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ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

DCAS-PER-080, SUBTASK 4

REVIEW OF FIVE CASES REEVALUATED BY NIOSH USING TBD-6000, APPENDIX BB, REVISIONS 2 AND 3

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ABBREVIATIONS AND ACRONYMS

ABRWH or Advisory Board	Advisory Board on Radiation and Worker Health
AP	antero-posterior
AEC	Atomic Energy Commission
CAD	chronic annual dose
CATI	computer-assisted telephone interview
DCAS	Division of Compensation Analysis and Support
DCF	dose conversion factor
DOL	U.S. Department of Labor
DR	dose reconstruction
EE	energy employee
GCS	Granite City Steel
GSI	General Steel Industries, Inc.
H*(10)	ambient dose equivalent
ICD	International Classification of Diseases
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
IREP	Interactive RadioEpidemiological Program
LLI	lower large intestine
mrem	millirem
NCI	National Cancer Institute at the National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT technical information bulletin
PA	postero-anterior
PER	program evaluation report
POC	probability of causation
Ra	radium
R	roentgen
SCPR	Subcommittee for Procedure Reviews
TBD	technical basis document
U	uranium

ULI	upper large intestine
WG	work group

1 BACKGROUND INFORMATION

On June 25, 2007, the National Institute for Occupational Safety and Health (NIOSH 2007a) issued Appendix BB to "Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals." This appendix was a site profile of the General Steel Industries, Inc. (GSI), steel foundry located in Granite City, Illinois. The issuance of the appendix was followed by extensive reviews of this document by SC&A, and meetings and interviews with former GSI employees and their advocates. The ensuing reports were presented first at meetings of the Work Group on Procedure Reviews of the Advisory Board on Radiation and Worker Health (ABRWH),[1] later at the newly formed Work Group on TBD 6000/6001,[2] and at meetings of the full Advisory Board. NIOSH issued detailed responses to the SC&A findings and observations, as well as to the work group recommendations.

On June 23, 2014, following these reviews, NIOSH (2014) issued Appendix BB, Rev. 1, which embodied recommendations of the ABRWH and its Work Group on TBD 6000. The revised appendix was reviewed by SC&A and the work group (WG) and discussed at several WG meetings. It became apparent that further revisions were needed; however, due to the time elapsed since the original Appendix BB, NIOSH (2015) issued a Program Evaluation Report, DCAS-PER-057, based on revision 1, which reevaluated all previously completed claims. The ABRWH Subcommittee for Procedure Reviews (SCPR) tasked SC&A with reviewing this PER. Because SC&A had already performed a detailed review of revision 1, it was only necessary for us to perform a Subtask 4 review of selected cases that had been evaluated by NIOSH. The subcommittee directed SC&A to draft a set of criteria for selecting cases from this PER that embodied a cross section of periods of employment, job categories, and types of cancer. Based on our recommended criteria, the subcommittee asked NIOSH to furnish SC&A four or five cases to review; NIOSH subsequently furnished us five case numbers. SC&A (2016) submitted a Subtask 4 review of DCAS-PER-057 on December 12, 2016, which included four findings regarding incorrect or questionable assignments of workers to job categories that resulted in lower doses and incorrect dates for intake regimes.

In parallel to PER-057, NIOSH continued work on Appendix BB, Rev. 2, addressing SC&A findings on revision 1 and the recommendations of the Work Group on TBD 6000. Revision 2 (NIOSH 2016) was issued on May 26, 2016. Anigstein and Mauro (2016a) reviewed the revised appendix and concluded that NIOSH had resolved eight of the 10 findings on revision 1. NIOSH (2017a) resolved the two remaining findings by issuing Appendix BB, Rev. 3. NIOSH (2017b) then issued DCAS-PER-080, based on revisions 2 and 3, which reevaluated all previously completed claims.

As requested by the SCPR during its meeting by teleconference on November 20, 2017, SC&A submitted a set of criteria for selecting cases for a Subtask 4 review that embodied a cross section of periods of employment, job categories, and types of cancer. NIOSH furnished SC&A five case numbers on January 25, 2018. The objective of the present review is to confirm that

[1] This work group was later redesignated the ABRWH Subcommittee for Procedure Reviews.

[2] In March 2010, this work group was divided into two separate work groups—the Work Group on TBD 6000 and the Work Group on TBD 6001.

cases affected by PER-080 were in fact reevaluated in accordance with revisions 2 and 3 of Appendix BB to TBD-6000 (NIOSH 2016, 2017a).

1.1 GUIDELINES FOR REVIEWING A PROGRAM EVALUATION REPORT

SC&A (2009) drafted a set of protocols for conducting a PER review that were approved by the ABRWH. These protocols specify five subtasks that SC&A may be tasked to perform by the ABRWH, the SCPR, or a cognizant WG. The present assignment is to perform Subtask 4 and, by implication, Subtask 5, which are specified as follows:

- Subtask 4: Conduct audits of dose reconstructions (DRs) affected by the PER under review. The number of DRs selected for audit for a given PER will vary, based on important elements such as (1) the number of target organs and tissues that may be impacted by a PER, and (2) the time period, work location, and job functions that characterize the DR of a claim. (It is assumed that the total number of DR audits for each PER will be determined by the ABRWH, the SCPR, or the cognizant WG, while the actual cases will be selected by NIOSH.)

- Subtask 5: Prepare a comprehensive written report that contains the results of the above-stated subtask, along with our review conclusions.

2 REVIEW OF INDIVIDUAL CASES

In fulfillment of the Subtask 4 guidelines listed above, we audited the five cases selected by NIOSH to represent the DRs that were affected by DCAS-PER-080 (NIOSH 2017b). Our goal was to determine if the exposure scenarios and the resulting DR methodology prescribed in Appendix BB, Rev. 3 (NIOSH 2017a) were applied correctly and if the methodology was consistent with NIOSH practices for other claimants and for other worksites. Because SC&A (2016) had already performed a Subtask 4 review related to Appendix BB, Rev. 1 (NIOSH 2014), which also involved reviewing the DRs for five cases of presumed former GSI workers, it was expeditious to use the same format as that in our previous report in reviewing the new cases.

2.1 CASE [REDACTED]

This section of the report presents the results of an independent audit of a DR performed by NIOSH for an energy employee (EE) who was employed as a [redacted] and a [redacted] at GSI from [redacted] 1963 through [redacted] 1965, which was during the period of Atomic Energy Commission (AEC) operations, and again from [redacted] 1967 through [redacted] 1972, which was during the residual period. [redacted] was diagnosed with [redacted] cancer on [redacted], 2005. The original DR was approved on August 7, 2007. The probability of causation (POC), as listed in the file [redacted], which is found on the PER-080 web page and is accessible via the [redacted], was [redacted]. The POC based on the DR that was revised to conform with the PER was [redacted]. Because the revised POC was >45%, further runs of the Interactive RadioEpidemiological Program (IREP) were performed. As stated in [redacted], "The average PC value of the 99th percentiles from 30 runs with 10000 iterations is [redacted]."

2.1.1 Review of Job Category

Since the EE was employed during the operational period at GSI, the EE's job category is relevant to the DR. The EE was assigned doses to operators. This is an appropriate assignment: as a [redacted] and [redacted], the EE clearly worked inside the plant which, according to NIOSH (2017a), defines the operator category at GSI.

2.1.2 Review of Occupational External Doses

The external photon exposures assigned in this DR were derived in the Excel file [redacted], found on the PER-080 web page.

The [redacted] was selected as the target organ in the present case, in accordance with OTIB-0005 (ORAUT 2012), which listed the [redacted] as the target organ for estimating doses from external exposure in cases of [redacted].

External Photon Doses During 1963–1965

The doses to the [redacted] from external exposure to photon radiation during 1963–1965 were derived from an annual exposure rate of [redacted] as listed by NIOSH (2017a, Table 8), multiplied by [redacted], the effective dose conversion factor (DCF) for converting exposure

to photons in the 30–250 keV energy range, incident in the antero-posterior (AP) orientation, to dose to the [redacted]. The 1963 dose was prorated to reflect the EE's assumed start of employment on [redacted], while the 1965 dose was prorated for the assumed end of the first period of the EE's employment on [redacted]. These doses were entered as fixed values in the IREP input file.

Reviewer's Comment

NIOSH used a fixed value of the DCF to convert exposures to photons to doses to the [redacted]. This would appear to be inconsistent with the directions of OCAS-IG-001 (NIOSH 2007b), which state that an uncertainty distribution about the DCF is appropriate. In the present case, however, the use of fixed values is justified. The results of the MCNPX simulation that constitute the basis of the limiting exposure rate in 1963–1966 show that ~85% of the exposure is from photon energies >250 keV. The maximum DCF for exposure of the [redacted] to photons in this energy range is [redacted]. Use of a DCF of [redacted] thus yields a bounding estimate; there is no need for an uncertainty distribution. NIOSH may wish to include some discussion of the use of fixed values vs. distributions of DCFs in any future revisions of Appendix BB to avoid the appearance of inconsistency with the guidance of OCAS-IG-001. We find that NIOSH correctly assigned doses to the [redacted] from external exposure during the period of AEC operations in accordance with the guidance of NIOSH (2017a).

External Photon Doses During the Residual Period

In accordance with NIOSH (2017a), the DR assigned an exposure rate of [redacted] during the residual period. The exposures were divided equally between photons of energies of 30–250 keV and >250 keV. These exposures were multiplied by the effective exposure-to-[redacted] DCF for photons incident in the postero-anterior (PA) orientation in the applicable energy range: [redacted] for 30–250 keV photons or [redacted] for photons with energies >250 keV. Because the exposure rates were bounding estimates, the DCFs were applied as fixed values according to the explicit direction from NIOSH (2017a) that supersedes the instructions of OCAS-IG-001 (NIOSH 2007b). The 1967 doses were prorated to reflect the start of the EE's second period of employment on [redacted] 1967.

Neutron Doses

The DR used the neutron ambient dose equivalent (H*[10]) rate for organs, other than the skin of the hands and forearms, of 751 mrem/y, listed by NIOSH (2017a, Table 8), to assign neutron doses to the [redacted] for the years 1963–1965. These doses were derived by multiplying the H*(10) rate by [redacted], the H*(10)-to-[redacted]-dose-equivalent DCF for neutrons with energies <10 keV. Anigstein and Mauro (2016b) had found that assigning such DCFs produced claimant-favorable doses to all 14 organs and tissues for which neutron DCFs are listed by NIOSH (2007b). Since such doses constitute bounding estimates, they are appropriately entered as fixed values. The 1963 and 1965 doses were prorated to reflect the beginning and end of the EE's first period of employment: [redacted], 1963–[redacted], 1965.

We verified that all doses to the [redacted] from occupational external exposures were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.1.3 Review of Internal Doses

NIOSH (2017a, Table 10) presented intakes of airborne uranium dust at GSI for the operational period (October 1, 1952–June 30, 1966), while NIOSH (2017a, Table 11) presented the corresponding information for the residual period (July 1, 1966–December 31, 1993). These intakes, both by inhalation and by ingestion, were tabulated in units of dpm/calendar day. The calculated [redacted] doses from alpha rays for each calendar year, from the start of the EE's employment in 1963 until the date of cancer diagnosis in 2005, were listed in the IREP input file, as shown in the Excel file [redacted].

We audited the internal doses to the [redacted] by performing independent calculations using integrated doses derived from the DCAL computer code (ORNL 2006). DCAL is "a comprehensive software system for the calculation of tissue dose and subsequent health risk from intakes of radionuclides or exposure to radionuclides present in environmental media" (Eckerman et al. 2006). This totally independent methodology allows us to audit the doses using the same International Commission on Radiological Protection (ICRP) models and parameters that are employed by the Integrated Modules for Bioassay Analysis (IMBA). We calculated the annual doses from intakes during [redacted], 1963–[redacted], 1965, and during [redacted], 1967–[redacted], 1972, the EE's first and second periods of employment. The doses for each calendar year were calculated, starting on [redacted], 1963, and ending on [redacted], 2005, the day before the cancer diagnosis, using the [redacted] as a surrogate organ for the [redacted].

We found notable relative differences between the NIOSH- and SC&A-calculated doses for some years. These differences were presumed to stem from the methodology in the chronic annual dose (CAD) workbook that assigned the daily intakes during the years of partial exposures uniformly during the entire calendar year, rather than assigning the actual daily intakes during the actual periods of exposure, as will be discussed in greater detail in section 2.2.3 of the present review. However, the total dose calculated for the 42-y period, from the beginning of the EE's employment until the date of diagnosis, was [redacted] mrem in both cases. Given this small value and the good agreement between the total doses, we concluded that the discrepancies in the annual doses would have no significant impact on this case and did not perform any further analyses. We confirmed that NIOSH correctly calculated the total internal dose to the [redacted], which we verified by summing the internal doses listed in the Excel file [redacted].

2.1.4 Review of External Doses from Medical X Rays

In accordance with OTIB-0006 (ORAUT 2011), the EE was assumed to have had one chest x ray during each year of the operational period as part of the annual physical exam. An acute [redacted] dose of [redacted] was assigned for each year, 1963–1965, as a normal distribution, with a standard deviation of 0.0075 rem. This is the dose to the [redacted] from a PA examination through 1970 listed by ORAUT (2011, Table A-7). The standard deviation was computed as 30% of the mean dose, as recommended by ORAUT. We verified that all doses to the [redacted] from medical x rays were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.2 CASE [REDACTED]

This section of the report presents the results of an independent audit of a DR performed by NIOSH for an EE who was employed as a [redacted] at GSI from [redacted] 1962 through [redacted] 1973, which included both the period of AEC operations and the residual period. The EE was diagnosed with [redacted] cancer on [redacted], 1994. The original DR was approved on [redacted], 2007. The POC, as listed in the file [redacted], was [redacted]. The POC based on the DR that was revised to conform with the PER was [redacted]. Because the revised POC was >45%, further IREP runs were performed. According to the file [redacted], "The average PC value of the 99th percentiles from 30 runs with 10000 iterations is [redacted]."

2.2.1 Review of Job Category

Since the EE was employed during the operational period at GSI, the EE's job category is relevant to the DR. The EE was assigned doses to operators. This is an appropriate assignment: as a [redacted], the EE clearly worked inside the plant which, according to NIOSH (2017a), defines the operator category at GSI.

2.2.2 Review of Occupational External Doses

The external photon exposures assigned in this DR were derived in the Excel file [redacted].

External Photon Doses During Period of AEC Operations

One component of the external exposure of operators during 1962 was expressed by NIOSH (2017a, Table 8) as a triangular uncertainty distribution with a minimum, mode, and maximum of 6.279, 9.69, and 12 R/y, respectively. These parameters were multiplied by [redacted], the effective DCF for converting exposure to photons in the 30–250 keV energy range, incident in the AP orientation, to dose to the [redacted]. The result was a triangular distribution of dose rates to the [redacted]. The EE was also assigned an external dose to the [redacted] from 30-keV photons, derived from an air kerma dose rate of 5.112 rad/y, multiplied by [redacted], the air-kerma-to-[redacted] DCF for 30-keV photons incident in the PA orientation. This dose was entered into IREP as a constant distribution. The 1962 doses were prorated to reflect the EE's assumed start of employment on [redacted].

The EE was assigned external photon exposures during 1963–1965 of [redacted] as specified by NIOSH (2017a, Table 8). The 1966 exposure was [redacted], reflecting the end of the operational period on [redacted]. These exposures were multiplied by the DCF of [redacted] to yield doses to the [redacted] that were entered into IREP as constant distributions.

External Photon Doses During the Residual Period

The DR assigned an exposure rate of 0.2925 R/y for the residual period from [redacted], 1966 to [redacted], 1973—from the beginning of the residual period to the end of the EE's employment. The exposures were divided equally between photon energies of 30–250 keV and >250 keV. These exposures were multiplied by the effective exposure-to-[redacted]-dose DCF for photons

incident in the PA orientation in the applicable energy range: [redacted] for 30–250 keV photons or [redacted] for photons with energies >250 keV. These DCFs were applied as fixed values, as discussed in section 2.1.2 of the present review.

Neutron Doses

The DR assigned neutron doses to the [redacted] for the years 1962–1966. These doses were based on the annual neutron doses for organs other than the skin of the hands and forearms listed by NIOSH (2017a, Table 8), multiplied by [redacted], the H*(10)-to-[redacted]-dose-equivalent DCF for neutrons with energies <10 keV, the energy range specified by NIOSH, incident in the AP orientation. The 1962 dose was prorated to reflect the EE's assumed start of employment on [redacted]. The doses were listed as fixed values in the IREP input file.

Reviewer's Comment

NIOSH used a fixed value of the DCF to convert photon exposures to doses to the [redacted]. This would appear to be inconsistent with the directions of OCAS-IG-001 (NIOSH 2007b), which states that an uncertainty distribution about the DCF is appropriate. However, in developing the triangular distributions used to estimate the external exposures in 1952–1962, NIOSH largely relied on information regarding radiography of steel castings using sealed ^{226}Ra sources. Such sources, which contain all the radium progeny, emit photons with an average energy of 655 keV. Use of the effective exposure-to-[redacted]-dose DCF of [redacted] for 30–250 keV photons is highly claimant favorable, since the maximum [redacted] DCF for photons with energies >250 keV incident in the AP orientation is [redacted]. Since the derived doses represent bounding estimates, it is appropriate to use a fixed value of the DCF.

NIOSH (2017a) assigned the hypothetical stray photon radiation from the betatron following shutdown a fixed energy of 30 keV and a fixed PA orientation. Such exposure conditions lead to a unique value of the DCF; there was thus no need to assign an uncertainty distribution. The justification for using a fixed value of the DCF with the external photon exposures in 1963–1966 was discussed in section 2.1.2 of the present review, as was the use of a fixed value of the DCF to calculate neutron doses.

We verified that all doses to the [redacted] from occupational external exposures were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.2.3 Review of Internal Doses

As previously noted, NIOSH (2017a, Table 10) presented intakes of airborne uranium dust at GSI for the operational period, while NIOSH (2017a, Table 11) presented the corresponding information for the residual period. These data were entered into the Excel worksheet [redacted], which listed the daily intakes of ^{234}U (used by NIOSH as a surrogate for the actual mix of uranium isotopes) by both pathways for the years 1962–1973. The [redacted] doses from alpha rays for each calendar year, from the start of the EE's employment in 1962 until the date of cancer diagnosis in 1994, calculated by the CAD workbook, were listed in the IREP input file, as shown in the Excel file [redacted].

We audited the internal doses to the [redacted] by performing independent calculations using integrated doses derived from the DCAL computer code (ORNL 2006), as discussed in section 2.1.3. We calculated the annual doses from intakes from [redacted], 1962 to [redacted], 1973, the beginning and end of the EE's employment. The doses for each calendar year were calculated, starting on [redacted], 1962, and ending on [redacted], 1994, the day before the cancer diagnosis. We found that the NIOSH dose for 1962 was 15% higher than our calculated value, with smaller differences in some subsequent years.

Based on previous DR reviews, we hypothesized that these differences stemmed from the way NIOSH apportioned the intakes during years of partial exposures. Because the total internal dose of [redacted] calculated by NIOSH was a significant contributor to the total [redacted] dose of [redacted], and hence a potentially significant contributor to the POC, this issue required further study. We therefore performed new analyses in which the intakes during each calendar year were distributed over the entire year. During years of partial exposure, the daily intakes were reduced in proportion to the shorter exposure duration—the annual intakes remained the same. The results of these analyses matched the annual doses calculated by NIOSH within <1%, thus confirming our assumption.

The NIOSH internal dose methodology was the subject of a finding in our previous GSI PER review (SC&A 2016). At that time, the CAD tool used by NIOSH could only accommodate full-year exposures, requiring the DR analyst to prorate the daily intakes to account for shorter exposure durations. This issue was discussed at a subsequent SCPR meeting (ABRWH 2017), at which time David Allen (NIOSH/DCAS) stated that the CAD tool has been revised: it was now able to model the actual daily intakes and the actual beginning and end dates of the exposures. We confirmed that the version of the tool used in the current [redacted], did in fact list these dates and the actual daily intakes during these time intervals; its calculations nevertheless mimicked the earlier version of the tool by distributing the intakes over the entire year.

Observation: NIOSH Used Efficiency Measures to Estimate Internal Doses

The total internal [redacted] doses calculated by NIOSH and SC&A in the present case agree within 0.3%, which we verified by summing the internal doses listed in the Excel file [redacted]. Given this good agreement, and the fact that the POC was [redacted], the differences in the annual doses were not likely to affect the compensation decision for this EE. However, this methodology could affect the outcome in cases where the POC was close to 50%.

2.2.4 Review of External Doses from Medical X Rays

In accordance with OTIB-0006 (ORAUT 2011), the EE was assumed to have had one chest x ray during each year of the operational period as part of the annual physical exam. An acute [redacted] dose of [redacted] was assigned for each year, 1962–1966, as a normal distribution, with a standard deviation of 0.02514 rem. This is the dose to the [redacted] from a PA examination through 1970 listed by ORAUT (2011, Table A-7). The standard deviation was computed as 30% of the mean dose, as recommended by ORAUT. We verified that all doses to the [redacted] from medical x rays were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.3 CASE [REDACTED]

This section of the report presents the results of an independent audit of a DR performed by NIOSH for an EE who was employed as a [redacted] at GSI from [redacted] 1963 through [redacted] 1973, which included the period of AEC operations and the residual period. He was also credited with employment from [redacted] 1977.[3] He was diagnosed with [redacted] cancer on [redacted], 1977. The original DR was approved on September 10, 2007. The POC, as listed in the file [redacted], was [redacted]. The POC based on the DR that was revised to conform with the PER was [redacted]. Because the revised POC was >45%, further IREP runs were performed. As stated in the file [redacted], "The average PC value of the 99th percentiles from 30 runs with 10000 iterations is [redacted]."

2.3.1 Review of Job Category

Since the EE was employed during the operational period at GSI, the EE's job category is relevant to the DR. The EE was assigned doses to operators. This is an appropriate assignment: as a [redacted], the EE clearly worked inside the plant which, according to NIOSH (2017a), defines the operator category at GSI.

2.3.2 Review of Occupational External Doses

The external photon exposures assigned in this DR were derived in the Excel file [redacted].

External Photon Doses During Period of AEC Operations

The EE was assigned an external exposure of [redacted] during 1963–1965, and [redacted] in 1966, as listed by NIOSH (2017a, Table 8). These exposures were multiplied by an exposure-to-[redacted] DCF of [redacted], which is for photons in the 30–250 keV energy range incident in the AP orientation. The 1963 dose was prorated to reflect the EE's assumed start of employment on [redacted]. The doses were entered into IREP as constant distributions.

External Photon Doses During the Residual Period

The DR assigned the exposure rate of [redacted] for the residual period from [redacted], 1966 to [redacted], 1973—from the beginning of the residual period to the end of the EE's first period of employment—and for [redacted], 1977, the assumed second period of employment. The exposures were divided equally between photon energies of 30–250 keV and

[3] The basis for the 1977 employment credit was earnings of [redacted] from National Roll (a division of GSI) during the second quarter of 1977, reported by the Social Security Administration. The policy of the U.S. Department of Labor (DOL) is to accept Social Security records as proof of employment, and to credit an EE with employment for the entire quarter in the absence of more exact dates. In the present instance, however, the EE could not have been employed at the GSI steel foundry in Granite City, Illinois, during the period in question, since GSI had shut down operations at that facility by the end of 1973. The land and buildings occupied by the foundry were acquired by the Granite City Steel (GCS) Division of the National Steel Corporation in 1974 (SC&A 2008). Only GCS employees who worked in the area formerly owned by GSI, that became known as the South Plant, could have been occupationally exposed after 1973. Although NIOSH is obligated to follow DOL's decision about the covered employment, we suggest that NIOSH inform DOL of this apparent discrepancy.

>250 keV. These exposures were multiplied by the effective exposure-to-[redacted] DCF for photons incident in the AP orientation in the applicable energy range: [redacted] for 30–250 keV photons or [redacted] for photons with energies >250 keV. These DCFs were applied as fixed values, as discussed in section 2.1.2 of the present review. The 1966 [redacted] dose was prorated to reflect the beginning of the residual period, while the 1973 and 1977 doses were prorated to reflect the periods of the EE's employment.

Neutron Doses

The DR assigned neutron doses to the [redacted] for the years 1963–1966. These doses were based on the annual neutron doses for organs other than the skin of the hands and forearms listed by NIOSH (2017a, Table 8), multiplied by [redacted], the H*(10)-to-[redacted]-dose-equivalent DCF for neutrons incident in the AP orientation with energies <10 keV, the energy range specified by NIOSH (2017a). The 1963 dose was prorated to reflect the EE's assumed start of employment on [redacted]. The doses were listed as fixed values in the IREP input file.

Reviewer's Comment

NIOSH used fixed values of the DCFs to convert external exposures to photon and neutron radiation to doses to the [redacted]. The justification for this practice is discussed in sections 2.1.2 and 2.2.2 of the present review. We verified that all doses to the [redacted] from occupational external exposures were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.3.3 Review of Internal Doses

As previously noted, NIOSH (2017a, Table 10) listed intakes of airborne uranium dust at GSI for the operational period, while NIOSH (2017a, Table 11) listed the corresponding information for the residual period. NIOSH calculated the internal doses to the [redacted] from these intakes using IMBA, performing eight separate runs. There were four runs each for intakes of ^{234}U [redacted] absorption types *M* and *S*. For each type, there were two runs for inhalation and two for ingestion. Pairs of runs were required, since IMBA is limited to 10 intake regimes and the intakes spanned 12 date ranges. The resulting doses were entered into IREP, as shown in the [redacted].

We audited the internal doses to the [redacted] by performing independent calculations using integrated doses derived from the DCAL computer code (ORNL 2006), as discussed in section 2.1.3 of the present review. Unlike IMBA, DCAL does not specify the [redacted] as a target organ. However, the program does specify its two components: [redacted]. According to the ICRP (2002, Table 6.9), the mean masses of these two organs in adult men are [redacted] and [redacted] g, respectively. We simulated the doses to the [redacted] by taking the average of the doses to the [redacted], weighted by the relative mass of each organ, for each calendar year. We calculated the annual doses from intakes during [redacted], 1963–[redacted], 1973, the beginning and end of the EE's first period of employment, and during [redacted], 1977, the assumed second period of employment. The doses for each calendar year were calculated, starting on [redacted], 1963, and ending on [redacted], 1977, the day before the cancer diagnosis. We found a difference from the dose calculated by NIOSH for 1963

that most likely stemmed from the way IMBA apportioned intakes during years of partial exposures. However, the total internal doses calculated by NIOSH and SC&A for the 15-y period were [redacted] mrem in both cases. Given this small value and the good agreement between the total doses, any discrepancies in the annual doses would have no significant impact on this case. We thus confirmed that NIOSH correctly calculated the total internal dose to the [redacted], which we verified by summing the internal doses listed in the Excel file [redacted].

2.3.4 Review of External Doses from Medical X Rays

In accordance with OTIB-0006 (ORAUT 2011), the EE was assumed to have had one chest x ray during each year of the operational period as part of the annual physical exam. An acute [redacted] dose of [redacted] was assigned for each year, 1963–1966, as a normal distribution, with a standard deviation of 0.0075 rem. This is the dose to the [redacted] from a PA examination through 1970 listed by ORAUT (2011, Table A-7). The standard deviation was computed as 30% of the mean dose, as recommended by ORAUT. We verified that all doses to the [redacted] from medical x rays were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.4 CASE [REDACTED]

This section of the report presents the results of an independent audit of a DR performed by NIOSH for an EE who was employed as a [redacted] at GSI from [redacted] 1952 through [redacted] 1953, which included the period of AEC operations. He was diagnosed with [redacted] cancer on [redacted], 1998.

[redacted]. However, since the purpose of the present review is to audit the doses received by workers at GSI, we will not examine the EE's radiation exposures at [redacted].

The original DR was approved on [redacted]. The POC, as listed in the file [redacted], was [redacted]. The POC based on the DR that was revised to conform with the PER was [redacted]. Because the revised POC was >45%, further IREP runs were performed. According to the file [redacted]: "The average PC value of the 99th percentiles from 30 runs with 10000 iterations is [redacted]."

2.4.1 Review of Job Category

Since the period of covered employment fell within the operational period at GSI, the EE's job category is relevant to the DR. The EE was assigned doses to operators. This is an appropriate assignment: [redacted], the EE clearly worked inside the plant which, according to NIOSH (2017a), defines the operator category at GSI.

2.4.2 Review of Occupational External Doses

The external photon exposures assigned in this DR were derived in the Excel file [redacted]. The [redacted] was selected as the target organ in the present case, as it was for the previous case of [redacted] cancer discussed in section 2.1.2 of the present review.

External Photon Doses

One component of the external exposure of operators in 1952–1955 was expressed by NIOSH (2017a, Table 8) as a triangular uncertainty distribution with a minimum, mode, and maximum of 6.279, 11.345, and 15 R/y, respectively. These parameters were multiplied by [redacted], the effective DCF for converting exposure to photons in the 30–250 keV energy range, incident in the AP orientation, to dose to the [redacted]. The result in the present case was a triangular distribution of dose rates to the [redacted] during 1952–1953. The EE was also assigned an external dose rate to the [redacted] from 30-keV photons, derived by assigning an air kerma dose rate of 5.112 rad/y, multiplied by [redacted], the air-kerma-to-[redacted] DCF for 30-keV photons incident in the PA orientation.

Neutron Doses

The DR assigned neutron doses to the [redacted] for the years 1952–1953. These doses were based on the annual neutron doses for organs other than the skin of the hands and forearms listed by NIOSH (2017a, Table 8), multiplied by [redacted], the effective H*(10)-to-[redacted]-dose-equivalent DCF for neutrons with energies <10 keV, the energy range specified by NIOSH.

The 1952 photon and neutron doses were prorated to reflect the start of the operational period on October 1, 1952, while the 1953 doses were prorated to reflect the end of EE's employment at GSI on [redacted]. All external doses were entered into IREP as constant distributions.

Reviewer's Comment

NIOSH used fixed values of the DCFs to convert external exposures to photon and neutron radiation to doses to the [redacted]. The justification for this practice is discussed in sections 2.1.2 and 2.2.2 of the present review. We verified that all doses to the [redacted] from occupational external exposure were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.4.3 Review of Internal Doses

We audited the internal doses to the [redacted] by performing independent calculations using integrated doses derived from the DCAL computer code (ORNL 2006), as discussed in section 2.1.3, using the [redacted] as a surrogate organ. We calculated the annual doses from intakes from [redacted], 1952 through [redacted], 1953—from the beginning of the operational period to end of the EE's employment at GSI. The doses for each calendar year were calculated, starting on [redacted], 1952, and ending on [redacted], 1998, the day before the cancer diagnosis. We found differences in the calculated doses for the first two years. As discussed in section 2.1.3, these differences most likely stemmed from the way NIOSH apportioned the intakes during years of partial exposures. However, the total doses calculated by NIOSH and SC&A for the 46-y period were [redacted] in each case, as we verified by summing the internal doses listed in the Excel file [redacted]. Given these small values and the good agreement between the total doses, the differences in the annual doses were not significant. We thus verified the internal doses calculated by NIOSH and confirmed that these doses were correctly entered into IREP, as shown [redacted].

2.4.4 Review of External Doses from Medical X Rays

In accordance with OTIB-0006 (ORAUT 2011), the EE was assumed to have had one chest x ray during each year of the operational period as part of the annual physical exam. An acute [redacted] dose of [redacted] was assigned for each year, 1952–1953, as a normal distribution, with a standard deviation of 0.0075 rem. This is the dose to the [redacted] from a PA examination through 1970 listed by ORAUT (2011, Table A-7). The standard deviation was computed as 30% of the mean dose, as recommended by ORAUT. We verified that all doses to the [redacted] from medical x rays were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.5 CASE [REDACTED]

This section of the report presents the results of an independent audit of a DR performed by NIOSH for an EE who was employed as a [redacted] at GSI from [redacted] 1963 through [redacted], 1969, which included the period of AEC operations and the residual period. He was diagnosed with [redacted], International Classification of Diseases (ICD)-9 Code [redacted], on [redacted], 2013. According to the National Cancer Institute's "Dictionary of Cancer Terms" (NCI n/d), "[redacted]" According to ORAUT (2012), the [redacted] is to be selected for both internal and external DRs in cases assigned this ICD-9 code.

The original DR was approved on [redacted], 2014. The POC, as listed in the file [redacted], was [redacted]. The POC based on the DR that was revised to conform with the PER was [redacted]. Because the revised POC was >45%, further IREP runs were performed. As stated in the file [redacted], "The average PC value of the 99th percentiles from 30 runs with 10000 iterations is [redacted]."

2.5.1 Review of Job Category

Since part of the EE's employment was during the operational period at GSI, the EE's job category is relevant to the DR. According to the computer-assisted telephone interview (CATI) report, the EE "worked in all buildings including the betatron building and others. [As a] [redacted] as everyone went in and out of the plant. Then went all over the plant as necessary to perform other [redacted] duties. [redacted] to different places. [redacted]." Although the EE was not a production worker, the description of the duties clearly indicates that the EE worked inside the plant which, according to NIOSH (2017a), defines the operator category at GSI. Therefore, the EE was properly assigned doses to operators.

2.5.2 Review of Occupational External Doses

The external photon exposures assigned in this DR were derived in the Excel file [redacted].

External Photon Doses During Period of AEC Operations

The EE was assigned an external exposure of [redacted] during 1963–1965, and [redacted] in 1966, as listed by NIOSH (2017a, Table 8). These exposures were multiplied by an exposure-to-[redacted] DCF of [redacted], which is for photons in the 30–250 keV energy range incident in the AP orientation. The 1963 dose was prorated to reflect the EE's start of employment on [redacted]. The doses were entered into IREP as constant distributions.

External Photon Doses During the Residual Period

The DR assigned the exposure rate of [redacted] for the residual period. The exposures were divided equally between photon energies of 30–250 keV and >250 keV. These exposures were multiplied by the effective exposure-to-[redacted] DCF for the applicable energy range: [redacted] for 30–250 keV photons or [redacted] for photons with energies >250 keV. These DCFs were applied as fixed values, as discussed in section 2.1.2 of the present review. The 1966 [redacted] dose was prorated to reflect the beginning of the residual period on July 1, while the 1969 dose was prorated to reflect the end of the EE's employment [redacted].

Neutron Doses

The DR assigned neutron doses to the [redacted] for the years 1963–1966. These doses were based on the annual neutron doses for organs other than the skin of the hands and forearms listed by NIOSH (2017a, Table 8), multiplied by [redacted], the H*(10)-to-[redacted]-dose-equivalent DCF for neutrons incident in the AP orientation with energies <10 keV, the energy range specified by NIOSH (2017a). The 1963 dose was prorated to reflect the EE's start of employment on [redacted]. The doses were listed as fixed values in the IREP input file.

Reviewer's Comment

NIOSH used fixed values of the DCFs to convert external exposures to photon and neutron radiation to doses to the [redacted]. The justification for this practice is discussed in sections 2.1.2 and 2.2.2 of the present review. We verified that all doses to the [redacted] from occupational external exposure were correctly entered into the IREP input file, as shown in the Excel file [redacted].

2.5.3 Review of Internal Doses

As stated previously, NIOSH (2017a, Table 10) presented intakes of airborne uranium dust at GSI for the operational period, while NIOSH (2017a, Table 11) presented the corresponding information for the residual period. These data were entered into the Excel worksheet [redacted], which listed the daily intakes of ^{234}U (used by NIOSH as a surrogate for the actual mix of uranium isotopes) by both pathways for the years 1963–1969. The [redacted] doses from alpha rays during these years, calculated by the CAD workbook, were listed in the IREP input file, as shown in the Excel file [redacted].

We audited the internal doses to the [redacted] by performing independent calculations using integrated doses derived from the DCAL computer code (ORNL 2006), as discussed in section 2.1.3 of the present review. We calculated the annual doses from intakes during [redacted],

1963–[redacted], 1969, the beginning and end of the EE's employment. The doses for each calendar year were calculated, starting on [redacted], 1963, and ending on [redacted], 2013, the day before the cancer diagnosis. We found no significant differences in the calculated annual doses. We summed the internal doses listed in [redacted] to obtain a total dose of [redacted], which matched the total dose calculated by SC&A. We thus verified the internal doses calculated by NIOSH for this case.

2.5.4 Review of External Doses from Medical X Rays

In accordance with OTIB-0006 (ORAUT 2011), the EE was assumed to have had one chest x ray during each year of the operational period as part of the annual physical exam. An acute [redacted] dose of [redacted] was assigned for each year, 1963–1966, as a normal distribution, with a standard deviation of 0.0075 rem. This is the dose to the [redacted] from a PA examination through 1970 listed by ORAUT (2011, Table A-7). The standard deviation was computed as 30% of the mean dose, as recommended by ORAUT. We verified that all doses to the [redacted] from medical x rays were correctly entered into the IREP input file, as shown in the Excel file [redacted].

3 SUMMARY AND CONCLUSIONS

SC&A has audited the five cases that were selected by NIOSH from the 71 claims that had been reevaluated in accordance with DCAS-PER-080 (NIOSH 2017b). The PER addressed changes in doses prescribed by revisions 2 and 3 to Appendix BB to TBD-6000 (NIOSH 2016, 2017a). At least one of the prescribed doses during each year of the operational period increased after Appendix BB, Rev. 1 (NIOSH 2014). NIOSH therefore reevaluated all GSI claims with DRs that were completed before February 9, 2017, the date of issuance of revision 3, with employment during the operational period, that had a POC <50%.

SC&A (2016) had previously reviewed DCAS-PER-057 (NIOSH 2015), which was issued following revision 1 (NIOSH 2014). That review resulted in three findings and several observations. These arose out of the methods used by NIOSH to implement revision 1, not from failures to follow the prescriptions in that revision. We believe that only a case audit, which is prescribed by the SC&A (2009) protocol for performing a PER review, would uncover any such deficiencies that persisted in the cases subject to the current PER.

Our audits included a review of the job category assigned to each worker, which was the subject of major findings in our previous review (SC&A 2016). In our current review, we find that, in all five cases, the workers had been properly assigned to the operator category.

We reviewed the external organ doses to verify conformity with the external exposures specified in revision 3 (NIOSH 2017a), and with the guidelines for converting these exposures to organ doses presented by NIOSH (2007b). Our previous review (SC&A 2016) uncovered some issues with the implementation of these guidelines; our current review found that these issues had been resolved.

We verified that inhaled and ingested intakes of uranium had been correctly assigned for the calculation of internal doses. In our previous review (SC&A 2016), we had observed that NIOSH sometimes used efficiency measures in estimating internal doses that had the potential of changing the annual doses and hence the POCs. The NIOSH methodology could lead to lowering some annual doses in cases where the intake regime ended before the end of the year. As we stated in our previous review, NIOSH should perform IMBA analyses using the actual dates of intake to calculate internal doses for cases where the internal doses make significant contributions to the total doses and the POC is close to 50%.

Finally, we confirmed that the doses from medical x rays were correctly assigned in each case. The prescribed methodology for assigning these doses had not changed from Appendix BB, Rev. 0 (NIOSH 2007a) to revision 3 (NIOSH 2017a). However, the files [redacted] and [redacted], which summarized the results of the NIOSH reevaluation of the respective cases under DCAS-PER-057 (NIOSH 2015), showed changes in these doses from the original DRs. We therefore inspected the medical x-ray doses that were assigned under the present PER and concluded that these previous changes were apparent anomalies, since the final medical x-ray doses under the current PER were the same as those in the original DRs.

In summary, we find that NIOSH has correctly implemented the changes to the DR methodology in Appendix BB, Rev. 3 (NIOSH 2017a), and therefore fulfilled the intent and purpose of DCAS-PER-080 (NIOSH 2017b).

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