A's (2005) report.

5.1 Finding 9 – inadequacies in addressing potential environmental exposures

Finding 9 of SC&A's (2005) site profile review stated:

> **The occupational environmental TBD does not adequately address potential environmental exposure from ambient airborne releases and resuspension of contaminated soil.** Routine and episodic ambient airborne releases have been brought into question, based on the adequacy of air monitoring results. Incidental releases determined by the state of Colorado are higher than the values used for the 1957 and 1969 fires in the TBD, resulting in non-claimant-favorable assumptions. The dose from resuspension of soil contaminated with plutonium, americium, and other radionuclides (e.g., ^{238}Pu, ^{137}Cs, and ^{237}Np) needs to be

> taken into consideration for soil contamination areas throughout the site, and should not be limited to the 903 Pad without some justification why other inactive waste sites (108 in all) are not included. SC&A also believes that resuspension of $^{239+240}$Pu and ^{241}Am throughout the site could be an important contributor to ambient dose for both monitored and unmonitored dose. In particular, the TBDs do not clearly address how internal dose assessments will consider the contribution of resuspended plutonium and americium to worker dose. [SC&A, 2005, p. 18]

For clarification, the issues raised in this finding are broken out for review in the following subsections.

5.1.1 Routine and episodic ambient airborne releases, including resuspension of contaminated soils

SC&A's 2005 site profile review noted the following:

> The RFP environmental TBD excluded internal dose as a result of soil resuspension and focus[ed] its efforts on only one soil contamination area without justification. Soil contamination has been found at many areas on the Rocky Flats site, including in the East Spray Fields and the buffer zone. There is no explanation of why dose from radioactive material in soil excluded these other areas. The ambient air monitoring data is of questionable validity for use in assessing onsite worker environmental dose. Annual inhalation intake values developed from atmospheric modeling appear to be underestimated. [SC&A, 2005, p. 119]

NIOSH's (2020b) revised TBD-4 prefaces its treatment of contaminated soil resuspension at RFP as follows:

> Total routine (nondiscrete) plutonium emissions from 1953 to 1989 are estimated to be on the order of 0.12 Ci (Voillequé and Till [1999]). This estimate does not include releases due to resuspension of contaminated soil downwind of the 903 Pad or resuspension of contaminated soil in other areas of the Plant due to deposition from the primary sources. Although the release of plutonium due to resuspension is not included in this estimate of routine emissions, it is addressed in this TBD as a contributor to exposure. [NIOSH, 2020b, p.12]

NIOSH provides its specific treatment for estimating occupational environmental doses from resuspension of soil contaminants in the model in attachment A of TBD-4, revision 03:

> Resuspension of previously deposited isotopes also contributed to onsite air concentrations. The model for this analysis (described in Attachment A) addressed contributions from the primary sources in the Phase I study (ChemRisk 1992, [1994]) as well as resuspension. [NIOSH, 2020b, p. 12]

NIOSH further justifies its modeling approach as (1) claimant favorable for incidental releases and (2) conservative based on available site monitoring data, including monitoring by the Colorado Department of Public Health and Environment (CDPHE):

> After 1964, suspension or resuspension (Rood, Grogan, and Till 1999, p. 72) of contaminated soil was the main source of plutonium releases to onsite air. Air monitoring data provided either total long-lived alpha (TLLα) concentrations, from which $^{239/240}$Pu values could be derived, or actual measurements of $^{239/240}$Pu. The annual environmental reports . . . were useful in providing summaries of air concentrations by sampler location based on monthly reporting through 1994. After 1994, Rocky Flats Environmental Technology Site (RFETS) monitoring reports and the CDPHE monitoring reports provided quarterly summaries of monitoring results. Activity concentrations of ^{241}Am were estimated after 1964 by assuming that the concentration of ^{241}Am was 30% of the $^{239/240}$Pu concentration based on measurements of the ^{241}Am/^{239}Pu activity in RFP soil by three separate researchers (Poet and Martell 1972; Krey et al. 1976; Litaor and Allen 1996). This assumption is favorable to claimants because the average measured activity ratios in soil were found to be less than 0.20 by these three groups of researchers. [NIOSH, 2020, pp. 12–13]

SC&A finds that NIOSH's revision of TBD-4 since the last version reviewed (revision 01; NIOSH, 2004e) has (1) added more specific information and guidance regarding the contribution of resuspension of soil contaminants for occupational environmental exposures and (2) provides better justification of its basis in available site monitoring data and the claimant favorability of the modeling provided. SC&A recommends that this issue be closed.

5.1.2 Comprehensiveness, scope, and source data for environmental exposure pathway analysis

SC&A's 2005 review made an observation about the lack of clear delineation of operational phases that was also of concern for this TBD analysis:

> **Observation 2:** The overlap in definition of phases of operation requires further study to identify dose from radionuclides such as tritium, thorium, enriched and depleted uranium $^{239+240}$Pu, ^{241}Pu and ^{241}Am which can be related to significant releases. A timeline is needed to distinctly delineate phases of operation, data types and availabilities, as well as data sources used. [SC&A, 2005, pp. 18–19]

In its site profile review, SC&A (2005) noted a number of observed deficiencies or omissions in data-based parameters used as a basis for environmental pathway analysis to estimate occupational environmental dose. SC&A noted the following about accounting for operations and data type, adequacy, and completeness:

> The overlap in the definitions of the phases of production and studies requires additional explanation. SC&A, therefore, recommends presenting a timeline of these phases in conjunction with data types and availabilities, as well as data sources used in support of the TDB [NIOSH, 2004e]. The report was not clear if the definitions of the two phases in Section 4.2.1 are the same as in Section 4.2.2.

> In addition, it seems that there is an overlap in the cutoff date (1992 and 1993) between the phases. No explanation was given for the basis of that overlap. In addition, the operational year in Section 4.2.1 [of TBD-4, rev. 01] was identified to have run until 1994, while Section 4.2.2 indicated that production ceased after 1992. SC&A recommends that these relationships be made clearer through the RFP operational and post-operational years. [SC&A, 2005, p. 95]

In its most recent revision to TBD-4 (rev. 03), NIOSH (2020b) has expanded its definition of the two phases (operational and post operational), providing additional information and bases, and has included attachment A to give more substantiation of source term, operations, and data adequacy and completeness. The revision also more precisely differentiates the two phases to avoid any overlap. On this basis, SC&A recommends closure of observation 2.

Questions surrounding particle size are addressed, in detail, by an expanded section 4.2.3 in TBD-4, revision 03, which gives the following guidance:

> The recommendation to assume an AMAD of 1.0 µm from 1970 through 1993 is based on the fact that air concentrations downwind of the 903 Area, which are better characterized by an AMAD of 5.0 µm, tended to be only slightly (less than an order of magnitude) higher than other onsite areas, but not always. In 1972, the onsite airborne concentrations downwind of the 903 Area were 2 to 3 times higher than in other areas of RFP (Dow 1972–1973). However, in 1990 to 1992, the air concentrations in the main production areas of RFP (northern section of the industrial zone) exceeded those downwind of the 903 Area.
>
> These assumptions are favorable to the claimant in the following respects: (1) for most organs, assuming an AMAD of 1.0 µm increases the dose by about a factor of 1.5 to 1.9 over the dose calculated by assuming an AMAD of 5.0 µm; and (2) using the sitewide maximum intakes, based on the highest annual average concentration for any given sampler location, often implicitly assumes the worker was exposed to the air concentrations downwind of the 903 Area, which was not the location of most exposures. The extrathoracic airways dose factor is a factor of 1.5 to 1.9 times higher for the AMAD assumption of 5 µm (the particle size more appropriate for resuspended plutonium) versus 1.0 µm (ICRP 2001). Therefore, for cases in which the extrathoracic airways [ET, ET1, ET2, LN(ET)] dose is of most interest, the AMAD of 5.0 µm should be assumed for all years. [NIOSH, 2020b, p. 16]

SC&A finds that the additional specificity, justification, and information in TBD-4, revision 03, addresses the concerns identified in 2005 regarding the lack of such details in revision 01 of the TBD (NIOSH, 2004e). SC&A recommends that this issue be closed.

5.1.3 Source data for dose estimation questionable based on effectiveness of air sampling

SC&A found that the "source data for calculation of airborne environmental dose is questionable, based on effectiveness of environmental air sampling" (SC&A, 2005, p. 115).

NIOSH acknowledges the limitations of relying on environmental air sampling prior to 1964 and has developed air dispersion modeling to account for those source terms. NIOSH provides a technical basis for the model in attachment A of the revised TBD-4, as it notes:

> Air concentrations of $^{239/240}$Pu and ^{241}Am were estimated as described in Attachment A. Onsite air monitoring data are the preferred source of air concentrations (see Attachment A) for $^{239/240}$Pu, but in the early years (until 1964) such data were not sufficiently descriptive or complete to allow reliable estimates. Therefore, dispersion modeling results were used to estimate air concentrations of $^{239/240}$Pu for these years. During these early years, stack or building vent emissions were the main source of plutonium to onsite air, and measurements of these releases are available. Resuspension of previously deposited isotopes also contributed to onsite air concentrations. The model for this analysis (described in Attachment A) addressed contributions from the primary sources in the Phase I study (ChemRisk 1992, [1994]) as well as resuspension. [NIOSH, 2020b, p. 12]

As noted earlier, SC&A finds that use of dispersion modeling based on onsite CDPHE air monitoring measurements and founded on the technical basis in attachment A of the revised TBD satisfies SC&A's original concerns about the use of those data. SC&A recommends closure of this issue.

5.1.4 Need to clarify if maximum estimates of annual intakes are applied

In its 2005 site profile review, SC&A found that "It is not clear if the maximum or average estimates of annual intakes were applied in 1965–2002, and if the 50th percentile or the 95th percentile values in Table 4-1 were used for dose reconstruction" (SC&A, 2005, p. 96).

SC&A's basis for this finding was as follows:

> In reference to work recently completed by the National Institute for Occupational Safety and Health (NIOSH) on the revised TBDs for Mallinckrodt and Bethlehem Steel, NIOSH has adopted the 95th percentile value from available data as the basis for filling in missing bioassay, air sampling, and external dosimetry data for claimants with missing data. This strategy represents a revision to previous strategies in which NIOSH often applied the entire distribution as a surrogate for missing data. As we have discussed in the past, we believe the latter approach can be characterized as claimant neutral, while the former approach appears to us to be more claimant favorable and more in keeping with the letter and intent of 42 CFR Part 82. As such, we believe that the "95th percentile" approach be adopted in this TBD [NIOSH, 2004e] also. [SC&A, 2005, p. 96]

In terms of whether the maximum or average estimates of annual intakes were applied for 1965–2002, NIOSH's changes in revision 02 of TBD-4 included (emphasis added) an "update [to] Section 4.1.1 with standard NIOSH text, updated intakes to reflect sitewide **maximum intakes** which required obtaining location-specific model output as opposed to location-averaged output" (NIOSH, 2007b, p. 2). Those changes remain in revision 03 (NIOSH, 2020b).

TBD-4, revision 03, also provides guidance on applying the "maximum annual median" air concentrations for intake calculations of plutonium (Pu)-239/240 and americium (Am)-241 in the following passages (emphasis added):

> To calculate **intakes of $^{239/240}$Pu and ^{241}Am**, the estimated sitewide **maximum annual median** . . . air concentrations of these isotopes in the RFP environment were multiplied by an annual inhalation rate. The assumed breathing rate was 3,000 m^3 /yr, corresponding to an hourly rate for light activity of 1.2 m^3 (based on ICRP Publication 66; 1994), and a 2,500-hr work year. Intake rates should be scaled to account for occupancy times other than 2,500 hr of exposure. [NIOSH, 2020b, p. 12]

> Table 4-2 lists estimated **annual intakes of $^{239/240}$Pu and ^{241}Am from 1953 to 1964**, based on the atmospheric modeling described in Attachment A. The values are expressed in becquerels per year. The calculated intakes represent a **maximum annual median** (50th percentile) of the six computational nodes evaluated in the RFP industrial area for 500 Monte Carlo model realizations simulated for each year, and are exclusive of the buffer zone (Figure 4-1). [NIOSH, 2020b, p. 13]

> Table 4-3 lists estimated annual intakes of $^{239/240}$Pu and ^{241}Am between 1965 and 2005. The values for $^{239/240}$Pu in this table are based on sitewide **maximum annual median** measured concentrations at samplers across the site, and therefore represent concentrations at the locations of higher concentration (typically near the 903 Area). [NIOSH, 2020b, pp. 13–14]

Table 4-1 in TBD-4, revision 01 (NIOSH, 2004e) listed 50th and 95th percentile average and maximum inhalation intake values for Pu-239/240 for 1953–1964. The revised TBD-4, revision 03, replaces that table with table 4-2, which provides "Sitewide maximum annual median inhalation intakes (Bq/yr) of $^{239/240}$Pu and ^{241}Am based on atmospheric modeling, 1953 to 1964" (NIOSH, 2020b, p. 13).

The preceding revisions in TBD-4, revisions 02 and 03 apply the "standard NIOSH text," with (emphasis added) "updated intakes to reflect sitewide **maximum intakes** which required obtaining location-specific model output as opposed to location-averaged output" (NIOSH, 2020b, p. 2). With the aforementioned table substitutions, and with "estimated annual intakes of $^{239/240}$Pu and ^{241}Am between 1965 and 2005" (NIOSH, 2020b, p. 13) based on sitewide **maximum annual median** measured plutonium concentrations at samplers across the site (NIOSH, 2007b, 2020b), SC&A recommends closure of this issue.

5.1.5 Resolution of finding 9

SC&A recommends closure of finding 9 regarding inadequacies in addressing potential environmental exposure from routine and ambient airborne releases and resuspension of contaminated soil. SC&A finds that NIOSH's revision of TBD-4 (1) has added more specific information and guidance about the contribution of resuspension of soil contaminants for occupational environmental exposures and (2) provides better justification of its basis in available site monitoring data. The use of dispersion modeling based on both onsite and CDPHE

air monitoring measurements, with a technical basis provided in attachment A, gives further substantiation of source term, data availability, exposure pathway analysis, particle size, and uncertainties involved.

5.1.6 Observation 3 – use of RATCHET air dispersion model

SC&A's site profile review observed that:

> The use of the RATCHET air dispersion model is not able to take into account unexpected air flows around close-in buildings, where the height of those buildings may perturb estimates because of wake effects. This may be a confounding problem at RFP and needs to be addressed. [SC&A, 2005, p. 19]

In its revision 03 to TBD-4, NIOSH discussed the issue of building wake effects on air dispersion modeling:

> However, the model application is such that building wake effects, a potential concern for areas close to the sources, are not significant for two reasons. First, releases from the Building 771 stack were not likely to be affected by building wakes because the 44-m stack is sufficiently high in relation to nearby buildings so that the plume was not significantly affected . . . . Second, all other elevated sources in the model were treated as area sources, such that initial dispersion was assigned, which implicitly accounts for the effects of building wakes. [NIOSH, 2020b, p. 40]

Based on this explanation, SC&A is satisfied that this issue is addressed and recommends closure of this observation.

5.2 Consideration of the FBI investigation on environmental dose reconstruction

In a September 4, 2013, memorandum, SC&A (SC&A, 2013) suggested that the work group consider the potential impact of the 1989 FBI investigation on the DR methods NIOSH recommends in ORAUT-TKBS-0011-4, revision 02 (NIOSH, 2007b). SC&A provided additional details in a July 10, 2015, memorandum (SC&A, 2015a) concerning the need to consider the potential impact of the 1989 FBI investigation on DR. SC&A reviewed revision 03 of ORAUT-TKBS-0011-4 (NIOSH, 2020b) to determine if the potential impact of the 1989 FBI investigation had been addressed and resolved. The following documents are relevant to this review:

- ORAUT-TKBS-0011-4, revision 02 (NIOSH, 2007b)
- SC&A's September 4, 2013, memorandum, "SC&A Review of RFP Data Falsification Issue" (SC&A, 2013)
- SC&A's July 10, 2015, memorandum, "SC&A's Current Status of Evaluating the RFP Potential Data Falsification, Handling Bioassays, and Document Destruction Issues" (SC&A, 2015a)
- ORAUT-TKBS-0011-4, revision 03 (NIOSH, 2020b).

In its July 2015 memorandum, SC&A (2015a) provided the page, table, and figure numbers in ORAUT-TKBS-0011-4, revision 02 (NIOSH, 2007b), that contained information that could potentially be impacted by environmental monitoring issues raised in the 1989 FBI investigation.

SC&A reviewed the environmental intake information in TBD-4, revision 03 (NIOSH, 2020b), compared to the environmental intake information in revision 02 (NIOSH, 2007b) concerning the pages, tables, and figures that SC&A (2015a) found could have been impacted by environmental monitoring results. SC&A found an approximately 25 percent increase in the recommended intake values in tables 4-2 and 4-3 of revision 03 compared to those in tables 4-2 and 4-3 of revision 02. This increase was the result of basing the intake on 2,500 hours per year in revision 03 (section 4.2.3) compared to 2,000 hours per year in revision 02 (section 4.2.3). SC&A found that the numerical values in the tables and figures in attachment A of TBD-4, revision 03 (NIOSH, 2020b), remained the same as in revision 02 (NIOSH, 2007b).

SC&A found that the potential impact of the 1989 FBI investigation concerning environmental monitoring for DR purposes is addressed in TBD-4, revision 03 (NIOSH, 2020b), in section 4.1.4, pages 9 and 10. The last bullet point and conclusion of section 4.1.4 state:

> - A review of the Colorado Federal District Court Report of the Federal District Special Grand Jury ([Colorado Federal District Court] 1992) indicates that RFP had a number of violations. These included a deficient ground-water monitoring system, failure to notify government agencies of environmental law violations, storage issues, and chemical violations. However, the grand jury review of the FBI's findings did not identify any deficiencies with the radiological monitoring programs (i.e., no deficiencies are assumed to exist with the external ambient data and/or environmental air data).
>
> Based on this information, the ORAU Team concluded this information has no effect on its ability to perform onsite ambient or environmental dose reconstructions with sufficient accuracy. [NIOSH, 2020b, p. 10]

SC&A reviewed the cited document, "Colorado Federal District Court Report of the Federal District Special Grand Jury 89-2 January 24, 1992*"* (Colorado Federal District Court, 1992), and found that the proposed violations were related to environmental issues, such as groundwater monitoring and the Clean Water Act, and not to the monitoring of workers' environmental intakes; therefore, they would not impact DR as stated in ORAUT-TKBS-0011-4, revision 03 (NIOSH, 2020b).

SC&A finds this issue has been adequately addressed.

5.3 Summary and conclusions for TBD-4

SC&A's review of TBD-4, revision 03 (NIOSH 2020b), on occupational environmental dose, found that the revised TBD addressed and resolved SC&A's finding 9 from its original 2005 site profile review regarding inadequacies in addressing potential environmental exposure from routine and ambient airborne releases and resuspension of contaminated soil at RFP. SC&A found that NIOSH has added more specific information and guidance about the contribution of resuspension of soil contaminants for occupational environmental exposures and provides better

justification of its basis in available site monitoring data. Therefore, SC&A recommends closure of this finding.

SC&A likewise found satisfactory the treatment by the revised TBD-4 of other issues, such as use of the Regional Atmospheric Transport Code for Hanford Environmental Tracking (RATCHET) air dispersion model and consideration of environmental DR issues stemming from the 1989 FBI investigation. SC&A also performed a general review of TBD-4, revision 03, and did not identify any additional findings.

6 Review of TBD-5 Occupational Internal Dose, ORAUT-TKBS-0011-5, Rev. 04

The following documents are relevant to this review:

- ORAUT-TKBS-0011-5, revision 00 (NIOSH, 2004c)
- SCA-TR-TASK1-0008, revision 0 (SC&A, 2005)
- ORAUT-TKBS-0011-5, revision 04 (NIOSH, 2020c)

In its original site profile review for RFP, SC&A (2005) raised issues related to high-fired plutonium and uranium; DR guidance for neptunium, thorium, curium, tritium, and other source terms identified; additional information for radionuclide solubility and particle size; and guidance for wound and ingestion pathways. SC&A reviewed the most recent occupational internal dose TBD, TBD-5, revision 04 (NIOSH, 2020c), for its (1) consideration and resolution of issues raised in SC&A's 2005 site profile review, (2) reflection of site profile issues identified during work group proceedings, and (3) treatment of SEC issues that had been closed out by the work group but were considered relevant as "site profile" issues and were to be addressed as such.

Based on these considerations, SC&A reviewed the following issues for TBD-5, revision 04 (NIOSH, 2020c):

- Finding 1: "Suggested use of urine bioassay MDA values for plutonium and americium appear low and are likely to yield body burdens/organ doses that are proportionately low and, therefore, claimant unfavorable." (SC&A, 2005, p. 15 and section 5.1)

- Finding 2: "Internal dosimetry TBD lacks definitive direction in some instances and has gaps that need to be addressed." (SC&A, 2005, p. 15 and section 5.2)

- Finding 7: "The internal TBD does not consider potential contribution of ingestion pathway." (SC&A, 2005, p. 17 and section 5.3)

- Observation 4: "With an appropriate wound dose model not available, the cited approach for estimating wound-related uptakes in the internal dose TBD is claimant favorable for relevant types of cancer, except for lymph nodes and skin cancers. A more claimant-favorable approach for these affected organs needs to be addressed, for which a recently

proposed model (Guilmette and Durbin 2003) for wound-site retention of soluble radionuclides may be relevant." (SC&A, 2005, p. 19 and section 5.2.7)

- Critical Mass Laboratory (CML) intakes concerning DR: This issue had been evaluated by NIOSH in a white paper, "Reassessment of Internal Radiation Dose from Sources at the Rocky Flats Plant Critical Mass Laboratory," revision 0 (NIOSH, 2016).

- Evaluation of the potential for internal dose from Np-237: This concern stemmed from an existing SEC issue from NIOSH's evaluation report for Petition-00192 (NIOSH, 2013).

- Reported presence of Mg-Th alloy: This issue originated from comments by SC&A, NIOSH, and petitioners during the work group's review of NIOSH's evaluation report for SEC Petition-00192 (ABRWH, 2006b, 2006c, 2007).

- Tritium exposure issues: This issue was raised by petitioners as part of the RFP work group's review of NIOSH's evaluation report for SEC Petition-00192 (ABRWH, 2013).

SC&A reviewed these issues as described in the following sections. SC&A used NIOSH white papers and reports, SC&A reviews, and RFP work group meeting transcripts to establish issue descriptions, assessments, and the status of work group resolutions and closures.

6.1 Suggested use of urine bioassay MDA values appear low

SC&A noted the following in finding 1 of its site profile review (SC&A 2005, p. 15):

> **Suggested use of urine bioassay MDA values for plutonium and americium appear low and are likely to yield body burdens/organ doses that are proportionately low and, therefore, claimant unfavorable.** NIOSH's use of median MDA (minimum detectable activity) values for plutonium and americium appear unduly low and likely to yield body burdens or organ doses that would be non-conservative, given the uncertainties involved. Given the limited data and uncertainties of the key variables (e.g., sample count time, detector counting efficiency, self-absorption, and various sampling assumptions) from which MDAs are defined, SC&A understands the need to apply certain assumptions to bridge these gaps in information. However, the concern is that a number of these assumptions are not adequately supported and may not be claimant favorable. Likewise, the use of these assumed median MDA values, themselves, in dose reconstruction, may be inappropriate. This is because urine activity levels monitored at RFP for plutonium and americium were likely well in excess of assumed median MDA values, most notably where workers were assigned "zero" or "background" readings in the past when urinalysis results were found to be less than 10% of the tolerance level. SC&A believes more conservative assumptions should be applied in the formulation of MDA values that would more realistically reflect the range of uncertainties involved.

The urinalysis MDA values in TBD-5, revision 04, tables A-11 and A-12 (NIOSH, 2020c, p. 82), for plutonium are the same as the MDA values in the corresponding tables on pages 46 and 47 of TBD-5, revision 00 (NIOSH, 2004c). The urinalysis MDA values in tables A-18 and A-19

(pp. 84, 85), for americium in TBD-5, revision 04, are the same as the MDA values in the corresponding tables on page 49 of TBD-5, revision 00. However, SC&A reviewed the post-2004 TBD-5 documents for three other major DOE sites (Los Alamos National Laboratory (LANL), Hanford, and Oak Ridge National Laboratory(ORNL)) for plutonium and americium MDA values and found the MDA values recommended for RFP to be in most instances in the same range, or larger, than for other sites. Additionally, the RFP TBD-5 provides for extreme conditions (95th percentile) (table A-12 for plutonium and table A-19 for americium) for the dose reconstructor to use if needed. SC&A finds that this issue has been addressed and recommends closure.

6.2 TBD lacks definitive direction in some instances

In Finding 2 of its 2005 review of NIOSH's TBD, SC&A found:

> **Internal dosimetry TBD lacks definitive direction in some instances and has gaps that need to be addressed.** There is limited guidance for use by the dose reconstructor regarding the process and assumptions that should be used to calculate internal dose. Notably, this TBD does not provide clear guidance for assessment of dose for unmonitored workers, nor does it specifically address what "missed dose" may exist and how it is to be addressed. The use of the assumed default particle size of 5 µm AMAD needs to be reconsidered for those RFP operations for which actual particle size measurements exist (e.g., a 0.3 µm mass median diameter for airborne particles involved in at least two fires at RFP). The approaches regarding solubility need to be reviewed, particularly for Type "S" or "Super-S" plutonium compounds whose high insolubility may lead to more exposure to gastrointestinal and respiratory tract organs. Uncertainties are not addressed in the TBD regarding the ^{241}Am assay of plutonium processed at RFP and how lung counting was calibrated to these values. The assumptions (full equilibrium) regarding the methodologies to assess the internal exposure to depleted uranium based on estimates of ^{238}U activity may not be claimant favorable for some circumstances. The sensitivity of the bioassay methods was not adequate to detect incidental intakes of insoluble compounds.
> [SC&A, 2005, p. 15]

The following subsections describe SC&A's review of TBD-5, revision 04 (NIOSH, 2020c), for these issues compared with SC&A's (2005) discussion of revision 00 (NIOSH, 2004c).

6.2.1 SC&A (2005) section 5.11.3 – completeness of internal monitoring data

In its original review of the 2004 internal dose TBD, SC&A (2005) found that TBD-5 used several techniques to assign dose in the case of an unmonitored worker. To calculate internal dose for workers not involved in an incident, revision 00 of TBD-5 provided the following guidance (NIOSH, 2004c, p. 30):

> The suggested approach is to estimate the time spent by the worker in a building involved in a radionuclide of interest and credit the worker with a chronic intake at an arbitrary fraction of the in-plant guide (or official limit), whichever is more claimant favorable. . . .

> Claims files may include event-specific data that should be used to reconstruct internal dose. When such data is not available default assumptions may be made.

SC&A (2005, p. 105) noted:

> In the case of an unmonitored worker not involved in an incident but having access to radiological areas, it is not clear whether the method outlined is bounding. Information, such as job title, work location, skill or task, time spent in an area, and radionuclides of concern are not readily available and would have to be evaluated for the particular individual. The process for assigning dose to an individual in multiple job locations would further complicate the matter. In the case of an incidental exposure, not collecting samples in a timely manner may prevent dosimetry from collecting needed follow-up samples, or render bioassay techniques ineffective (e.g., insoluble plutonium).

In reviewing TBD-5, revision 04 (NIOSH, 2020c), SC&A finds that NIOSH reflects the SEC determination for Petition-00193 and has defined an SEC class for all workers at RFP, as follows (NIOSH, 2020c, p. 18):

> NIOSH has determined that doses to unmonitored RFP workers from neptunium, thorium, and ^{233}U (and its associated ^{232}U and ^{228}Th progeny) cannot be reconstructed from April 1, 1952, through December 31, 1983, inclusive (NIOSH, [2013]).
>
> The class includes all workers during the SEC period. Because of the identified dose reconstruction infeasibility, all dose reconstructions for monitored workers during the SEC period are considered partial dose reconstructions.

For potential tritium exposures, NIOSH has added attachment G to TBD-5, revision 04, as a basis for assigning tritium doses to unmonitored RFP workers.

For the application of an internal co-exposure model for unmonitored workers other than for the radionuclides discussed in this section, NIOSH added attachment D to revision 04 of TBD-5 (NIOSH, 2020c). Attachment D notes that the RFP work group "suggested and agreed that the use of the 95th percentile internal co-exposure intake for unmonitored workers with nontrivial exposure potential would satisfy [the work group's] concern" that "the number of samples in HIS-20 and CEDR [electronic datasets] were different in some cases," thereby raising questions about a comparison using the epidemiology-based CEDR urinalysis dataset as a means to validate the HIS dataset for RFP (NIOSH, 2020c, p. 145).

Based on these changes, SC&A finds that NIOSH has addressed the original issue of reconstructing internal dose for unmonitored workers and recommends closure of this issue.

6.2.2 SC&A (2005) section 5.2.3 – default particle size

SC&A found that the "use of the assumed default particle size of 5 µm AMAD needs to be reconsidered for those RFP operations for which actual particle size measurements exist (e.g., an 0.3 µm mass median diameter for airborne particles involved in at least two fires at RFP, which

may be typical of 'high-fired' plutonium generated in processes involving temperatures exceeding 400°–600° C)" (SC&A, 2005, p. 12).

NIOSH addressed this issue by providing specific guidance on the application of smaller particle sizes for workers potentially exposed to plutonium fires at RFP. NIOSH noted that:

> In general, particle size and distributions are not available for work areas or incidents at RFP. Therefore, dose reconstructions should use the default value of 5-µm activity median aerodynamic diameter (AMAD) (NIOSH 2002).
>
> One exception is the plutonium fire on October 15, 1965, in Buildings 776 and 777 (Dow 1965), for which Mann and Kirchner (1967) measured a mass median diameter of 0.3 µm (1-µm AMAD) with a geometric deviation of 1.83. Therefore, for individuals potentially involved with a plutonium fire, the more favorable particle size of 1-µm or 5-µm AMAD should be assumed. [NIOSH, 2020c, p. 22]

Based on the provision of more specific guidance on the application of smaller particle size, SC&A recommends this issue be closed.

6.2.3 SC&A (2005) section 5.2.1 – type S and Super S solubility

SC&A found that the manner in which the TBD approaches solubility needs to be reviewed, particularly for type S or Super S plutonium compounds whose high insolubility may lead to more exposure to gastrointestinal and respiratory tract organs. At Rocky Flats, high-fired oxides were generated during the two big fire accidents and more than likely as a result of smaller plutonium fires and high-temperature processes in furnaces, incinerators, and production areas.

SC&A's (2005) review evaluated the effect of using the high-fired plutonium (Super S) lung retention parameters in the interpretation of bioassay results by using the type S Pu-239 lung retention parameters in simulating different scenarios. This analysis showed that:

> the incidental acute intake of insoluble plutonium compound, in the first 20 years, may be difficult to identify because of several factors, including the relatively high MDA value (0.01 Bq), the low fraction of activity intake excreted through the urine (10^{-6} Bq), and historic delay in or lack of performing post-incident urinalysis or fecal analysis. It was found that the contribution of chronic intake in urinary activity increases over the time of exposure, obviating the detection of incidental intakes, unless the activity is extremely high or the chronic exposure is very low, or undetectable. [SC&A, 2005, p. 41]

In its 2020 internal dose TBD revision, NIOSH provided specific information and guidance regarding assumed insolubility for plutonium:

> The plutonium [redacted] on [redacted], in Buildings [redacted], is a special case. The plutonium, which was strongly retained in the [redacted] of exposed workers with relatively low transfer to the urine, exhibited highly insoluble (type SS) characteristics ([NIOSH, 2020d]).

> Plutonium in chemical processing operations can be either soluble (type M), insoluble (type S), highly insoluble (type SS), or a mixture of solubilities. Dose reconstructors should select the material type that is most favorable to the claimant ([NIOSH, 2018b]). [redacted] count data in conjunction with urine data can help to determine absorption type. [NIOSH, 2020c, p. 22]

SC&A agrees with this guidance and recommends closure of this issue.

6.2.4 SC&A (2005) section 5.2.6.2 – calibration of lung counting to Am-241

SC&A (2005) found that the TBD did not address uncertainties regarding the Am-241 assay of plutonium processed at RFP and how lung counting was calibrated to these values. SC&A (2005) noted that the TBD (NIOSH, 2004c, p. 18) stated the following:

> Reporting levels are not easily defined, because quantification was preceded by verification counts and professional judgments. In addition, before 1974, the practice was not to quantify a positive detection of ^{241}Am unless the deposition could be associated with a known incident with a known ppm ^{241}Am. Affected workers were classified as positive unknowns or some variation. Starting in 1974, the practice was changed to quantify the plutonium depositions for positive unknowns by assuming a default value of 1,000 ppm ^{241}Am on the date of the most likely intake or on the date of the first positive lung count. The ppm ^{241}Am was then calculated for the date of the lung count to account for the ingrowth of ^{241}Am from the nuclear transformation of ^{241}Pu and the radioactive decay of the initial ^{241}Am.

SC&A found, however, that "There is no clear instruction on how the dose reconstructors should choose the appropriate value of ppm ^{241}Am, and also there is no clear explanation of the basis to choose 1,000 ppm as the default value for ppm ^{241}Am" (SC&A, 2005, p. 54).

NIOSH's (2020c) revision of the internal dose TBD added an attachment B, "Minimum Detectable Amounts for in vivo Lung Counts," which provides calibration factors for various historical detection systems, including MDA conversion factors for values of parts per million (ppm) Am-241 and Am-241 ingrowth in plutonium. Based on this detailed calibration and MDA information applicable to various detection systems used during RFP's operational history, SC&A recommends closure of this issue. SC&A did find that table B-11, page 104, lacks units for the MDA values; it appears that it should specify the unit of nanocuries.

6.2.5 SC&A (2005) section 5.2.6.2 – assumptions of full equilibrium for depleted uranium

SC&A found that "The assumptions (e.g., full equilibrium) regarding the methodologies to assess the internal exposure to depleted uranium based on estimates of ^{238}U activity may not be claimant favorable for some circumstances" (SC&A, 2005, pp. 12–13). For example, SC&A pointed out that "If the worker is exposed to depleted uranium metal with a deficiency of ^{234}Th, the assumption of equilibrium will underestimate the ^{238}U activity in the lung of the workers exposed to depleted uranium metal with a deficiency of ^{234}Th" (SC&A, 2005, p. 55).

In its most recent version of TBD-5 for internal dose, NIOSH indicates:

> The major uncertainty is the assumption of equilibrium of the ^{234}Th with the ^{238}U before 1990, when DU was still being processed. Part of the process was to remove decay chain radionuclides, especially thorium, by heating the uranium ingot to drive the smaller atoms of thorium to the surface or top of the ingot, which was then cut off. The result was DU metal with a deficiency of ^{234}Th for several weeks plus scrap DU with an excess of ^{234}Th (super-equilibrium). The assumption of equilibrium when super-equilibrium existed is favorable to claimants. If a superequilibrium situation was operative and the ^{234}Th lung count result was used to calculate the DU assuming equilibrium, the calculated DU would be higher than the actual activity. Therefore, the approach is favorable to claimants. The effect of a deficiency of ^{234}Th (not favorable to claimants) is mitigated by the rapid ingrowth of the ^{234}Th into the DU. Fifty-percent equilibrium occurs after 24 days after a thorium strike, and 90% occurs after 80 days. [NIOSH, 2020c, p. 36]

Based on NIOSH's addition of these considerations regarding claimant favorability, SC&A recommends closure of this issue.

6.2.6 SC&A (2005) section 5.2.1 – sensitivity of bioassay methods to detect incidental intakes of insoluble compounds

SC&A pointed out this issue, as it pertains to plutonium, based on an "evaluation of the effect in using the high-fired plutonium (Super S) lung retention parameters in the interpretation of bioassay results was carried out using the Type S ^{239}Pu lung retention parameters simulating [four] different scenarios" (SC&A, 2005, p. 40), as detailed in attachment 9 of its 2005 site profile review. SC&A found that:

> This analysis shows that the incidental acute intake of insoluble plutonium compound, in the first 20 years, may be difficult to identify because of several factors, including the relatively high MDA value (0.01 Bq), the low fraction of activity intake excreted through the urine (10^{-6} Bq), and historic delay in or lack of performing post-incident urinalysis or fecal analysis. It was found that the contribution of chronic intake in urinary activity increases over the time of exposure, obviating the detection of incidental intakes, unless the activity is extremely high or the chronic exposure is very low, or undetectable. [SC&A, 2005, p. 41]

TBD-5, revision 04 (NIOSH, 2020c), section 5.2.1.2 (p. 22), recommends assigning plutonium with a solubility type that is most claimant favorable per ORAUT-OTIB-0060, revision 02 (NIOSH, 2018b), and ORAUT-OTIB-0049, revision 02, "Estimating Doses for Plutonium Strongly Retained in the Lung" (NIOSH, 2020d). These recommendations include consideration of type Super S plutonium. Both of these technical information bulletins were issued after revision 00 of TBD-5 (NIOSH, 2004c) was issued, which was the version SC&A (2005) had originally reviewed. SC&A finds this issue resolved and recommends closure.

6.3 TBD does not consider potential contribution of ingestion pathway

SC&A's finding 7 from its 2005 site profile review is as follows:

> **The internal TBD does not consider potential contribution of ingestion pathway.** The internal dose potential for ingesting radionuclides has not been considered in the occupational internal dosimetry TBD ([NIOSH, 2004c]). The ingestion pathway should not be ignored, except for the organs related to the respiratory tract where the dose from inhalation predominates. For other organs, ingestion dose is often higher than any dose received from inhalation. This is particularly true for plutonium, americium, and uranium. The ingestion pathway was also not considered in the derivation of co-worker dose data. The use of bioassay results to back-calculate intake and doses will produce higher internal exposures for certain organs if the ingestion pathway is taken into account. [SC&A, 2005, p. 17]

SC&A concluded that the TBD does not provide adequate guidance for DR associated with tritium, neptunium, thorium, curium, noble gases, and fission products. Ingestion exposure pathways were not considered in the TBD in the dose assessment process, especially for cancers of the gastrointestinal tract. TBD-5 only refers to ORAUT-OTIB-0060, revision 02 (NIOSH, 2018b), on page 22, in reference to selecting solubility type. ORAUT-OTIB-0060 addresses ingestion intakes on pages 16 and 38, all of which refer to OCAS-TIB-009, revision 0 (NIOSH, 2004f). TBD-5 should include recommendations for ingestion intakes or direct reference to the appropriate ingestion-intake-related document. Although this issue has been resolved in practice, ingestion intakes should be addressed in TBD-5 with reference to OCAS-TIB-009. Therefore, SC&A recommends that this issue remain open until appropriate revisions are made in TBD-5.

6.4 Available proposed wound dose model may be more claimant favorable

In observation 4 of its 2005 site profile review, SC&A noted:

> With an appropriate wound dose model not available, the cited approach for estimating wound-related uptakes in the internal dose TBD is claimant favorable for relevant types of cancer, except for lymph nodes and skin cancers. A more claimant-favorable approach for these affected organs needs to be addressed, for which a recently proposed model (Guilmette and Durbin 2003) for wound-site retention of soluble radionuclides may be relevant. [SC&A, 2005, p. 19]

NIOSH's (2020c) internal dose TBD-5 notes that guidance on assessing wound intakes is provided in ORAUT-OTIB-0022, revision 00, "Guidance on Wound Modeling for Internal Dose Reconstruction" (NIOSH, 2005). This updated guidance references Guilmette and Durbin (2003), as well as other assessments; therefore, it addresses SC&A's 2005 observation.

6.5 Critical Mass Laboratory intakes concerning dose reconstruction

The purpose of this review was to determine if the potential internal exposures from the CML had been addressed in revision 04 of ORAUT-TKBS-0011-5 (NIOSH, 2020c). SC&A had reviewed NIOSH's evaluation of the potential exposure from mixed fission and activation

products (MFAPs) at the CML as detailed in previous reports. Documents relevant to the review of the CML in this context are as follows:

- NIOSH's June 9, 2015, white paper, "Assessment of Sealed Radioactive Sources, and Fission and Activation Products as Radiological Exposure Sources in the Rocky Flats Plant Critical Mass Laboratory (Building 886 Cluster)" (NIOSH, 2015a)
- SC&A's July 8, 2015, report, "Review of NIOSH's White Paper: Assessment of Sealed Radioactive Sources, and Fission and Activation Products as Radiological Exposure Sources in the Rocky Flats Plant Critical Mass Laboratory (Building 886 Cluster)" (SC&A, 2015b)
- NIOSH's November 28, 2016, white paper, "Reassessment of Internal Radiation Dose from Sources at the Rocky Flats Plant Critical Mass Laboratory" (NIOSH, 2016)
- SC&A's 2017 report, SCA-TR-2017-SEC003, revision 0, "SC&A's Evaluation of NIOSH's White Paper, 'Reassessment of Internal Radiation Dose from Sources at the Rocky Flats Plant Critical Mass Laboratory,' of November 28, 2016" (SC&A, 2017)

These NIOSH and SC&A RFP documents determined that there was not a potential for the internal intake of dosimetrically significant MFAPs. This is summarized by NIOSH in its 2016 white paper (p. 36):

> NIOSH concludes that no significant personnel dose to Rocky Flats workers or contractors resulted from the generation of fission or activation products in the uranyl nitrate fuel or resuspended contamination from fuel spills as a result of criticality experiments conducted at CML over its lifetime.

SC&A's (2017) evaluation of NIOSH's (2016) white paper concurred (SC&A, 2017, p. 8):

> Various parameters and scenarios could be used to estimate the potential MFAP intakes at the CML, with differing results. However, as indicative of the very small MFAP doses derived by both NIOSH and SC&A, even a change of a factor of 10 or 100 in the results would not alter the conclusions that the potential doses from MFAP were very small, and much less than 1 mrem, the minimum dose used in dose reconstruction.

Revision 04 of TBD-5 (NIOSH, 2020c, p. 26) addressed the CML as follows:

> Building 886 housed the Critical Mass Laboratory (CML) at RFP. Mixed fission and activation products (MFAPs) in both the fuel and containment materials present an internal dose potential for personnel who might ingest or inhale them. CML staff submitted routine bioassay (urinalysis and whole-body counts) to detect intakes of plutonium, uranium, and/or americium, but MFAPs were not routinely monitored.
>
> Attachment H provides a detailed analysis of the CML. Based on this analysis, no significant unmonitored exposure is associated from the generation of fission or activation products.

Attachment H of ORAUT-TKBS-0011-5 (NIOSH, 2020c) contains approximately the same analysis as NIOSH's 2016 white paper and reaches a similar conclusion:

> Based on this modeling, no significant personnel dose to RFP workers or contractors resulted from the generation of MFAPs in the UNH fuel or resuspended contamination from fuel spills as a result of criticality experiments at CML over its lifetime. [NIOSH, 2020c, p. 245]

SC&A concurs with this assessment, as summarized in SC&A's (2017) report, page 8.

SC&A finds that the potential intake of MFAPs from the CML has been included in revision 04 of ORAUT-TKBS-0011-5 (NIOSH, 2020c) and that this item has been adequately addressed.

6.6 Evaluation of the potential for internal dose from neptunium-237

The purpose of this review was to determine if the potential internal exposures from Np-237 had been addressed in revision 04 of TBD-5 (NIOSH, 2020c), the details of which are presented in attachment E of that TBD.

SC&A reviewed a January 8, 2015, NIOSH white paper, "Evaluation of the Potential for Internal Dose from Np-237 at the Rocky Flats Plant after 1983," revision 1 (NIOSH, 2015b). SC&A also participated in some of the early data capture reviews at the Environmental Management Consolidated Business Center and DOE Legacy Management facility in Denver, CO, as well as in most of the interviews conducted with former RFP workers who had some involvement in or knowledge of neptunium operations.

NIOSH's (2015b) white paper examined neptunium operations at RFP and compared the period 1962 through 1983 with the period after 1983. For the period after 1983, document reviews and interviews have uncovered only one neptunium operation: an approximately 1-year campaign in the mid-1980s that processed plutonium scrap containing residual amounts of neptunium in order to recover neptunium and purify plutonium (resulting in the purification of 58,282 grams of plutonium). Key attributes of this operation (plutonium-neptunium separation and residue recovery) were (1) the processing of the Pu/Np scrap in a "closed" separation system involving a glovebox containing a "wet" section (for aqueous processes) and a "dry" section (for calcining precipitates and weighing powders) separated by an air lock, with tanks containing feed material (plutonium and neptunium nitrate solution) being piped directly into the gloveboxes, and (2) lack of any "pure" plutonium or neptunium source term (both metals were produced with impurities of the other, i.e., "purified" plutonium contained 0.0069 percent neptunium and "purified" neptunium was co-generated with plutonium at a Pu:Np mass ratio of 6.4) (NIOSH, 2015b, p. 4).

The implication of the first attribute of this particular operation is that no routine exposure potential would have existed for workers performing the extractions at the glovebox. The implication of the second attribute is likewise important, in that the continuing presence of plutonium with neptunium product provides a means for radiological monitoring of this operation, given the much greater specific activity attributable to plutonium compared to neptunium, making any uptake of the Pu/Np mixture detectable via bioassay results (all personnel were provided routine bioassays during this operation).

Beyond the one post-1983 neptunium operation identified, NIOSH (2015b) observes that neptunium was present at RFP from 1962 to 2003, with quantities ranging from 29 grams to 1,318 grams (Idaho Completion Project, 2005). While the one post-1983 neptunium program was reportedly terminated by 1988, neptunium remained in inventory and as residual contamination in gloveboxes, ductwork, and other process equipment. In its review of an interview with a former RFP [redacted] (ORAU, 2014), NIOSH concluded that for post-1983 handling of this contaminated equipment (e.g., during decontamination and decommissioning (D&D) and site closure activities), it does not "dispute the potential for personnel Np exposures," but "contends that the exposure would be dominated by the Pu (nothing involved purified or pure Np), and nothing provided up to this point disputes that contention" (ORAU, 2014, p. 9). In summary, NIOSH (2015b) concludes that there is "no evidence that Np-237 intakes occurred at RFP after December 31, 1983," and that if intakes did occur after 1983 from the single neptunium operation that was identified, "the resulting organ doses would be adequately accounted for by the available Pu bioassay data" (NIOSH, 2015b, p. 10).

In its May 29, 2015, response to the NIOSH (2015b) white paper, SC&A (2015c) concurs with NIOSH that only one processing operation in the post-1983 period involved neptunium: the Plutonium-Neptunium Separation and Residue recovery operation, which ran from late 1985 to the end of 1987. Other activities at RFP involved neptunium contamination, including radioactive waste handling and later D&D, but in all of these instances, there is no evidence to date that neptunium source terms existed without the presence of plutonium. SC&A concurs with NIOSH that the co-presence of neptunium with plutonium enables radiological monitoring to account for any neptunium exposure component in a claimant-favorable manner. All workers involved with this one post-1983 operation, as well as other work activities in Building [redacted], were routinely bioassayed for plutonium intakes during the years in question (as were radiological waste handlers and D&D workers). Pure neptunium metal forms were stored and transported, but no internal intake (e.g., from surface oxidation) would have been likely, and none was detected through routine bioassay monitoring.

The assessment and conclusions in revision 04 of TBD-5 (NIOSH, 2020c) reflect these SC&A findings and conclusions, and SC&A concurs with this TBD revision.

6.7 Reported presence of magnesium-thorium alloy

The purpose of this review was to evaluate how the presence of Mg-Th alloys was addressed in revision 04 of TBD-5 (NIOSH, 2020c), the details of which NIOSH presents in attachment F.

SC&A originally raised the possibility of Mg-Th alloy being received by RFP during its SEC evaluation report review for Petition SEC-00030. In this review, SC&A found that "it is clear from NUREG-1717 and the other considerations presented above that knowledge of the approximate quantities, periods, and processing status of the magnesium-thorium alloy is needed before any reliable conclusions can be arrived at regarding doses to Rocky Flats workers from this material" (SC&A, 2007, p. 466).

During this review, SC&A interviewed a Dow Madison worker who had claimed that shipments of Mg-Th alloy material were being sent to Rocky Flats during a 12-year period from 1963 to about 1975 (SC&A, 2007, p. 491-497). At the Rocky Flats Work Group request, NIOSH subsequently interviewed four site experts from RFP regarding the degree of exchange of Mg-Th

between RFP and Dow Madison, if any. As noted in NIOSH's August 13, 2014, response paper (NIOSH, 2014b), the four experts interviewed did not recall any large quantities of magnesium alloy in use at RFP and did not recall any shipments of such material between RFP and Dow Madison.

The issue was raised again by the petitioner for petition SEC-00192 via e-mail on May 31, 2013, which indicated that a third party had reported that Mg-Th alloy plates had been brought to RFP, refined in Building 881, and then sent to the Transportation Modification (MOD) center for modification to fit "Semi Trucks" to make them bullet proof (NIOSH, 2014b, p. 2). NIOSH conducted a further records review of the Site Research Database (SRDB) to locate any documentation establishing a link between Mg-Th alloy and RFP, conducted new keyword searches of available RFP documents (e.g., using "HK-31" and "HK-31A" as key search parameters), performed additional onsite document searches, and interviewed additional former RFP workers, in particular, one who worked at the MOD center. None of those investigations surfaced new information, which has led NIOSH to change its original conclusions from 2007 that there is no evidence of the use of Mg-Th alloy material at RFP. NIOSH opined that there is likely "confusion between RFP and other Denver-area sites, as well as confusion regarding Mg-Th alloy plates and other similar materials at RFP" (NIOSH, 2014b, p. 8).

While SC&A's (2014) review of NIOSH's (2014b) response paper identified a need at that time for additional investigation of the issue of Mg-Th receipt and use at RFP, SC&A also concluded that the value of that effort would need to be weighed by the work group against the resources required to investigate the remaining records, if they could even be identified at that stage. The reported Mg-Th use period for the Atomic Energy Commission weapons complex (1956–1969; ABRWH (2008)) falls within the current SEC period for RFP (1952–1983) and, therefore, would only influence partial DRs. While the reported concentration of thorium in the alloy material (2 percent–3 percent) is relatively low, SC&A concluded that the dose contribution to workers, if they were involved with certain intrusive handling of the material (e.g., grinding, smelting, or fabricating), could potentially be significant, as pointed out by SC&A's 2007 review of NUREG -1717 and potential worker exposures from 4 percent thoriated welding rods (SC&A, 2007).

The work group ultimately closed this issue. SC&A concurs with NIOSH's conclusion in revision 04 of ORAUT-TKBS-0011-5 that, based on the research performed for this assessment, there is no corroborating evidence for the use of Mg-Th at the RFP site.

6.8 Tritium issues

The purpose of this review was to assess how the potential for tritium exposure at RFP was addressed in revision 04 of ORAUT-TKBS-0011-5 (NIOSH, 2020c), as detailed in attachment G of the TBD, based on issues raised within the work group since the previous version of the TBD.

In revision 04, NIOSH (2020c, p. 217) noted:

> Although tritium was used as a boost gas in weapons and as target material in neutron generators, it was not processed or handled in significant quantities at RFP. Tritium was monitored in the environment around the site for a time, but that monitoring ceased and was left to the State of Colorado for a brief period before an environmental release that occurred in April 1973. No analytical records

have been found that might help establish the RFP workplace tritium environment before 1973.

NIOSH and SC&A exchanged a series of white papers to support work group discussions of this subject, culminating in a December 28, 2015, response by NIOSH, "Follow-up Efforts on SEC-00192, Rocky Flats Plant Tritium Issues," revision 3 (NIOSH, 2015c), to address work group and SC&A comments on revision 2 (NIOSH, 2015d) regarding the 1973 tritium model.

NIOSH (2015c) presents NIOSH's approach to DR for tritium exposures in the three parts of appendix 1, as follows:

- Part I, "Analysis of Rocky Flats Plant Tritium Exposures for 1959–1973," by J. S. Bogard, Oak Ridge Associated Universities Team (ORAUT)
- Part II, "Rocky Flats Tritium Dose Assignment for 1973 and Later," by E. M. Brackett, ORAUT, and attachment A, "Tritiated Water Models," by Thomas LaBone, Nancy Chalmers, and E. M. Brackett, ORAUT
- Part III, "Example RFP Tritium Dose Reconstruction," by Mutty Sharfi, ORAUT

SC&A and the work group found no issues with NIOSH's approach for dose reconstructing tritium exposures for 1959–1973, wherein a pre-1973 dose was assigned using the bounding estimate of 37.5 millirem (mrem)/year (0.15 mrem/day during 250 days a year) of potential exposure prior to 1973. That approach was accepted at the work group's July 2015 meeting.

For the time periods 1973 and post-1973, SC&A reviewed NIOSH's two 2015 white papers: "Follow-up Efforts on SEC-00192, Rocky Flats Plant Tritium Issues," revisions 2 and 3 (NIOSH, 2015c, 2015d). SC&A provided its responses in its July 13, 2015, paper, "Review and Commentary on the NIOSH White Paper, 'Follow-up Efforts on SEC-00192, Rocky Flats Plant Tritium Issues,' Revision 2" (SC&A, 2015d), and in its June 6, 2016, response to NIOSH's revision 3 (SC&A, 2016).

For 1973 tritium exposures, SC&A reviewed alternative dose estimation models for comparison and found the resulting differences to be minor. For example, if NIOSH had used the new ICRP model[2] or the model published by David Taylor (2003), the dose would be a little higher, i.e., 40 mrem to 50 mrem higher, depending on which dosimetric model is applied. As this dose is just assigned to one year, 1973, for unmonitored workers, the difference in dose estimated will not be substantive and will have negligible influence on the Interactive RadioEpidemiological Program (IREP) probability of causation calculations (SC&A, 2016).

For post-1973 exposures, NIOSH concluded that the 95th percentile of the co-exposure study for 1974–1975 yielded doses much less than 1 mrem for everyone. SC&A supported NIOSH's conclusion that no workers experienced undetected exposures to tritium following the April 1973 incident that could have resulted in doses in excess of 1 mrem/year. Using a worst-case scenario, for 1974 the air sample results prior to August 30 had an average of 5,343 plus or minus

[2] This is the International Commission on Radiation Protection (ICRP) retention and dosimetric model for tritiated water contained in ICRP Publication 78 (1997).

4,518 picocuries per cubic meter (pCi/m^3) (NIOSH, 2015d, p. 16). This gives a 95th percentile of about 15,000 pCi/m^3, which, assuming a normal distribution, comes to about 2.4 mrem/year. NIOSH assumed zero doses for 1974–1975 based on coworker urine samples and the 95th percentile. SC&A concluded that the addition of a dose of 2.4 mrem for 1974 does not make a difference.

SC&A agrees with NIOSH's conclusion that, for all time periods in question at RFP, NIOSH can reconstruct tritium doses with sufficient accuracy. This assessment and conclusion are adequately addressed in revision 04 of ORAUT-TKBS-0011-5.

6.9 Summary and conclusions for TBD-5

For TBD-5, SC&A's original site profile review (2005) had three findings and one observation. Later work group proceedings had identified additional concerns for internal exposures related to the CML, neptunium, Mg-Th, and tritium. For these later concerns, SC&A addressed and resolved each of them during work group deliberations and finds that they are adequately incorporated into TBD-5 as appendices.

For finding 1 of its 2005 review ("suggested use of urine bioassay MDA values for plutonium and americium appear low"), SC&A now finds that while the urinalysis MDA values provided for plutonium and americium for the original and most recent revised TBDs are the same, they compare favorably with those of other DOE facilities (e.g., LANL, Hanford, and ORNL), and MDA values are provided for conservative conditions (95th percentile). On that basis, SC&A recommends closure of this finding.

For finding 2 ("TBD lacks definitive direction in some instances"), SC&A performed a comprehensive review of the various issues upon which this finding was based (e.g., data completeness, particle size, type S solubility) and found that all of the identified issues were addressed and resolved in TBD-5, revision 04 (NIOSH, 2020c), with one suggested clarification needed in table B-11, page 104, which apparently lacks units for the MDA values, which appear to be in nanocuries.

For finding 7 ("TBD does not consider potential contribution of ingestion pathway"), SC&A continues to find a lack of clarity about how ingestion intakes would be handled by dose reconstructors. TBD-5, revision 04 (NIOSH, 2020c), only refers to ORAUT-OTIB-0060, revision 02 (NIOSH, 2018b), on page 22 in reference to selecting solubility type. ORAUT-OTIB-0060, revision 02, addresses ingestion intakes on pages 16 and 38, all of which refer to OCAS-TIB-009, revision 0 (NIOSH, 2004f). For clarity, SC&A believes that TBD-5 should include recommendations for ingestion intakes or direct reference to the appropriate ingestion intake-related document. Although SC&A understands that this issue has been resolved in practice, ingestion intakes should be addressed by specific guidance in TBD-5 with reference to OCAS-TIB-009. Therefore, SC&A recommends this issue remain open until appropriate revisions are made in TBD-5.

For observation 4 ("with an appropriate wound dose model not available, the cited approach for estimating wound-related uptakes in the internal dose TBD is claimant favorable for relevant types of cancer, except for lymph nodes and skin cancers"), SC&A found that TBD-5, revision 04, adequately addressed a concern that an available proposed wound dose model may

be more claimant favorable by including references to Guilmette and Durbin (2003) and other assessments for purposes of guiding dose reconstructors. SC&A recommends that this observation to be resolved.

SC&A performed a general review of TBD-5, revision 04, and did not identify any additional issues.

7 Review of TBD-6 Occupational External Dose, ORAUT-TKBS-0011-6, Rev. 03

The following sections summarize SC&A's evaluation of the revised TBD-6 for occupational external dose, ORAUT-TKBS-0011-6, revision 03 (NIOSH, 2019b), in view of previously identified issues and a general review of the document.

7.1 Previously identified issues

In its 2005 site profile review, SC&A (2005) identified several potential external DR issues in ORAUT-TKBS-0011-6, revision 00 (NIOSH, 2004d), for RFP energy employees. SC&A reviewed revision 03 of TBD-6 (NIOSH, 2019b) to determine if the potential DR issues had been addressed and resolved. The following documents are relevant to this review:

- ORAUT-TKBS-0011-6, revision 00 (NIOSH, 2004d)
- SCA-TR-TASK1-0008, revision 0 (SC&A, 2005)
- ORAUT-TKBS-0011-6, revision 03 (NIOSH, 2019b)

The potential DR issues that needed further consideration identified in SC&A's 2005 report were as follows (SC&A, 2005, pp. 69–82; relevant section numbers are in parentheses at the end of each list item):

- Issue 5: External dose calculation and methodologies (section 5.5)
- Issue 6: Neutron dosimetry and exposures (section 5.6)
- Issue 7: Other external dosimetry issues (section 5.7)

SC&A (2005) presented these three major issues and their subtopics in narrative form in the sections given in the preceding list, as opposed to developing a topic followed by a concluding finding (or observation), as is presently done in SC&A's reviews. Therefore, this report summarizes the important points to be addressed from the SC&A (2005) sections 5.5–5.7 issues and their subtopics.

The following is SC&A's evaluation of the status of these three major issues in view of the information provided in TBD-6, revision 03 (NIOSH, 2019b), and in documents, procedures, and accepted practices that have been developed since SC&A's (2005) review of TBD-6, revision 00.

7.1.1 SC&A (2005) section 5.5 – Issue 5: External dose calculations and methodologies

In this section, SC&A described concerns about a number of areas. The following subsections address each of these concerns.

7.1.1.1 SC&A (2005) section 5.5.1 – areas of concern in records and dose reconstruction

Issue: SC&A (2005) observed a number of areas of concern when evaluating the information for DR provided in the TBD. There appeared to be inconsistencies or gaps in some of the information. Some of these areas of concern were as follows:

- **SC&A (2005) section 5.5.1.1 – Dose reconstruction from badge readings versus historical documents**

  SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in table 6-3 (p. 30) and on pages 40–42. Equations for shallow and deep doses are provided for various time periods. SC&A recommends closure of this issue.

- **SC&A (2005) 5.5.1.2 – Incomplete or inconsistent dose information**

  SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern about the interpretation of the external dosimetry records in section 6.3 on pages 14–19 and table 6-2 (p. 20). SC&A recommends closure of this issue.

7.1.1.2 SC&A (2005) section 5.5.2 – job exposure matrix study

Issue: SC&A noted that NIOSH agrees that the DOE-funded job exposure matrix study (Ruttenber et al., 2003) is important to characterizing worker exposures at RFP and will be especially critical to external DR, where coworker assignments will benefit from job-specific exposure data.

SC&A finds that revision 03 of TBD-6 addressed this issue in section 6.3.5.3. NIOSH (2019b, p. 19) states:

> NIOSH reviewed the data available from this project and concluded that the material is valuable for epidemiological studies but is of limited utility for NIOSH dose reconstruction.

Therefore, the job exposure matrix study has not been found useful for DR purposes. SC&A recommends closure of this issue.

7.1.1.3 SC&A (2005) section 5.5.3 – below 10 mrem dose reported as zero

Issue: TBD-6, revision 00 (NIOSH, 2004d), stated on page 20 that any dose below 10 mrem was reported as zero dose at RFP in 1993. The DR should take this into account when assigning dose and base it on the appropriate LOD at the time.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern about missed dose and the LOD in section 6.6.3 (pp. 42–43) and table 6-11. SC&A recommends closure of this issue.

7.1.1.4 SC&A (2005) section 5.5.4 – badges only calibrated for one work location

Issue: Individuals sometimes worked on temporary or overtime assignments in other facilities (or at other jobs) in addition to the assignment for which their badge was calibrated. This could lead to an underestimate of the worker's dose if this was a common practice.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern about photon energy groups in section 6.6.1 (pp. 39–42) and table 6-9. SC&A recommends closure of this issue.

7.1.1.5 SC&A (2005) section 5.5.5 – exposure geometry

Issue: In the DR process, the assignment of isotropic and rotational instead of anterior-posterior geometry may not reflect the true radiation dose to some workers.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern about exposure geometry in section 6.5.4 (pp. 31–33) and tables 6-5 and 6-6. SC&A recommends closure of this issue.

7.1.1.6 SC&A (2005) section 5.5.6 – angular dependence for beta/gamma, NTA film, and TLDs

Issue: In TBD-6, revision 00, the issue of angular dependence for different types of radiation and different dosimetry systems used through the years is not sufficiently addressed, and at least some general guidelines for consistency would be helpful.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in section 6.6.4.1 (p. 44) for photons and section 6.7.4.1 (p. 53) for neutrons. NIOSH found that the angular dependence is approximately 1.0 for photon dosimeters, NTA film, and thermoluminescent dosimeters (TLDs). The small variability does not warrant a correction factor for DR purposes and is sometimes claimant favorable for some dosimeters. SC&A recommends closure of this issue.

7.1.1.7 SC&A (2005) section 5.5.7 – use of dosimeters under lead aprons

Issue: In some buildings and jobs, workers wore their dosimeters outside their protective lead aprons where the dosimeter would register the exposure dose, but in other buildings and jobs, workers wore their dosimeters under their protective lead aprons where the dosimeters would not register the total dose to the head, neck, and lower parts of the body.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in section 6.5.5 (pp. 33–34), concerning the use of lead aprons, and in the recommendations summarized in table 6-7. SC&A recommends closure of this issue.

7.1.1.8 SC&A (2005) section 5.5.8 – location of dosimeters when working around gloveports/boxes

Issue: The location of dosimeters when working around gloveports/boxes was not identified or addressed in the TBD and should be investigated because of the possibility of unmonitored doses to gloveport/box workers, especially over extended periods.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern about glovebox work in section 6.5.4 (p. 31), which refers the dose reconstructor to DCAS-TIB-0010, revision 04, “Best Estimate External Dose Reconstruction for Glovebox Workers” (NIOSH, 2011). SC&A recommends closure of this issue.

7.1.1.9 SC&A (2005) section 5.5.9 – elevated ambient levels of external radiation affect net dose

Issue: Elevated ambient levels of external radiation may have occurred at RFP. This could have occurred at locations where radioactive materials were handled, transported, piped, stored, or dispersed into the environment. Therefore, there is a need to account for ambient levels of external radiation as occupational exposures in situations where the control dosimeters were stored in locations with ambient levels of external radiation.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern about the potential elevated background at the RFP in section 6.5.7 (pp. 35–36). Section 6.5.7 refers the dose reconstructor to ORAUT-PROC-0060, revision 01, "Occupational Onsite Ambient Dose Reconstruction for DOE Sites" (NIOSH, 2006), which is in the process of being replaced by ORAUT-OTIB-0088, revision 02, "External Dose Reconstruction" (NIOSH, 2021). SC&A recommends closure of this issue.

7.1.2 SC&A (2005) section 5.6 – Issue 6: Neutron dosimetry and exposures

In this section, SC&A described concerns about a number of areas. The following subsections address each of these concerns.

7.1.2.1 SC&A (2005) section 5.6.1 – the likelihood of unmeasured neutron exposures

Issue: Documentation exists that establishes the considerable uncertainties and primitive nature of neutron measurements in the early years, as evidenced by the incomplete criticality safety program of the era.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in section 6.7.3.3 (pp. 51–53), using the NDRP and neutron-to-photon ratios in tables 6-20 and 6-21 (p. 54). If available, information in an energy employee's files can be used for neutron DR; however, there are insufficient data to create a co-exposure model for neutron exposures prior to 1967 according to the results of RFP SEC-00030 (NIOSH, 2007c). SC&A recommends closure of this issue.

7.1.2.2 SC&A (2005) section 5.6.2 – use of neutron track plates and uncertainties in dosimetry, 1951–1957

Issue: In view of the uncertainties in the neutron dosimetry processes during the time period 1951 through 1957, it is not apparent that the recorded neutron dose is correct or claimant favorable.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in section 6.7.3.3 (pp. 51–53) using the NDRP. If available, information in an energy employee's files can be used for neutron DR; however, there are insufficient data to create a co-exposure model for neutron exposures prior to 1967 according to RFP SEC-00030 (NIOSH, 2007c). SC&A recommends closure of this issue.

7.1.2.3 SC&A (2005) section 5.6.3 – NTA neutron energy threshold may lead to missed dose in RFP records

Issue: The neutron dose sections in the TBD need to be revised in view of the NDRP report (Falk et al., 2005), and similar analysis is needed to include other non-plutonium workers exposed to neutrons.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in section 6.7.3.3 (pp. 51–53), using the NDRP and neutron-to-photon ratios in tables 6-20 and 6-21 (p. 54). If available, information in an energy employee's files can be used for neutron DR; however, there are insufficient data to assign other neutron doses or to create a co-exposure model for neutron exposures prior to 1967 according to the results of RFP SEC-00030 (NIOSH, 2007c). SC&A recommends closure of this issue.

7.1.2.4 SC&A (2005) section 5.6.4 – NDRP report lacks important dose reconstruction information

Issue: There are limitations to applying the NDRP report (Falk et al., 2005), as follows:

- **NDRP does not cover non-plutonium workers (SC&A, 2005, section 5.6.4.1)**

  SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in section 6.7.3.4 (p. 53) through the use of neutron-to-photon ratios during DR for any applicable RFP energy employee with dose information from any facility, and the use of co-exposure data in tables C-5 and C-8 for uranium workers. SC&A recommends closure of this issue.

- **Use of neutron/photon ratios and film/TLD comparisons needed (SC&A, 2005, section 5.6.4.2)**

  SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern by the use of the NDRP and neutron-to-photon ratios provided in tables 6-20 and 6-21, and the fact that there are insufficient data to assign other neutron doses or to create a co-exposure model for neutron exposures prior to 1967 according to the results of RFP SEC-00030 (NIOSH, 2007c). SC&A recommends closure of this issue.

7.1.2.5 SC&A (2005) section 5.6.5 – neutron dose multiplication factor

Issue: Information concerning the use of the neutron dose missed by NTA film needs to be corrected.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in section 6.7.3 (pp. 49–53) per the analysis in the NDRP. SC&A recommends closure of this issue.

7.1.3 SC&A (2005) section 5.7 – issue 7: Other external dosimetry issues

In this section, SC&A described concerns about a number of areas. The following subsections address each of these concerns.

7.1.3.1 SC&A (2005) section 5.7.1 – unmonitored individuals

Issue: There is concern that some workers, especially during the early years, may not have been recognized as having the potential to receive radiation doses from their work at RFP.

SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in section 6.9 (p. 62) concerning unmonitored individuals, and in the co-exposure data in attachment C (pp. 94–109). SC&A recommends closure of this issue.

7.1.3.2 SC&A (2005) section 5.7.2 – photon and beta dose determination

SC&A (2005) described several areas of concern in this section:

- **Photons with E > 250 keV (SC&A, 2005, section 5.7.2.1)**

  SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in tables 6-8, and 6-9 (pp. 39–40) with default photon energy ranges. SC&A recommends closure of this issue.

- **Use of VARSKIN software (SC&A, 2005, section 5.7.2.2)**

  SC&A finds that revision 03 of TBD-6 adequately addressed this area of concern in table 6-28 (p. 61), which includes protactinium-234 metastable, and through the use of VARSKIN Mod 3 instead of the previous version that used Mod 2 for the applicable radionuclides in table 6-28. SC&A recommends closure of this issue.

7.1.3.3 SC&A (2005) section 5.7.3 – extremity dose

SC&A (2005) described several areas of concern in this section:

- **Use of NTA film in wrist badges (SC&A, 2005, section 5.7.3.1)**

  SC&A finds that it appears that NTA film was not used in extremity dosimetry; neutron monitoring of extremities was initiated in 1971 (page 62 of revision 03 of TBD-6). According to the results of SEC-00030, neutron dose cannot be reconstructed prior to 1967 (NIOSH, 2007c). Neutron dose can be reconstructed if records are available per the NDRP, according to pages 51–53 of revision 03 of TBD-6. SC&A recommends closure of this issue.

- **Extremity dose assumed to be equal to whole-body dose (SC&A, 2005, section 5.7.3.2)**

  SC&A finds that section 6.10 (p. 62) of revision 03 of TBD-6 addresses extremity dosimetry. RFP used film dosimetry for extremity dose measurement during 1951–1970, then changed to TLDs in 1971. RFP dosimetrists applied hand-to-wrist ratios ranging from 1.5 to 3 as per work location (p. 62). Additionally, page 31 of TBD-6, revision 03, recommends use of the glovebox factors in DCAS-TIB-0010 (NIOSH, 2011). SC&A recommends closure of this issue.

- **Valid hand-to-wrist ratios (SC&A, 2005, section 5.7.3.3)**

  SC&A finds that section 6.10 (p. 62) of revision 03 of TBD-6 addresses extremity dosimetry. RFP used film dosimetry for extremity dose measurement during 1951–1970, then changed to TLDs in 1971. RFP dosimetrists applied hand-to-wrist ratios ranging from 1.5 to 3 as per work location (p. 62). SC&A recommends closure of this issue.

7.1.3.4 SC&A (2005) section 5.7.4 – industrial x-ray units and neutron generators

Issue: The number of units, energies, periods of operations, operating procedures, etc., needs to be determined to assess the potential radiation exposures, and if radiation doses were under-recorded or missed.

SC&A did not find that revision 03 of TBD-6 specifically addressed industrial x-ray units and neutron generators (maximum energy of 14 mega-electron volts (MeV)). However, the photon and neutron energy intervals that TBD-6 recommends to use in DR include energies likely to be encountered from these radiation sources, which would be required to be shielded for industrial use. A default photon energy interval of >250 keV is listed in table 6-8 (p. 39) and table 6-9 (p. 40), and default neutron energy ranges include 2.0–20 MeV neutrons in table 6-16 (p. 48). SC&A recommends closure of this issue.

7.1.3.5 SC&A (2005) section 5.7.5 – decontamination and decommissioning activities not addressed

Issue: D&D activities present nonroutine situations and unique external and internal monitoring requirements. These issues were not mentioned or addressed in the TBD.

SC&A finds that revision 03 of TBD-6 addressed D&D workers on page 92 of attachment B. Tables 6-2 (p. 29), 6-5 (p. 33), and 6-6 (p. 33) include D&D workers in their recommendations. SC&A recommends closure of this issue.

7.2 Resolution of findings

SC&A's (2005) site profile review summarized these issues in findings 3, 4, 6, 10, and 11 of the "Executive Summary" (pp. 15–18). These five findings were as follows:

- Finding 3: Interpretation of NTA film data for workers who were not included in NDRP reevaluation is not evident; guidance on use of neutron/photon ratios not available.

- Finding 4: Unclear treatment in TBD of personal dosimeter placement and angular dependence.

- Finding 6: The site profile, while incorporating methodologies for assignment of missed dose, has not adequately bound exposure conditions, compensated for calibration errors and technology deficiencies, and addressed possible data integrity issues, all of which may contribute to missed dose.

- Finding 10: Hand and wrist doses are not adequately addressed in the external dosimetry TBD.

- Finding 11: The TBDs (NIOSH, 2004d, 2004g) do not address the potentially significant doses from industrial x-ray and neutron generators for R&D and nondestructive work done at RFP.

As summarized in section 7.1 of this report, SC&A has reviewed the issues covered by these five findings and found that they have been addressed and resolved. SC&A recommends closure of findings 3, 4, 6, 10, and 11.

7.3 General review of ORAUT-TKBS-0011-6, revision 03

SC&A had not performed a general review of the RFP occupational external dose TBD since 2005. Several revisions of TBD-6, new and revised OTIBs applicable to RFP DR, and accepted practices have been developed since revision 00 was issued in 2004 (NIOSH, 2004d). Therefore, SC&A reviewed TBD-6, revision 03 (NIOSH, 2019b), to determine its technical accuracy and applicability to the RFP DR process. The following subsections summarize the results of SC&A's review.

7.3.1 Sections added to revision 03 of TBD-6

TBD-6 has been progressively updated to address RFP issues that have arisen since revision 00 was issued (NIOSH, 2004d). NIOSH added the following sections to accomplish these updates in order to address external DR issues:

- 6.1.3, "Special Exposure Cohort"
- 6.3.2.3, "Shallow Dose Minus Neutron Dose Is Less than Photon Dose"
- 6.3.4, "Interpretation of Dosimetry Data"
- 6.4.5, "Recorded Dose Practices"
- 6.5.5, "Lead Aprons"
- 6.5.6, "Recycled Uranium"
- 6.5.7, "Potential Elevated Background Subtraction"
- 6.5.8, "Badge Reading Policy, 1969 to 1970"
- 6.5.9, "Gammacell 220 Cobalt-60 Irradiator"
- 6.6.1.2, "Dosimeter-Indicated Photon Energy"
  - 6.6.1.2.1, "Pre-1960"
  - 6.6.1.2.2, "1960 to 1970"
  - 6.6.1.2.3, "1970 to Present"
- 6.7.3.4, "Default Neutron-to-Gamma Ratio"
- 6.11, "Attributions and Annotations"

Additionally, NIOSH has expanded sections to further address external dose issues or address issues that had been identified since revision 00 was issued (NIOSH, 2004d). For example, section 6.7.3.3 addressing the NDRP contains addition information concerning neutron dose assignments.

7.3.2 TBD-6 section 6.5.9 – Gammacell 220 cobalt-60 irradiator

NIOSH added section 6.5.9 concerning Co-60 sources to revision 03 of TBD-6. There were two Co-60 sources of exposure in Building 779 at RFP: (1) a Gammacell 220 irradiator in room 218 and (2) a Co-60 orphan source found in room 125.

7.3.2.1 Gammacell 220 irradiator

The Gammacell 220 irradiator was installed in RFP Building 779 in the late 1960s and removed in October 1999. It contained 21,900 curies (Ci) of Co-60 as of April 1971 (Rocky Mountain Remediation Services, 1999, PDF p. 3). The Co-60 sources were sealed and not removable from the unit. There were concerns that the unit may not have been properly monitored to prevent exposure to personnel.

NIOSH addressed this concern in section 6.5.9 of ORAUT-TKBS-0011-6, revision 03 (NIOSH, 2019b, p. 38), as follows:

> No quantitative leak test results are available during or before 1989. However, a 1987 report indicates that of 21 sources (22,249 Ci total activity) surveyed there were no leaking ^{60}Co sealed sources . . . . Therefore, it is assumed that source integrity verification requirements existed sometime before 1989, and that some leak test measurements were conducted. In addition, unmonitored personnel exposure from leaking ^{60}Co sources (including the Gammacell 220) are unlikely. If the Gammacell 220 had leaked, the resulting contamination would have been detected in later surveys, some documentation of which has been captured. Therefore, no additional exposures need to be assessed associated with the Gammacell 220.

The issue of the Gammacell 220 irradiator source has been addressed, resolved, and previously closed.

7.3.2.2 Orphan cobalt-60 source

An orphan Co-60 sealed source was found in a cabinet in room 125 of Building 779 in 1998. Although the source had no marking or other labels, it appeared to be a check source and could not have been associated with the Gammacell 220 in room 218. The orphan source was disposed in November 1998 (RFETS, 1998, PDF pp. 2–4).

At the RFP work group meeting of October 28, 2015 (ABRWH, 2015, p. 31), the work group discussed and closed the Co-60 issues. SC&A finds that the concerns about Co-60 sources in Building 779 at RFP have been addressed, resolved, and closed by the work group.

7.3.3 Tables added to revision 03 of TBD-6

NIOSH added the following tables to revision 03 of TBD-6:

- Table 6-1, “Interpretation of reported data”
- Table 6-3, “Summary of historical recorded dose practices”

- Table 6-7, "Bias correction factors for application to dose received while wearing a lead apron"
- Table 6-20, "RFP lognormal neutron-to-photon ratio values, 1970 to 1976"
- Table 6-21, "ORAU Team-developed neutron-to-gamma ratios"
- Tables in attachment C, "External Coworker Dosimetry Data for Rocky Flats Plant":
  - Table C-1, "Missed external doses"
  - Table C-2, "Lognormal neutron-to-photon ratio values, 1970 to 1976"
  - Table C-3, "Annual external coworker doses for plutonium workers, 1952 to 1970"
  - Table C-4, "Annual external coworker doses for plutonium workers, 1971 to 2005"
  - Table C-5, "Annual external coworker doses for uranium workers, 1952 to 2005"
  - Table C-6, "Annual external coworker doses for plutonium workers, 1952 to 1970, modified in accordance with ORAUT-OTIB-0052"
  - Table C-7, "Annual external coworker doses for plutonium workers, 1971 to 2005, modified in accordance with ORAUT-OTIB-0052"
  - Table C-8, "Annual external coworker doses for uranium workers, 1952 to 2005, modified in accordance with ORAUT-OTIB-0052"

NIOSH discusses the origin and application of the photon, neutron, and nonpenetrating dose values in the tables in attachment C on pages 94–100 of TBD-6, revision 03. The information and data in the tables in attachment C were incorporated from the NDRP analysis and former technical information bulletins that have been previously reviewed by the RFP work group, NIOSH, and SC&A.

7.3.4 Changes in tables from revision 00 to revision 03

SC&A reviewed the information and dose values recommended in the tables in revision 03 of TBD-6 and found that they were correct and in agreement with the previous data in the respective tables in revision 00 of TBD-6, except for the following items.

7.3.4.1 Default neutron energy distribution

The values in the third column of table 6-16 (p. 48) of revision 03 of TBD-6 (reproduced here as table 1) are all less than those in the third column of table 6-14 (p. 31) of revision 00 of TBD-6 (reproduced here as table 2). This results in the dose multiplier values being corresponding less in the fourth column; therefore, slightly less neutron dose would be assigned using the values in table 6-16 of revision 03 compared to using the values in table 6-14 of revision 00 of TBD-6.

Table 1. TBD-6, rev. 03, table 6-16, "Default neutron energy distribution"

Neutron energy intervals	Fraction of dose (NCRP 38)	Dose multiplier (ICRP 60)	Dose multiplier[a]
<10 keV	0.035	2.13	0.0755
10 - 100 keV	0.017	1.86	0.0309
0.1 - 2.0 MeV	0.687	1.91	1.31
2.0 - 20.0 MeV	0.261	1.32	0.345
>20 MeV	0	None	None

a Multiply the reported dose by these factors to determine the ICRP 60 neutron dose for each neutron energy interval.

Source: Reproduced from NIOSH (2019b), p. 48.

Table 2. TBD-6, rev. 00, table 6-14, "Default neutron energy distribution"

Neutron energy intervals	Fraction of dose (NCRP 38)	Dose multiplier (ICRP 60)	Dose multiplier[a]
<10 keV	0.035	2.40	0.0851
10 - 100 keV	0.017	2.06	0.0342
0.1 - 2.0 MeV	0.687	1.98	1.36
2.0 - 20.0 MeV	0.261	2.50	0.654
>20 MeV	0.00	--	0.00

a Multiply the reported dose by these factors to determine the ICRP 60 neutron dose for each neutron energy interval

Source: Reproduced from NIOSH (2004d), p. 31.

Observation 1: Different neutron dose multiplier factors need clarification

The reason for the change in neutron dose multiplier factors listed in table 6-16 of revision 03 compared to table 6-14 of revision 00 needs clarification.

7.3.4.2 Tables 6-18 and 6-19 of revision 03

In table 6-18 (p. 50) of revision 03, the fourth column lists a LOD value of 226 mrem for 1962 and 1963. However, using the formula in column two of table 6-18 and a background blank value of 16 tracks per 10 square millimeters, the correct value would appear to be 369 mrem, which would also apply to the second column of table 6-19 (p. 51) for 1962 and 1963.

Observation 2: LOD values for 1962 and 1963 need clarification

The reason for recommending 226 mrem instead of the calculated value of 369 mrem in tables 6-18 and 6-19 needs clarification.

7.3.4.3 LOD values for 2004 and 2005

LOD values for photons in table 6-11 (p. 43), for neutrons in table 6-19 (p. 51), and for betas in table 6-23 (p. 58) of TBD-6, revision 03, are recommended for the years 2004 and 2005, which is an update from the corresponding tables in revision 00 of TBD-6. While the recommended LOD values are reasonable, they are an addition to the recommended values for 2003 as listed in revision 00. Therefore, references or discussion concerning where the 2004 and 2005 LODs were obtained are needed.

Observation 3: References for LOD values for 2004 and 2005 are needed

References for recommending photon, neutron, and beta LOD values for 2004 and 2005 are needed.

7.3.5 Missing or incorrect information

SC&A found that the following references were used in the text but were not listed in the reference section on pages 64–69:

- Page 10: Sebelius (2013)
- Page 11: NIOSH (2013)
- Page 94: NIOSH (2006)

SC&A found that the caption for table C-8 given in the list of tables at the bottom of page 93 should use the phrase "uranium workers" not "plutonium workers," per the actual caption for table C-8 on page 108.

7.4 Summary and conclusions for TBD-6

SC&A summarized the issues previously presented in a narrative form in SC&A's (2005) review of TBD-6, revision 00 (NIOSH, 2004d), to determine if the issues were addressed in TBD-6, revision 03 (NIOSH, 2019b), other external dose-related documents, or currently accepted practices. SC&A found that the three previously identified major issues (external dose calculations and methods, neutron dosimetry and exposures, and other potential exposure concerns) and their associated subtopics have been addressed and resolved and, therefore, recommends closure of findings 3, 4, 6, 10, and 11 and all related issues in these findings. The issues of the Gammacell 220 irradiator and Co-60 orphan source had been addressed, resolved, and previously closed.

SC&A performed a general review of TBD-6, revision 03, and did not identify any findings but did have three observations concerning clarifications of changes, or additions, made in the tables. SC&A's review of TBD-6, revision 03, indicated that NIOSH used the information available to provide reasonable occupational external DR considering some of the limited information and data available in the early years, especially for neutron doses.

SC&A did note (1) that several references used in the text were not listed in the references section, and (2) the incorrect use of "plutonium" instead of "uranium" in the appendix C list of tables entry for table C-8 on page 93.

8 Overall Conclusions

SC&A reviewed five RFP TBDs that have been revised as of January 2021 to determine if previous issues identified by its original 2005 site profile review were resolved and addressed by NIOSH. SC&A also performed a general review of these documents.

SC&A found that for TBD-2, all previous issues have been addressed in revision 02 (NIOSH, 2020a). A general review found this TBD revision to be more comprehensive in scope and depth and to include more details on site closure and decommissioning, as well as information about

specific operations involving recycled uranium and U-233. SC&A recommends closure of finding 8 (inadequate information regarding recycled uranium) from its 2005 review, based on updated treatment of the issue in the internal dose TBD (TBD-5). However, no such updated assessment was noted in TBD-2, and it is recommended that TBD-2 be revised to be consistent with TBD-5. SC&A considers all other identified issues resolved.

For TBD-3, SC&A similarly found that all previous issues as expressed in finding 5 (which was concerned with radiation exposure from occupationally necessitated medical x-ray) have been addressed and resolved in revision 03 of TBD-3 (NIOSH, 2019a) and recommends closure. A general review of this most recent revision did not identify any findings, although some incorrect tables were listed in the publication record on page 2 of the TBD.

SC&A's review of TBD-4, revision 03 (NIOSH, 2020b), found that the revised TBD addressed and resolved SC&A's finding 9 from its original 2005 site profile review regarding inadequacies in addressing potential environmental exposure from routine and ambient airborne releases and resuspension of contaminated soil at RFP. SC&A found that NIOSH (1) has added more specific information and guidance about the contribution of resuspension of soil contaminants for occupational environmental exposures and (2) provides better justification of its basis in available site monitoring data. Therefore, SC&A recommends closure of this finding.

SC&A also found satisfactory the TBD-4, revision 03, treatment of other issues, such as use of the RATCHET air dispersion model and consideration of potential environmental DR issues stemming from the 1989 FBI investigation.

For TBD-5, SC&A's original site profile review (2005) had three findings and one observation, and later work group proceedings had identified additional concerns for internal exposures related to the CML, neptunium, Mg-Th, and tritium. For these later concerns, SC&A, together with NIOSH and the work group, addressed and resolved each of them during work group deliberations and finds that they are adequately incorporated into TBD-5 as appendices.

For finding 1 of its 2005 review (suggested use of urine bioassay MDA values appears low) and finding 2 (TBD lacks definitive direction in some instances), SC&A now finds that NIOSH (2020b) has addressed and resolved them in revision 03 and recommends closure.

For finding 7 (TBD does not consider potential contribution of ingestion pathway), SC&A continues to find a lack of clarity about how ingestion intakes would be handled by dose reconstructors. TBD-5, revision 04 (NIOSH, 2020c), only refers to ORAUT-OTIB-0060, revision 02 (NIOSH, 2018b), on page 22 in reference to selecting solubility type. ORAUT-OTIB-0060 addresses ingestion intakes on pages 16 and 38, both of which refer to OCAS-TIB-009, revision 0 (NIOSH, 2004f). For clarity, SC&A believes that TBD-5 should include recommendations for ingestion intakes or direct reference to the appropriate ingestion-intake-related document. Although SC&A understands that this issue has been resolved in practice, ingestion intakes should be addressed by specific guidance in TBD-5 with reference to OCAS-TIB-009. Therefore, SC&A recommends that this issue remain open until appropriate revisions are made in TBD-5.

For the one observation by SC&A (2005) regarding additional guidance for wound modeling, SC&A finds that additional references are now included, including one recommended in the 2005 site profile review.

The issue of potential internal exposures from the CML had been addressed, resolved, and previously closed.

SC&A reviewed revision 03 of TBD-6 (NIOSH, 2019b), compared it with the issues described in its 2005 site profile review, and determined that the previously identified issues in the five findings (3, 4, 6, 10, and 11) have been addressed and resolved. Therefore, SC&A recommends closure of all TBD-6 findings and issues from SC&A (2005). The five findings were as follows:

- Finding 3 was concerned with the interpretation of NTA film data for workers who were not included in the NDRP. The revised TBD-6 addressed this finding.

- Finding 4 was concerned with the treatment of personal dosimeter placement and angular dependence. The revised TBD-6 addressed this finding by analysis of angular dependence of the monitoring devices.

- Finding 6 was concerned with potential calibration errors, technology deficiencies, and possible data integrity issues that could have contributed to missed dose. The revised TBD-6 addressed these issues.

- Finding 10 was concerned with hand and wrist doses. The revised TBD-6 addressed these extremity doses.

- Finding 11 was concerned with the potentially significant doses from industrial x-ray and neutron generators for R&D and nondestructive work. The revised TBD-6 addressed these issues.

The issue of the Gammacell 220 irradiator and cobalt-60 (Co-60) orphan source was previously addressed, resolved, and closed.

SC&A's general review of the TBD found no further issues but did result in three observations:

1. Use of different neutron dose multiplier factors needs clarification.
2. LOD values for 1962 and 1963 need clarification.
3. References for LOD values for 2004 and 2005 are needed.

Additionally, several other references need to be added, and the attachment C list of tables on page 93 incorrectly substitutes "plutonium" for "uranium" in the table C-8 caption.

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