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ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

A REVIEW OF NIOSH'S PROGRAM EVALUATION REPORT DCAS-PER-061: BRIDGEPORT BRASS COMPANY

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ABBREVIATIONS AND ACRONYMS

Advisory Board or Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
AP	anterior-posterior
AWE	Atomic Worker Employer
BRH	Bureau of Radiological Health
Bq	becquerel
DCAS	Division of Compensation Analysis and Support
DCF	dose conversion factor
DHEW	U.S. Department of Health, Education, and Welfare
DOE	U.S. Department of Energy
dpm	disintegrations per minute
dpm/m^2	disintegrations per minute per square meter
dpm/m^3	disintegrations per minute per cubic meter
DR	dose reconstruction
FDA	U.S. Food and Drug Administration
FUSRAP	Formerly Utilized Sites Remedial Action Program
GM	geometric mean
GSD	geometric standard deviation
H	effective dose
Hp(10)	personal dose equivalent
H_T	organ dose equivalent (for organ T)
HASL	Health and Safety Laboratory
ICRP	International Commission on Radiological Protection
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron volt
LOD	limit of detection
MCNPX	Monte Carlo N-Particle eXtended
MeV	mega-electron volts
µg	microgram
mrad	millirad
mrem	millirem
mrad/hr	millirad per hour

mR	milliroentgen
mR/hr	milliroentgen per hour
n/cm^2	neutron per square centimeter
NIOSH	National Institute for Occupational Safety and Health
Np	neptunium
OCAS	Office of Compensation Analysis and Support
ORAUT	Oak Ridge Associated Universities Team
OTIB	Oak Ridge Associated Universities Team Technical Information Bulletin
pCi	picocurie
pCi/mg	picocurie per milligram
pCi/µg	picocurie per microgram
PEP	program evaluation plan
PER	program evaluation report
PoBe	polonium beryllium (neutron source)
POC	probability of causation
pSv-cm^2/n	pico-Sievert-square centimeter per neutron
Pu	plutonium
RU	recycled uranium
SCDRR	Subcommittee for Dose Reconstruction Reviews
SRDB	Site Research Database
Sv	sievert
Sv/Bq	sievert per becquerel
TBD	technical basis document
Th	thorium
TIB	technical information bulletin
U	uranium
XRD	x-ray diffraction analysis

1.0 STATEMENT OF PURPOSE

The National Institute for Occupational Safety and Health (NIOSH) and the Oak Ridge Associated Universities Team (ORAUT) have assembled a large body of guidance documents, workbooks, computer codes, and other tools to support dose reconstruction (DR). In recognition that these supporting elements may be subject to programmatic revisions, provisions exist for evaluating the effect of such revisions on the outcome of previously completed DRs. Revisions may be prompted by new information, misinterpretation of guidance, policy changes, and/or programmatic improvements.

The process for evaluating potential impacts of programmatic changes on previously completed DRs appears in the procedure OCAS-PR-008, *Preparation of Program Evaluation Reports and Program Evaluation Plans*, Revision 2 (NIOSH 2006a). This procedure describes the format and methodology to be employed in preparing a program evaluation report (PER) and a program evaluation plan (PEP). A PEP describes plans for evaluating specific program details or issues.

A PER provides a critical evaluation of the effect(s) that a given issue/programmatic change may have on previously completed DRs. This includes a qualitative and quantitative assessment of potential impacts. Most important in this assessment is the potential impact(s) on the probability of causation (POC) of previously completed DRs with POCs of <50%; i.e., do the changes increase a claimant's POC above 50% so that he or she may be compensated?

During the 115th full meeting of the Advisory Board on Radiation and Worker Health (the Advisory Board) held on January 25, 2017, SC&A was directed to perform a review of DCAS-PER-061, *Bridgeport Brass Company*, Revision 0 (NIOSH 2015, hereafter referred to as PER-061).

SC&A performs five subtasks in a PER review, each of which is discussed in this report:

Subtask 1: Assess NIOSH's evaluation/characterization of the issue and its potential impacts on DR to ensure that the issue is fully understood and characterized in the PER.

Subtask 2: Assess NIOSH's specific methods for corrective action. In instances where the PER involves a technical issue that is supported by document(s) (e.g., white papers, technical information bulletins [TIBs], procedures) that have not yet been subjected to a formal SC&A review, Subtask 2 will include a review of the scientific basis and/or sources of information to ensure the credibility of the corrective action and its consistency with current/consensus science. Conversely, if such technical documentation has been formalized and previously subjected to a review by SC&A, Subtask 2 will simply provide a brief summary/conclusion of this review process. In this particular PER review, Subtask 2 will also serve as a site profile review for ORAUT-TKBS-0030, *An Exposure Matrix for the Adrian Facility and Bridgeport Brass Company*, Revision 02 (NIOSH 2013b, hereafter referred to as TKBS-0030, Revision 02), because it was never reviewed by SC&A in its entirety.

Subtask 3: Evaluate the PER's **approach** for identifying the potentially affected DRs and assess the **criteria** by which NIOSH selected a subset of potentially affected DRs for reevaluation. The second step may have important implications in instances where the number of previously denied DRs is very large and, for reasons of practicality, NIOSH's reevaluation is confined to a subset of DRs that, based on their scientific judgment, have the potential to be significantly affected by the PER. SC&A will also evaluate the timeliness for the completion of the PER.

Subtask 4: Conduct audits of DRs affected by the PER under review. The number of DRs selected for audit for a given PER will vary. It is assumed that the selection of the DRs and the number of DR audits per will be made by the Advisory Board using case selection criteria recommended by SC&A based on the results of Subtask 2.

Subtask 5: Prepare a written report that contains the results of DR audits under Subtask 4 and SC&A's review conclusions.

2.0 RELEVANT BACKGROUND INFORMATION

SC&A performed a focused review of the technical basis document (TBD) ORAUT-TKBS-0030, *An Exposure Matrix for Bridgeport Brass: Havens Laboratory and Adrian Plant*, Revision 00, also referred to as the site profile or exposure matrix (NIOSH 2005, hereafter referred to as TKBS-0030, Revision 00) in May 2008 (SC&A 2008). Unlike most site profile reviews performed by SC&A on behalf of the Advisory Board, this particular review was authorized by the Subcommittee for Dose Reconstruction Reviews (SCDRR) as a special focused investigation because, at that time, comprehensive site profile reviews were performed only for U.S. Department of Energy (DOE) facilities and not Atomic Weapons Employer (AWE) facilities. Rather, TBDs for AWE facilities were reviewed only to the extent required to evaluate a given DR. The chairman of the SCDRR judged that it was time to begin the process of performing more complete reviews of AWE TBDs, starting with Bridgeport Brass. Administratively, the review of the TBD for Bridgeport Brass was delivered to the Advisory Board as Attachment 1 to the 8th set of DR audit reports, and not as a standalone site profile review authorized by a designated site profile review work group.

SC&A's focused review of the Bridgeport Brass TBD in 2008 (SC&A 2008) contained five findings. Discussions of these findings, including NIOSH's responses, occurred at an SCDRR meeting on March 12, 2009; SC&A evaluated NIOSH's responses and discussed the issues involved in its white paper, *SC&A Follow-Up to NIOSH's Responses to Bridgeport Brass Site Profile Review Findings* (SC&A 2009). These issues were again raised as a subject of discussion during the February 4, 2013, meeting of the SCDRR. As a follow-up, SC&A issued a special memo, *Questions/Status of Bridgeport Brass Findings* (SC&A 2013), explicitly addressing Finding 4, which deals with the statistical issue referred to as "leave-one-out." SC&A concluded that this finding can be withdrawn in recognition of NIOSH adopting a revised method for building a co-worker model based on ORAUT-OTIB-0020, *Use of Coworker Dosimetry Data for External Dose Assignment*, Revision 03 (NIOSH 2011c, hereafter referred to as OTIB-0020).

After these meetings and the publication of the associated technical reports and memo cited above, which were based on TKBS-0030, Revision 00, NIOSH issued ORAUT-TKBS-0030, *An Exposure Matrix for Bridgeport Brass: Havens Laboratory and Adrian Plant*, Revision 01 (NIOSH 2013a, hereafter referred to as TKBS-0030, Revision 01), and then TKBS-0030, Revision 02 (NIOSH 2013b) in 2013. NIOSH then issued PER-061 (NIOSH 2015), evaluating the effect of Revision 02 to the TBD on all previously completed claims, including those first made in Revision 01. In recognition of this history, this SC&A PER review includes:

(1) An assessment of the degree to which TKBS-0030, Revision 02, addresses SC&A's original five findings associated with its review of TKBS-0030, Revision 00, and whether any of the findings can be withdrawn based on a reconsideration of these findings, or whether any were subsequently resolved in other venues.

(2) Because SC&A's review of TKBS-0030, Revision 00, was a focused review, it was limited to specific subject areas and did not address some of the topics included in the TBD, such as exposures to thorium and recycled uranium (RU), and the residual period after operations had ceased. This report includes a summary description of all the

technical areas addressed in TKBS-0030, Revision 00, to establish a baseline against which to compare and address the changes made to the TBD in subsequent revisions.

(3) A technical review of new material contained in TKBS-0030, Revisions 01 and 02 (i.e., a conventional site profile review), including a discussion of the changes from TKBS-0030, Revision 00.

3.0 SUBTASK 1: IDENTIFY THE CIRCUMSTANCES THAT NECESSITATED THE NEED FOR DCAS-PER-061

As explained in the "Publication Record" section of TKBS-0030, Revision 02 (NIOSH 2013b):

> *Revision* [01 was] *initiated to address comments from the Advisory Board Subcommittee on Dose Reconstruction. Updated external unmonitored dose in accordance with ORAUT-OTIB-0020* [NIOSH 2011c]. *Added an internal approach to account for remediation efforts in 1976, 1985, and 1995. Incorporates formal internal and NIOSH review comments.*

and

> *Revision* [02 was] *initiated to address change made by the Division of Energy Employees Occupational Illness Compensation to the DOE facilities website impacting the Bridgeport Brass facility description and time period. Incorporates formal internal and NIOSH review comments.*

These descriptions are very general. More detailed descriptions and assessments of the revisions are provided in Section 4.0 of this report.

4.0 SUBTASK 2: ASSESS NIOSH'S SPECIFIC METHODS FOR CORRECTIVE ACTION

The procedure used in this section to assess NIOSH's methods for corrective action is to first describe the methods used by NIOSH in TKBS-0030, Revision 00, and SC&A's focused review of the TBD (SC&A 2008), and then compare that material to the DR protocols in TKBS-0030, Revision 02. This comparison is then followed by a technical review of the methods, data, and assumptions adopted in TKBS-0030, Revision 02, for performing DRs. This review will result in either a confirmation that the methods are scientifically sound and claimant favorable, or that there are some technical deficiencies that require resolution by the work group and the Advisory Board. As noted below, SC&A has only one finding and several observations.

As a preface to the review, SC&A found that no substantive changes were made to the dates and nature of AWE operations at the Havens Laboratory or the Adrian Plant that appear in the Bridgeport Brass TBDs. However, some changes were made to the methods used to reconstruct internal, external, and occupational medical exposures during AWE operations and exposures during the residual period.

4.1 INTERNAL DOSE RECONSTRUCTION DURING OPERATIONS

4.1.1 Revision 00 to ORAUT-TKBS-0030

As described in TKBS-0030, Revision 00, (NIOSH 2005) and SC&A's focused review (SC&A 2008), air monitoring and bioassay data are available for use in DR for many workers at Bridgeport Brass. These workers may have been involved in a broad range of activities associated with the extrusion operations and handling of rods that generated fumes and oxide particulates of natural, slightly enriched, and RU, as well as thorium. These data, along with process knowledge, such as uranium enrichment levels, the quantities and types of RU, computer-assisted telephone interviews, and job categories, were used to reconstruct the internal doses to workers at Bridgeport Brass.

Uranium bioassay data, expressed in units of milligrams per liter of urine, were used as the starting point for reconstructing the internal dose and for building a co-worker model for workers who had limited or no bioassay data. TKBS-0030, Revision 00, converted the observed mass concentrations in urine to activity concentrations using the bounding assumption that the uranium had an enrichment level of 2% (i.e., 1,616 picocuries (pCi) uranium (U) per mg, as opposed to 683 pCi/mg for natural uranium). The TBD also used the conventional and claimant-favorable assumptions that all the uranium was U-234 and chose the form of uranium that is limiting for the organ of concern (i.e., Type S for lung dose and Type M for other organs and tissues).

Because of limitations in the completeness of the uranium bioassay data, NIOSH elected to pool the bioassay data and select an upper-end uranium mass concentration in urine to derive the annual intake rates for Type S and Type M uranium for the Havens Lab and Adrian Plant. These values are provided in Table 3-9 of TKBS-0030, Revision 00. SC&A reviewed the available bioassay data and found the values chosen by NIOSH to be reasonably bounding. SC&A also compared the derived default uranium intake rate based on bioassay data with air sampling data and found that the air sampling data were compatible with the selected default intake rates based on bioassay data.

Notwithstanding these generally favorable findings, SC&A's review of TKBS-0030, Revision 00, identified one area of concern dealing with limitations in the amount bioassay data associated with the pre-1960 time period. Our review revealed that the bioassay data set heavily emphasized the post-1960 time period and may not be representative of the pre-1960 time period, especially considering that the historical record indicates continuing problems with dust accumulations at the Adrian Plant in areas where uranium was extruded through 1956; these problems were subsequently corrected. In its review of Revision 00 to the TBD, SC&A acknowledged that the importance of this issue was somewhat lessened by the conservative assumption that all intakes assumed 2% enriched uranium, when many exposures appear to have been to natural uranium. SC&A, therefore, had the following finding: "*The site profile would benefit from additional analyses that demonstrate that the default intake rates adopted in the exposure matrix are claimant favorable for early operational time periods and job categories*" (SC&A 2008, Finding 1, page 5).

Upon further consideration, SC&A would like to withdraw this finding, as the use of the upper 95th percentile of the bioassay data, coupled with the assumption that all internal exposures assumed 2% enriched uranium, provide a level of assurance that the assigned internal exposures during the early years, though based on a relatively limited amount of bioassay data, remain claimant favorable because of the use of these bounding assumptions**. This is a subjective judgment made by SC&A and is certainly an appropriate topic for discussion with the subcommittee.**

SC&A's examination of and commentary on TKBS-0030, Revision 00, was the result of a focused review performed at the request of the subcommittee; i.e., SC&A limited its review of internal exposures to uranium inhalation. However, the TBD also addressed distinctions between the Adrian and Havens plants, thorium intakes, RU, and the residual period, which were not addressed in SC&A's focused review. These subjects are covered in the following sections of this report.

In order to derive intakes of radionuclides other than uranium, Revision 00 to TKBS-0030 uses the activity fractions shown in Table 3-8 (reproduced here as Table 1).

Table 1. Reproduction of Table 3-8, "Assumed Activity Fractions of Other Radionuclides Relative to Uranium (pCi other radionuclides per pCi uranium)" (NIOSH 2005)

Uranium	Th-228	Th-232	Pu-239	Np-237
1	0.0161	0.0161	0.00246	0.00182

The RU activity fractions for plutonium-239 (Pu-239) and neptunium-237 (Np-237) are based on Hanford RU data, and the thorium-232 (Th-232) and Th-238 fractions are derived from the assumption that the Th-232 mass intake was 10% of the uranium mass intake based on the mass throughput of the two radionuclides at Bridgeport Brass. Other progeny in the Th-232 decay chain are ignored because of their very small potential to contribute to the dose. These topics are addressed as part of SC&A's review of the methods adopted for the reconstruction of internal exposures in Revision 02 to TKBS-0030, which follows.

4.1.2 Revision 02 to ORAUT-TKBS-0030

This section describes the changes that were made in Revision 02 to TKBS-0030 with respect to reconstructing internal doses during the operations period, and includes SC&A's assessment. No changes were made to the assigned radionuclide intake rates except for the intake of isotopes associated with RU. Revision 02 to the TBD adopts the RU concentration of Battelle-TBD-6000, *Site Profile for Atomic Weapons Employers that Worked Uranium Metals*, Revision 01 (NIOSH 2011a, hereafter referred to as TBD-6000), which provides generic methods and data for AWEs. SC&A previously reviewed Revision 01 to TBD-6000 and all issues have been resolved. Hence, SC&A concurs with the values used in Revision 02 to TKBS-0030 to derive uranium and RU intake rates.

Thorium operations and the default intake rates of Th-232 and its progeny adopted in TKBS-0030, Revision 00, were not addressed in SC&A's focused review (SC&A 2008). SC&A notes that NIOSH's treatment of thorium remains unchanged through Revision 02 to TKBS-0030. Information in the historical records for Bridgeport Brass indicates that thorium was processed during the 1950s at both the Havens and the Adrian facilities. However, there are no environmental or personnel monitoring records pertaining to thorium. The following is an excerpt from Section 3.2 of all the revisions to the Bridgeport Brass TBD (NIOSH 2005, 2013a, and 2013b):

> *It is not clear when thorium work started at Havens Laboratory. The Adrian Plant records indicate that extrusion of thorium most likely started on May 25, 1954. Records indicate that thorium work might have slowed down or ceased after 1955, but no inventory records were found after this date. AEC records indicate that there was continuing interest in thorium after 1955. It is favorable to claimants to assume that thorium processing continued throughout the AEC work periods. To date, no records of thorium air monitoring or bioassay for either site have been found.*

NIOSH recommends assigning unmonitored internal dose from thorium exposure for the entire operation period. In the absence of thorium monitoring data, NIOSH applies the ratio of the processed uranium by mass to processed thorium by mass to the derived uranium intakes. SC&A reviewed the document, *Source and Special Nuclear Materials Accountability Statements* (Dowling 1955), which reports the amount of natural uranium received from July 1, 1953, to June 30, 1954, as 10,821 kg and the amount of thorium received as 190 kg. TKBS-0030, Revision 02, rounds these values to 11,000 kg and 190 kg, respectively, which result in the thorium representing less than 5% of the uranium by mass. For the time July 1, 1954, through May 31, 1955, the amount of normal uranium received was 50,473 kg and the amount of thorium was 1,570 kg. The TBD states: "*To simplify calculations for both Haven Laboratory and Adrian Plant and to account for uncertainty in the relative masses of handled uranium and thorium, this analysis assumed that the mass of processed thorium was 10% of the mass of processed uranium.*" SC&A agrees that, for dose reconstruction, the assumption that the mass of processed thorium is 10% of the mass of processed uranium is bounding and claimant favorable.

All three revisions to the TBD contain the same assumptions regarding the thorium exposure period at both facilities. Section 3.4 states:

> *At Havens Laboratory, intakes are assumed to be from naturally enriched uranium (0.683 pCi/μg). Thorium intakes should be assumed beginning June 26, 1952. Recycled uranium contaminants are included after 1952. There are two periods of operational exposure:*
>
> - *November 8, 1950, to December 31, 1950; and*
> - *June 26, 1952, to August 27, 1962.*
>
> *The 1950 intake is assigned to all Havens Laboratory workers, whose covered work period overlapped the 1950 intake period. For unmonitored work periods or workers, two exposure scenarios for Havens are shown in Table 3-9. The first can be used for unmonitored internal exposures that did not include work during the period from April 15 to 21, 1961. The second scenario accounts for the higher exposures during the period from April 15 to 21, 1961, and should be used for unmonitored exposures that overlapped this period.*
>
> *At Adrian Plant, intakes are likely to be from natural (0.683 pCi/μg) or low enriched (0.973 or 1.616 pCi/μg) uranium and thorium. Only natural uranium enrichment is likely before 1960. The default enrichment assumption for 1960 through 1962 is 2% (1.616 pCi/μg).*
>
> *There is one period of operational exposure: May 25, 1954, to December 31, 1962.*
>
> *At Adrian Plant, thorium and recycled uranium contaminant intakes should be assumed for the entire operational exposure period.*

The guidance for unmonitored thorium doses from Revision 02 to TKBS-0030 (page 25) is as follows:

> *To account for unmonitored thorium exposures at Havens Laboratory and Adrian Plant, it is assumed that the thorium intake is equal to 10% of the uranium intake by mass for the same period. Natural uranium has a lower specific activity than enriched uranium, so it is favorable to claimants to assume natural uranium when determining the relative activity of thorium. To determine the relative activities of uranium to thorium, the specific activity of ^{232}Th is divided by the specific activity of natural uranium and multiplied by 10%. This results in a relative ^{232}Th -to-uranium intake fraction by activity of 0.0161. Further, it is assumed that ^{232}Th is in equilibrium with ^{228}Th, so the ^{228}Th to uranium activity fraction is also 0.0161. Exposure from ^{228}Ra (half-life of 5.75 years) is assumed to be insignificant because the thorium was likely to have been recently produced and because the dose conversion factor is small compared to thorium. Thorium intakes are summarized in Table 3-8.*

Revision 00 to TKBS-0030 uses the uranium air concentrations to derive the uranium intakes, but in Revisions 01 and 02, the uranium intakes are derived using bioassay data. Table 3-8 of both Revisions 01 and 02 (reproduced below as Table 2) lists the estimated thorium intake rates based on the uranium intakes.

Table 2. Reproduction of Table 3-8, "Estimated Thorium Intake Rates Based on Uranium Intakes" (NIOSH 2013a and 2013b)

[Location]	Start	End	Intake mode	Radionuclide	Absorption type	Exposure rate (pCi/d)
Havens Plant	11/8/1950	12/31/1950	Inhalation	Th-232 & Th-228	M, S	3.33E0
	11/8/1950	12/31/1950	Ingestion	Th-232 & Th-228	(a)	6.96E-2
	6/26/1952	8/27/1962	Inhalation	Th-232 & Th-228	M, S	1.19E-1
	6/26/1952	8/27/1962	Ingestion	Th-232 & Th-228	(a)	2.48E-1
Adrian Plant	5/25/1954	12/31/1962	Inhalation	Th-232 & Th-228	M, S	1.19E1
	5/25/1954	12/31/1962	Ingestion	Th-232 & Th-228	(a)	2.48E-1

SC&A finds this approach to reconstructing internal exposures to thorium to be scientifically sound and claimant favorable.

4.2 EXTERNAL DOSE RECONSTRUCTION DURING OPERATIONS

4.2.1 Revision 00 to ORAUT-TKBS-0030

Because of limited worker-specific records, NIOSH uses pooled 2-week film badge dosimetry data from the Adrian Plant and Havens Laboratory as the basis for constructing a co-worker model to derive annual external doses to unmonitored workers during AWE operations. The specific methodology is described in Section 4 of TKBS-0030, Revision 00(NIOSH 2005). This methodology includes the evaluation of existing external radiation dosimetry and the extrapolation and application of the results to individuals who were not monitored over the time periods of interest. Minimal personnel monitoring data are pooled across several time periods and analyzed to determine geometric means (GMs) and geometric standard deviations (GSDs). The 95th percentile doses are used to estimate the doses of non-monitored workers during the time periods in question.

Using these assumptions for the Adrian Plant, NIOSH derives an external electron dose distribution with a GM of 31.2 millirad (mrad) per nominal 2-week period for unmonitored workers, with a GSD of 3.83. For photon doses, the GM per 2-week monitoring period is 4.27 millirem (mrem) and the GSD is 3.70. For the Havens Laboratory, the GM photon dose per 2-week monitoring period is 3.31 mrem and the GSD is 3.57. For the beta measurements at Havens, the GM dose per 2-week monitoring period is 6.99 mrad and the GSD is 5.46.

NIOSH elected to derive annual 95th percentile doses for penetrating and non-penetrating external exposures at both facilities and use these as a constant value for reconstructing annual external doses. These derived assigned doses are provided in Table 4-1 of Revision 00 to TKBS-0030. For the Havens Laboratory, typical annual penetrating and non-penetrating doses are 0.335 rem/yr and 1.666 rem/yr, respectively. For the Adrian plant, typical penetrating and non-penetrating doses are 0.452 rem/yr and 3.558 rem/yr, respectively.

In its original review of Revision 00 to TKBS-0030, SC&A expressed some concern that the assigned doses for each year from pooled data may not be representative of all unmonitored workers and job categories. However, SC&A believes that the selection of the 95th percentile of the dose distribution for each year for each facility reduces the importance of this concern.

In its focused review of Revision 00 to TKBS-0030 (SC&A 2008), SC&A independently derived the external doses but limited its analysis to the Adrian Plant. The evaluation determined that "*default 95th percentile doses adopted by NIOSH for both non-penetrating and penetrating radiation are low by about a factor of 2*" (SC&A 2008, Finding 2, page 5). SC&A believes the approximate two-fold difference has to do with correlation issues, as explained in the report (SC&A 2008, page 25):

> *TKBS-0030* [NIOSH 2005] *states that "correlation" was assumed in the Crystal Ball simulation. Assumptions regarding correlation are very important to the construction of an exposure matrix, because it affects the degree of conservatism inherent in the derivation of default upper-end exposures. For example, let us assume we have film badge data for a number of time periods, and that the data set for each time period has a log-normal distribution. Using these data, it is possible to derive one distribution representing the entire dataset. However, there are a number of ways this can be accomplished, depending on whether one assumes that the exposures experienced by each worker are independent as a function or time or that the exposures a given worker experienced in one time period are correlated to the exposures that the worker experienced in other time periods. Lacking evidence to the contrary, the usual assumption would be that most workers performed the same or similar jobs repeatedly, indicating that the assumption of correlation is appropriate for conducting the Crystal Ball simulation. If "no correlation" is assumed, the high-end default annual exposures would be lower, because the simulation would be based on the assumption that the exposures associated with each* [2-week] *film badge change-out period are independent. Hence, under the "no correlation assumption," a worker might receive a high-end exposure during one change-out period and a lower-end exposure the next. As a result, the spread of the simulated distribution of annual doses is markedly reduced if non-correlation among the doses for each change-out period is assumed when building an exposure matrix. As is demonstrated below* [please see SC&A 2008 for more detailed discussion of this issue], *though the site profile states that correlation was assumed, our independent derivation of the dose distributions revealed that correlation was* ***not*** *assumed. As a result, we believe that the upper-end doses might have been underestimated by a factor of about 2.*

In addition to issues associated with correlation, SC&A 2008 found that "*exposures to localized parts of the body, such as the hands and forearms, from non-penetrating radiation for some workers could be missed by a film badge monitoring program and, as a result, the exposure matrix may not be claimant favorable for some workers*" (SC&A 2008, Finding 3, page 6). This conclusion arises from the fact that the non-penetrating dose assignments are based on film badge data and do not take into consideration situations where workers' hands and forearms, and perhaps other parts of the body, were in close proximity to a beta source. Under these circumstances, the doses to skin in close proximity to a beta source (such as uranium) may be substantively underestimated when based on film badge data.

Although neutron exposures are included in Section 4.0 of Revision 00 to TKBS-0030, SC&A's review of that document did not address the subject. The TBD (page 27) states:

> *Neutron doses were reported for periods ending May 1, 1960 through September 4, 1960 and from December 25, 1960 through September 17, 1961 (except the week ending March 5, 1961). It was noted that calculated neutron doses were based on the assumption of a fast neutron source term, and that 1 rem equaled 14E6 neutrons/cm^2. In the early periods, results were reported as less than 0.8E6 neutrons/cm^2, which using the conversion above, is consistent with the 60 mrem reporting threshold. Neutron dosimeters had an unshielded portion and a cadmium-shielded portion. All 938 reported results for the shielded portion of the dosimeter were less than 60 mrem. Five of the 938 results for the unshielded portion of the dosimeter equaled or exceeded the detection threshold (one other result reported neither as nonzero or "less than" was 0.3E6 neutrons/cm^2), and the maximum result was 1E6 neutrons/cm^2, which would equal about 100 mrem. Neutron dosimeters were calibrated with a polonium beryllium (PoBe) source. This analysis concludes that the reported neutron dose results are consistent with the assumption of no significant neutron exposures and the 0.5% rate of positive results is not necessarily indicative of workplace neutron exposures.*

4.2.2 Revision 02 to ORAUT-TKBS-0030

Gamma-Beta Exposure

Although Revision 02 to TKBS-0030 (NIOSH 2013b) uses the same original film badge data from the Adrian Plant and Havens Laboratory as previous TBD revisions, the methods used to develop a co-worker model were substantially revised using the methodology of OTIB-0020. Table 4-1 of Revision 02 to the TBD (reproduced as Table 3 below) provides the external dose co-worker doses, as follows:

Table 3. Reproduction of Table 4-1, "External Dose (rem) for Unmonitored Workers" (NIOSH 2013b)

Percentile	Havens		Adrian	
	Gamma	Beta	Gamma	Beta
50th	0.520	0.798	0.596	1.495
95th	1.225	2.932	1.221	5.832

As described above, for the Havens Laboratory, typical annual penetrating and non-penetrating doses adopted at the 95% confidence level in Revision 00 to TKBS-0030 are 0.335 rem/yr and 1.666 rem/yr respectively. For the Adrian plant, 95% confidence level doses for penetrating and non-penetrating doses are typically 0.452 rem/yr and 3.558 rem/yr, respectively. As may be noted, the assigned doses at the 95% confidence level in Revision 02 are several times higher than those in Revision 00. In addition, Revision 02 to the TBD explicitly addresses extremity doses, stating the following (page 29): "*If applicable, adjustments to the whole-body dose should be made for the extremities (e.g., hand and forearms) to account for geometry issues using the guidance in DCAS-TIB-0013, Selected Geometric Exposure Scenario Considerations for External Dose Reconstruction at Uranium Facilities (NIOSH 2010…).*"

TKBS-0030, Revision 02, assumes that, for the purpose of estimating doses from external exposure to uranium, most photons have energies in the 30–250 kiloelectron volt (keV) range. While this statement is correct with respect to **photon fluence**, we note that 87% of the **photon energy flux** is from photons with energies >250 keV (see below). Because absorbed dose is expressed in terms of deposited energy, the energy flux is the more relevant metric.

In conjunction with a scoping analysis to estimate the relative neutron dose from a representative external exposure scenario described below, we used Monte Carlo N-Particle eXtended (MCNPX) to calculate the personal dose equivalent, Hp(10), at distances of 1 foot and 1 meter from a uranium rod, 77 inches long and 1.405 inches in diameter. These are the average dimensions of the uranium rods received from Fernald at the Havens Laboratory in 1954, after cutting to the desired lengths. The MCNPX analysis shows that an average of 90% of the doses are from photons with $E\gamma > 250$ keV.

Although TKBS-0030, Revision 02, acknowledges that the photon radiation from uranium metal would have a hardened spectrum, it maintains that assigning the doses to photons in the 30–250 keV range is claimant favorable. A review of the factors for converting Hp(10) to organ dose listed in OCAS-IG-001, *External Dose Reconstruction Implementation Guideline*, Revision 3 (OCAS 2007), shows that for 13 of the 17 organs listed, the DCFs for the anterior-posterior (AP) orientation are higher for photons with $E\gamma > 250$ keV.

Observation: SC&A recommends that NIOSH assume photon energies >250 keV, except when calculating doses to the surface of bone, the testes, the thymus, and the thyroid.

Based on this discussion and comparison of the assigned external penetrating and non-penetrating doses in Revision 00 versus Revision 02 to TKBS-0030, we find that, with one exception, the external penetrating and non-penetrating doses assigned to workers at Bridgeport Brass during AWE operations in Revision 02 to the TBD are scientifically sound and claimant favorable. In addition, SC&A and the Advisory Board previously reviewed OTIB-0020 (NIOSH 2011c), the version used in support of Revision 02 to the TBD, and all issues are resolved.

The one exception has to do with the assumption that the hardened photon spectrum can be assumed to have an energy spectrum of 30–-250 keV. As discussed above, we believe a more scientifically and claimant-favorable approach for most organs would be to assume the photon energy spectrum to be >250 keV.

<u>Exposure to X-Ray Crystallography</u>

The Havens Laboratory performed x-ray crystallography (also known as x-ray diffraction analysis or XRD) on uranium and thorium samples. According to TKBS-0030, Revision 02 (page 13):

> *There is mention of X-ray crystallography work in the AEC contract to inspect metal samples, but no information about the design or safety precautions of this analytical equipment was found. Late 1958 to 1960 biweekly film badge results for areas specified as "X-ray" were usually reported as <10 mrem.*

TKBS-0030, Revision 02, does not further discuss this radiation source.

Although the TBD assigns photon doses based on film badge dosimetry reports, using either data for individual workers or a coworker model in cases where there are no individual dosimetry data, such readings cannot be used to determine exposures to XRD. Because of the small diameter of secondary x-ray beams from the XRD apparatus, not all radiation received by a worker would be registered on his film badge. Portions of the worker's body, especially the skin, fingers, and upper extremities, could have been exposed to scattered radiation that was not measured by the dosimeters. According to Lubenau et al. (1969, page 741):

> *Personnel monitoring devices, such as film badges, are local radiation recording devices. Results of a film badge worn on the shirt pocket may not be representative of the exposures to the eye or to the hands. Energy response of the devices must be considered.*

Exposure to XRD apparatus was a recognized hazard, as evidenced by the fact that the Bureau of Radiological Health (BRH) sponsored a conference on this topic (Moore et al. 1971). The participants stressed the need for improved monitoring and radiation safety. According to Rudman (1971, page 72): "*A number of manufacturers have recently (within the last five years) marketed special shutter assemblies that include various fail-safe features. However, there are still very many older x-ray units in operation and these must be checked very carefully*." This need would have been even more acute 10 years earlier—the time of the XRD work at Bridgeport Brass.

In the case of the Carborundum Company, another AWE site, SC&A identified a former worker who had performed XRD operations during the covered period at that site. This worker provided sufficiently detailed information about use of the XRD apparatus that it was possible to construct an exposure scenario that bounded the radiation exposures from this source. NIOSH should attempt to identify former workers or other data sources that would enable the construction of a bounding x-ray crystallography exposure scenario for Bridgeport Brass.

Neutron Exposure

Sections 4.0 of TKBS-0030, Revisions 01 and 02, include the same discussion of neutron doses as Revision 00, with only minor editing changes; the discussion is reproduced in the preceding section of this report. SC&A notes that a letter of March 9, 1961 (Grella 1961), from Bridgeport Brass to the Atomic Energy Commission (AEC) reports that two types of film badge holders and film inserts were supplied to the Adrian, Michigan, plant by Controls for Radiation, Inc.: a beta-gamma badge and one that also included a neutron filter (strip of cadmium) and a criticality monitoring foil (strip on indium). The Bridgeport, Connecticut, plant badges just recorded beta-gamma radiations (Grella 1961).

Another letter, dated January 16, 1963 (Jefferson 1963), from Bridgeport Brass to the AEC summarizes the total number of badges used in fiscal year 1962 at two sites: The Havens Lab (which had moved to Seymour, Connecticut) used 190 beta-gamma badges; and the Adrian, Minnesota, plant (which had moved to Ashtabula, Ohio) used 460 beta-gamma badges and 260 neutron badges (Jefferson 1963). This information about the badging practices supports the conclusion that at least some of the Bridgeport Brass employees were monitored for neutron exposures some of the time.

SC&A wanted to investigate several TBD claims related to neutron monitoring but was hampered by the TBD (in the previously quoted paragraph) not citing sources for neutron dose reports (938 results), the distribution of dose values, and the conversion factor for fast neutrons of 1 rem equaling 1.4×10^{6} neutrons/cm^2. SC&A was unable to locate the data sources in the Site Research Database (SRDB). Nonetheless, SC&A's understanding of neutron doses associated with plants that worked with natural or low-enriched uranium metal and oxides (natural uranium in the Havens plant and up to 2% enrichment in the Adrian plant, as noted in AEC 1960) and their short-lived progeny supports the TBD's conclusion that the potential penetrating neutron dose (from spontaneous fission and alpha-n reactions) is negligible compared to that from gamma radiation.

SC&A independently derived its own neutron fluence-to-dose conversion factor to compare to NIOSH'S claim that 1 rem equals 1.4×10^{7} neutrons per square centimeter (n/cm^2) and found that the claim is supported. Table A.5 of ICRP Publication 116, *Conversion Factors for Radiological Protection Quantities for External Radiation Exposures* (ICRP 2010), gives a conversion factor for 1 mega-electron volt (MeV) monoenergetic neutrons with AP geometry (i.e., the subject is facing the incoming neutrons) as 301 pico-sievert-cm^2/neutron (pSv-cm^2/n). Converting units to allow comparison to the NIOSH number:

$$(301\ pSv\text{-}cm^2/n) \times (100\ rem/Sv) \times (1.00\times10^{-12}\ rem/pico\text{-}rem) = 3.01\times10^{-8}\ rem\text{-}cm^2/n.$$

Inverting this number yields 1.4×10^{7} n/cm^2 per rem, which is the value used by NIOSH.

This is the conversion factor for effective dose (often denoted as H), which must be converted to organ dose equivalent (often denoted as H_T, where T represents a particular tissue or organ) to determine damage to that organ. Appendix A to OCAS-IG-001 (NIOSH 2007) provides extensive neutron DCFs for many organs in units of rem/neutron per cm^2. For example, the appendix gives a value of 3.238×10^{-8} rem to the stomach per neutron/cm^2 for AP geometry for neutrons with energies ranging from 0.1 to 2 MeV. This is consistent with the values in ICRP Publication 116 (ICRP 2010).

Section 4.0 of the site profile states that the maximum neutron dosimeter reading of the 938 values over the reported period corresponds to a fluence of 1×10^{6} n/cm^2, or a dose of about 100 mrem per 2-week change-out. SC&A acknowledges that NIOSH could have assigned a bounding value of annual neutron dose of 100 mrem per change-out (i.e., 2-week period) × 26 change outs- per year, which would equal 2.6 rem/yr. This is not an insignificant annual dose as compared to the annual beta and gamma doses described above (i.e., approximately 1 rem/yr assigned for photon doses). However, SC&A believes that the potential for neutron exposures of this magnitude is implausible at both the Havens Laboratory and the Adrian Plant because there are no reactors, sources of highly enriched uranium, or uranium nitrate or uranium hexafluoride (both of which could have been associated with alpha/n reactions). Hence, at these sites, we believe that it would be inappropriate to use the bounding approach described above or the ½-the-minimum-detection-limit approach, which is often used as a default approach for building a co-worker model. In this respect, we concur that the neutron doses at the two facilities were likely a very small fraction of the gamma doses.

One final point, although not stated explicitly in TKBS-0030, Revision 02, NIOSH's claim in Section 4.0, page 29, that "*the reported neutron dose results are consistent with the assumption of no significant neutron exposures and the 0.5% rate of positive results is not necessarily indicative of workplace neutron exposures*," leads SC&A to infer that NIOSH assigns a zero neutron dose to employees; **this assumption should be confirmed or explained by NIOSH**. As described below, SC&A independently estimated the neutron-to-photon ratio associated with spontaneous fission of about 0.01 for uranium metal rods of the types handled at Bridgeport Brass.

TKBS-0030, Revision 02, stated that neutron doses were reported during two periods. Because few of the results listed doses above the limit of detection (LOD), the TBD concluded that there were no significant neutron exposures. To test this hypothesis, SC&A calculated the Hp(10) neutron doses, using the same exposure geometry as for the photon dose analysis described above. We found that the neutron doses constituted 1.1% of the photon doses at the two dose points. Table 4-1 of the TBD lists 95th percentile gamma doses of ~1.2 rem/yr at the two Bridgeport Brass facilities. Applying the neutron-to-photon dose ratio resulting from our MCNPX analyses, we obtain annual neutron doses of ~12 mrem, which could be significant in cases with POCs just under 50%. This result is also consistent with the film badge data, because such dose rates would not be detected by the biweekly neutron film badges, which were reported to have an LOD = 60 mrem. The MCNPX analyses show that ~1% of the neutron doses are from neutrons with energies ≤100 keV, 72% are from 100 keV ≤ En ≤ 2 MeV, and 27% from 2 MeV ≤ En ≤ 20 MeV.

Finding 1. The site profile should assess the neutron doses from spontaneous fission. Although the potential neutron doses from spontaneous fission were likely to be extremely small, as compared to the assigned photon doses, SC&A believes a quantitative estimate of the doses from spontaneous fission should be performed.

4.3 REMEDIATION/RESIDUAL PERIOD

SC&A's original focused review of Revision 00 to TKBS-0030 (NIOSH 2005) did not address the remediation/residual period. Therefore, this section presents a review of the Section 5 of Revision 02 to TKBS-0030 (NIOSH 2013b), which addresses this subject. AWE operations at the Havens Laboratory and Adrian Plant ended in 1962, and both facilities were immediately surveyed following decontamination and the removal of equipment in 1962. Revision 02 to the TBD refers to the *Area Contamination Survey Report* (JG 1962) as the basis for determining that the residual radioactivity in 1962 at both facilities following decontamination was negligible and did not contribute substantively to post-AWE exposures. JG 1962 provides a description of the results of the surveys and may be used to help confirm that there were, in fact, insignificant levels of residual contamination following the termination of AWE operations and the 1962 decontamination activities. Both sites were further surveyed under the Formerly Utilized Sites Remedial Action Program (FUSRAP) implemented in 1977 and 1985.

The documents packaged in SRDB Ref. ID 9588 reveal that, following the 1962 decontamination operations and subsequent surveys, the site met the decontamination criteria at that time. It also appears that a definitive characterization of the residual contamination of the Havens Laboratory was performed as part of the FUSRAP program, which began in August 1980. The results of these surveys revealed both beta and gamma levels at most locations within the range of natural background (i.e., 5–10 microroentgen per hour (µR/hr) gamma and on the order of 0.02 mrad/hr beta). Some spots near walls had residual contamination on the order of twice background. However, the report explains that these slightly elevated readings were due to the slightly elevated levels of naturally occurring radionuclides in the brick walls, rather than from contamination. The maximum alpha contamination observed was at one spot with a level of 156 disintegrations per minute per 100 square centimeters (dpm/100 cm^2) (ORNL 1985).

Included among the files packaged in SRDB Ref. ID 9588 is correspondence between the Health and Safety Laboratory (HASL) and Bridgeport Brass beginning in 1962. The correspondence provides a wealth of information on the contractual relationship between Bridgeport Brass and the government related to AWE activities. There is also extensive correspondence between the AEC and Bridgeport Brass describing the nature and extent of the AWE activities at the facility beginning in 1950 up through 1962.

Among the correspondence packaged in SRDB Ref. ID 9588 is a memorandum dated October 30, 1964, from A.J. Breslin, Director of the HASL, to John W. Ruch, Director of the Feed Materials Division of Oak Ridge National Laboratory, “Contamination Survey at Reactive Metals, Inc., Seymour, Connecticut” (Breslin 1964). The memorandum states that a radiological survey of the facility revealed that the process areas have been satisfactorily cleaned up of uranium contamination and can be released for unrestricted use. A detailed description of the results of the survey is provided, which is consistent with the summary in Revision 02 to TKBS-0030. Some of the results are as follows:

- Direct alpha: 50% <300 dpm/100 cm^2; 87% <2,000 alpha dpm/100 cm^2; 97% <200 alpha dpm/100 cm^2; max 25,000 alpha dpm/100 cm^2
- Smear alpha: 20 to 90 dpm/100 cm^2
- Highest beta/gamma 0.5 mrad/hr

The Breslin memorandum concludes that the activity levels were quite low. The memorandum also states that they were not aware of any standards at that time to which these measurements could be compared. However, the memorandum references made to “Health Protection Program Review of Special Metals Development Department, Reactive Metals, Inc., Seymour, Connecticut - June 1964.” The memorandum includes many drawings where the results of individual measurements are provided on sketches of the facility. A draft letter from R.J. Hart, Manager, to William E. Sides, Director of Manufacturing of Brass Mill Products, to the manager of the facility refers to a May 1976 report by the U.S. Energy Research and Development Administration clearing Bridgeport Brass from any radiological concerns (Hart [n.d.]). In addition, a letter from Arthur J. Whitman to Andrew Wallo, of The Aerospace Corporation, dated October 23, 1985, states that surveys reveal that Bridgeport Brass can be eliminated from the FUSRAP (Whitman 1985).

Using these data, a crude estimate of the potential exposures can be derived by assuming surface contamination of 90 dpm alpha/100 cm^2. With the DCFs in Table 3.10 of TBD-6000 (NIOSH 2011a), the external photon dose associated with this surface alpha contamination is estimated as follows:

External photon exposure:

$$(90\ dpm/100\ cm^2) \times (3.94\times10^{-10}\ mR/hr\ per\ dpm/m^2) \times (1.00\times10^{4}\ cm^2/m^2) = 3.55\times10^{-6}\ mR/hr$$

This external photon exposure rate is negligible, even assuming 2,000 hours per year of exposure.

Inhalation exposure:

$$(90\ dpm/100) \times (1\times10^{-6}/m) \times (1.00\times10^{4}\ cm^2/m^2) = 9.00\times10^{-3}\ dpm/m^3$$

$$(9.00\times10^{-3}\ dpm/m^3) \times (1.2\ m^3/hr) \times (2{,}000\ hr/yr) \times (7.5\times10^{-5}\ Sv/Bq) \times (1.00\times10^{5}\ mrem/Sv) \times (60\ Bq/dpm) = 10\ mrem/yr$$

SC&A considers this a negligible dose because the assumptions are quite bounding and the resulting dose is very small.

In light of these data and correspondence, and the associated dose calculations, SC&A concurs with TKBS-0030, Revision 02, that any potential exposures during the residual period were negligible, and that exposures associated with decontamination operations were captured by the survey programs and their associated exposure matrix.

4.4 OCCUPATIONAL MEDICAL DOSE

Section 4.1 of Revision 02 to TKBS-0030 (NIOSH 2013b) recommends using the default values in ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* (NIOSH 2011b), to reconstruct occupational medical dose. This revision to ORAUT-OTIB-0006 has been reviewed and accepted by the Advisory Board. Accordingly, SC&A has no comments on the methods used in the TBD with regard to occupational medical dose.

5.0 SUBTASK 3: EVALUATE THE PER'S STATED APPROACH FOR IDENTIFYING THE UNIVERSE OF POTENTIALLY AFFECTED DOSE RECONSTRUCTIONS

Section 3.0 of PER-061 (NIOSH 2015, page 2) states that:

> *In order to evaluate the effect of revision 2 of the TBD on previously completed claims, a search was conducted for all completed claims that had a probability of causation (POC) of less than 50% and employment during the operational period at either site. This search identified 14 claims with employment at the Haven's Lab and 36 claims with employment at the Adrian Facility. All 50 claims had employment during the operational period for the particular site.*
>
> *A new dose estimate was performed for all 50 claims using revision 2 of the TBD as well as all applicable approved dose reconstruction methods. The resulting probability of causation (POC) was below 45% for 47 claims. The POC was greater than 50% for one claim. The remaining 2 claims resulted in a POC between 45% and 50%. For those two claims, IREP was run 30 times at 10,000 iterations per NIOSH procedures. The resulting POC was less than 50% for both claims.*

SC&A concurs with this comprehensive approach to implementing this PER.

6.0 SUBTASK 4: CONDUCT AUDITS OF A SAMPLE OF DOSE RECONSTRUCTIONS AFFECTED BY DCAS-PER-061

SC&A recommends the selection of a sufficient number of claims where the external, internal, and occupational medical DRs can be checked. At a minimum, we recommend three cases with any combination of these three exposure pathways.

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