TO: Advisory Board on Radiation and Worker Health Work Group on TBD-6000
FROM: Robert Anigstein and John Mauro, SC&A
SUBJECT: Review of Appendix BB, Revision 1
DATE: October 29, 2014

**Review of "Site Profiles for Atomic Weapons Employers that Worked Uranium Metals Appendix BB – General Steel Industries," Revision 1**

On June 23, 2014, David Allen (NIOSH/DCAS) issued a revision of Appendix BB to TBD-6000 (Allen 2014). In an e-mail message on June 30, 2014, Ted Katz, Designated Federal Official to the Advisory Board, asked SC&A to review this report. In our review, we confine the discussion to observations and issues in areas in which we and NIOSH are not in agreement. We also address, when appropriate, comments by the GSI copetitioner on the revised Appendix BB that were submitted jointly to James Melius, Chair of the Advisory Board on Radiation and Worker Health, Paul Ziemer, Chair of the Work Group on TBD 6000, and Ted Katz on July 21, 2014. Our comments address issues that affect the dose reconstruction methods prescribed in the revised appendix, and include observations on statements in the appendix that, while they do not affect dose reconstructions, fail to accurately describe the GSI facility in Granite City, Illinois, and its operations.

# 1 Review Comments

This review follows the sequence of topics presented by Allen (2014). Unless otherwise specified, the section, table, and figure numbers are from Allen 2014.

## 1.1 Section BB.2.1: Site Activities

In Section BB.2.1, Allen (2014) states "During the *late 1950s* and early 1960s, General Steel Industries used *a betatron* to x-ray uranium metal for the AEC under purchase orders issued by Mallinckrodt Chemical Works." (Italics added) We observe that this statement is not strictly correct, in that the period of covered operations at GSI is October 1, 1952–June 30, 1966. Although the starting date on the Mallinckrodt purchase orders that were furnished by DOE is March 1, 1958, it must be assumed that there were purchase orders prior to that date. Later in the site profile, Allen correctly credits the radiation exposures of GSI workers during this earlier period; however, the statements in this section may mislead or confuse the reader and should be corrected. The sentence quoted above should be further edited by replacing "a betatron" with "betatrons" to explicitly recognize the presence of two betatrons in 1963–1966.

## 1.2 Section BB.2.2: Frequency of Uranium X-Rays

In Section BB.2.2, Allen (2014) describes the Mallinckrodt purchase orders covering the period March 1, 1958–June 30, 1961, as stipulating limits on monthly expenditures for the radiography of uranium metal shapes. We observe that, in fact, these purchase orders only list estimates of monthly expenditures, not limits. Allen is correct in citing annual limits on expenditures in the purchase orders spanning the period July 1, 1961–June 30, 1966. We agree with NIOSH on the use of Mallinckrodt's estimated expenditures to derive the hours of uranium exposure during the March 1, 1958–June 30, 1961, period. However, presenting the estimates of monthly expenditures as limits overstates the degree of conservatism in the exposure assessments during the earlier period. These statements and the heading "Monthly limit" in the fourth column of Table 1 (Allen 2014) should be revised.

### 1.3 Section BB.4: Occupational External Dose

As pointed out by the copetitioner, the sources of external radiation exposure included *two* 250-kVp x-ray machines. This has no effect on worker exposures, since the two machines would not have been used simultaneously in the same location; however, the first sentence of Section BB.4 should be revised in the interest of accuracy. The second sentence of that section reads as follows: "Except for the uranium, all these sources were used to x-ray metal." This sentence needs to be edited. A suggested revision is: "Except for the *betatron*, all these sources were used to x-ray *steel castings*." (Italics added to identify changes)

### 1.4 Section BB.4.1: Betatrons

Expanding on a comment by the copetitioner, we suggest that references to the "old betatron" and the "new betatron" in the second paragraph of Section BB.4.1 be changed to "Old Betatron Building" and "New Betatron Building." The construction dates refer to when the two buildings were erected. The text could be misinterpreted as referring to when the machines were manufactured.[1] Similar references to the construction of the New Betatron Building should include the word "building" to distinguish it from the betatron apparatus itself.

To resolve a comment by the copetitioner regarding the source of the information on the betatron beam intensity, we suggest rewording the beginning of the third paragraph of Section BB.4.1 as follows (added text underlined and displayed in red, deleted text shown in blue with strikeout):

> Schuetz (2007) reported the intensity of the x-rays from the new betatron to be 250 R/min at 3 feet from the platinum target with the aluminum compensator removed. He reported that the compensator ~~reportedly~~ reduced the intensity by a third.

As suggested by the copetitioner, the sources of Figures 1–5 and Figure 8 should be cited. More legible versions of Figures 2–5 should be extracted from the original source documents. We suggest that the caption to Figure 1, "Drawing of the Old Betatron Building," be clarified to indicate that it is the floor plan of the second floor (Bechtel 1994).

[1] The "new" betatron went into operation at the General Steel foundry in Eddystone, Pennsylvania, in November 1951 and was later moved to the Granite City facility, while the "old" betatron became operational at the Granite City foundry in January 1952.

## 1.5 Section BB.4.2: Betatron Building Model

In Section BB.4.2, Allen (2014) describes the MCNP model of the New Betatron Building. In order to validate this model, NIOSH performed MCNP simulations of a radiation survey of this building described in NRC (2009a, pp. 34 et seq. of PDF file). Allen (2014, Table 3) lists the results of MCNPX simulations of the exposure rates at locations corresponding to those listed in the survey report. As observed by Anigstein and Olsher (2012),

> One significant difference between Allen's (2012) MCNPX simulation and information in the GSI AEC files is that Allen assumed a source strength of 80 Ci. Although it was referred to as an "80-Ci" source, the source had been procured 3 years prior to the survey. Assuming it had a nominal activity of 80 Ci at that time (there is no record of the actual assay of the source), the decayed activity at the time of the survey would have been approximately 54 Ci. . . . The results of Allen's (2012) MCNPX simulation, after adjustment for the lower source strength, are in reasonable agreement with the 1971 survey data.

The "modeled radiation levels" listed by Allen (2014, Table 3) should be adjusted to reflect the decayed activity of the $^{60}Co$ source used for the radiation survey. Although such a change does not affect the dose reconstructions of former GSI workers, the MCNPX results presented in Table 3 overstate the conservatism of the model. Furthermore, as suggested by the copetitioner, the source of the survey data should be explicitly cited.

## 1.6 Section BB.4.3: Betatron Operations External Dose Estimate

In the section with the subheading "Neutron and Gamma Dose from Freshly Exposed Material," Allen (2014, Section BB.4.3) discusses the neutron doses to the betatron operator. Although he does not identify the dosimetric quantities, these values are consistent with the neutron effective doses from this scenario calculated by SC&A (Anigstein and Mauro 2014). However, such doses cannot be used for dose reconstructions according to the guidelines in OCAS-IG-001 (OCAS 2007). This document does not list dose conversion factors for neutron effective dose to organ dose equivalent, the choices being fluence to organ dose equivalent; ambient dose equivalent, H*(10), to organ dose equivalent; and deep dose equivalent, $H_{p,slab}(10, 0^o)$ (also known as personal dose equivalent), to organ dose equivalent. The neutron-fluence-to-dose conversion coefficients for H*(10) and $H_{p,slab}(10, 0^o)$ listed by ICRP (1997, Table A.42) are significantly higher than those for effective dose (ICRP 1997, Table A.41); therefore, using neutron effective doses with either the ambient dose equivalent or deep dose equivalent conversion factors from OCAS-IG-001 would be neither scientifically correct nor claimant favorable.

As part of the present review, we have calculated neutron ambient dose equivalents to the betatron operator and the layout man using MCNPX, employing the same model we described previously (Anigstein and Mauro 2014), but substituting the neutron-fluence-to-ambient-dose conversion coefficients, H*(10) (ICRP 1997, Table A.42), for the fluence-to-effective-dose coefficients (ICRP 1997, Table A.41) used previously. The results are listed in Table 1 of this memo. As shown in this table, the dose from delayed neutrons emitted from uranium is

0.79 mrem ambient dose equivalent per shift. This numerical value is significantly higher than the 0.555 mrem (effective) dose cited by Allen (2014).

Table 1
Neutron Ambient Dose Equivalent, H*(10) to Betatron Operator and Layout Man (mrem/shift)

| Source of radiation | Betatron operator | Layout man |
|---|---|---|
| Uranium handling | 0.79 | — |
| Uranium radiography | 1.47 | — |
| Steel radiography | 0.86 | 1.84 |

Pursuant to an observation by the copetitioner, we note that neutrons emitted by the new betatron constituted a second source of exposure to an operator in the Old Betatron Building. To perform a bounding calculation, we calculated the ratio of the neutron fluxes from the old and new betatrons in the control room of the Old Betatron Building, based on the inverse square law. Figure 1 of this memo shows the location of the two betatron buildings, copied from the GSI layout drawing. The New Betatron Building is shown in the upper left-hand corner of the figure, while the Old Betatron Building, labeled "Gov. Betatron Bldg.," is in the lower right-hand corner. The red asterisk #1 in Figure 1 marks the position of the betatron operator in the control room of the Old Betatron Building, while asterisk #2 indicates the position of the head of the new betatron in the center of the shooting room of the New Betatron Building. According to the scale superimposed on this section of the plant plan, the distance between the two locations is 450 feet. In our MCNPX simulation of the neutron dose rate in the control room of the Old Betatron Building, the operator was 1,257 cm (41.25 ft) from the platinum target of the betatron. Applying the inverse square law, we find that the neutron flux from the new betatron would be 0.84% of the flux from the old betatron, taking no credit for the additional shielding of intervening strictures. This is well within the statistical uncertainty of the MCNPX simulations; therefore, this trivial contribution need not be considered further.

This conclusion is further bolstered by the fact that the limiting scenario for external exposure during 1963–1966, the years during which both betatrons were operating, is the layout man. In this scenario, the worker is assumed to be located just outside the New Betatron Building, in the area shown in the upper-left-hand corner of Figure 1. Any neutrons from the old betatron reaching this location would be attenuated by passing through the southwest shield wall of the New Betatron Building, in addition to being greatly reduced by the distance. We nevertheless recommend that the revised Appendix BB should take note of this potential contribution to resolve any questions regarding this issue.

### 1.6.1 Beta Skin Dose

Allen (2014, Table 5) lists ß doses to the skin of betatron operators. We compare these doses to the current SC&A estimates, which have several components. We have previously listed the ß dose rates from irradiated steel (Anigstein and Mauro 2013a, Table 2)—we reproduce the relevant portion in Table 2 of this memo. We have also previously listed the annual doses to the skin of betatron operators from exposures to uranium and to irradiated steel (Anigstein and Mauro 2013a,

Table 5). Our analysis incorporated Allen's (2014) assumption that the betatron operator was "1 foot from the [metal] object for half of the time he was exposed and 1 meter from the object for the remainder of the time." However, we had neglected to include the dose rate from irradiated steel at a distance of 1 m, shown in Table 2 of this memo, in the annual doses from irradiated steel. A corrected version of our earlier tabulation is shown as Table 3 of this memo.

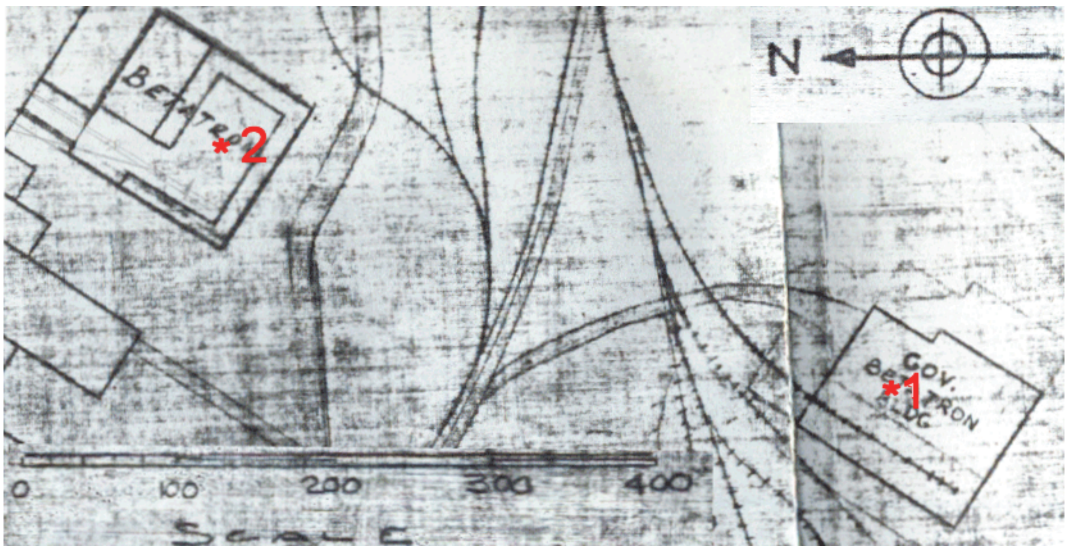


Figure 1. Detail from Plant Layout, Showing Betatron Buildings (GSCC 1969)

Table 2. Dose Rates to Skin from Beta Radiation from HY-80 Steel

| Distance | Shield | Dose (mrad/shift) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Betatron operator | | | Layout man | | |
| | | Short[a] | Long[a] | Composite | Short[a] | Long[a] | Composite |
| Contact | None | 9.35 | 5.11 | 7.84 | 3.44 | 7.75 | 4.98 |
| 1 ft | Cloth | 5.77 | 3.15 | 4.83 | 2.05 | 4.61 | 2.97 |
| 1 m | Cloth | 2.11 | 1.15 | 1.76 | 0.08 | 0.18 | 0.11 |

[a] Short and long shots

The total ß doses to the skin of the hands and forearms listed by Allen (2014, Table 5) are lower than those shown in Table 3 of this memo for the years 1963–1966. The doses to the skin, other than that on the hands and forearms, listed by Allen are lower than those shown in Table 3 for every year of the covered period. We recommend that NIOSH and SC&A reconcile these differences.

Allen (2014, Table 6) lists annual ß doses to the skin of the layout man: 807 mrads to the hands and forearms and 463 mrads to the skin of the whole body. As part of the present review, we recalculated the ß skin dose to the layout man, using the revised MCNPX analyses and the methodology we described previously (Anigstein and Mauro 2013a). We retained the exposure scenario described by SC&A (2008, p. 42): "To calculate the exposure of the layout man, we simplified the scenario described in Section 2.2.4 and made the claimant-favorable assumption that he would be exposed to the steel 15 min after the last irradiation and would be in contact with the casting 90% of the time for 75 min." As in our analysis of the ß dose to the skin of the betatron operator, we assumed that the skin of the layout man, other than that on the hands and forearms, was 1 ft from the casting while he was in close contact with the steel (90% of the time, vs. 50% for the betatron operator), and that he was at a distance of 1 m the remaining 10% of the time. The components of the ß skin dose per work shift derived from this analysis are listed in Table 2 of this memo. Using these results, we obtain annual doses of 2.07 and 1.25 rads to the skin of the hands and forearms and to the skin on the rest of the body, respectively, as shown in Table 4 of this memo—more than a 2-fold difference from the NIOSH results. We again recommend that NIOSH and SC&A reconcile these differences.

Table 3. Annual Doses to Skin of Betatron Operators from Beta Radiation (rads)

| Year | Annual number of shifts | | Hands and forearms | | | Other skin | | |
|---|---|---|---|---|---|---|---|---|
| | Uranium | Steel | Uranium | Steel | Total | Uranium | Steel | Total |
| 1952-1957 | 54.7 | 351.6 | 31.96 | 3.38 | 35.34 | 2.03 | 2.32 | 4.35 |
| 1958 | 45.8 | 360.4 | 26.79 | 3.46 | 30.25 | 1.70 | 2.38 | 4.08 |
| 1959-1960 | 42.2 | 364.1 | 24.66 | 3.50 | 28.15 | 1.57 | 2.40 | 3.97 |
| 1961 | 48.4 | 357.8 | 28.31 | 3.44 | 31.74 | 1.80 | 2.36 | 4.16 |
| 1962 | 35.2 | 371.1 | 20.55 | 3.56 | 24.11 | 1.31 | 2.45 | 3.75 |
| 1963 | 9.6 | 396.7 | 5.59 | 3.81 | 9.40 | 0.36 | 2.62 | 2.97 |
| 1964 | 3.5 | 402.7 | 2.05 | 3.87 | 5.92 | 0.13 | 2.66 | 2.79 |
| 1965 | 2.6 | 403.7 | 1.50 | 3.88 | 5.37 | 0.10 | 2.66 | 2.76 |
| 1966[a] | 0.8 | 202.3 | 0.47 | 1.94 | 2.41 | 0.03 | 1.33 | 1.36 |

[a] During contract period January 1–June 30

Source: Anigstein and Mauro (2013a, Table 5)

Table 4. Annual Exposures of Layout Man to External Radiation (1963–1966)

| External exposure (R/y) | Beta dose to skin (rads/y) | | Neutron H*(10) (rem/y) |
|---|---|---|---|
| | Hands and forearms | Other skin | |
| 9.00 | 2.07 | 1.25 | 0.746 |

As observed by the copetitioner, the second sentence of the last paragraph of p. 17 (Allen 2014) reads "MCNP was then used to *calculation* . . ." (Italics added) The word, of course, should be "calculate."

## 1.7 Section BB.4.4: External Dose Estimate for Isotope Source Operations

In the subsection entitled "Radium-226 Radiography," Allen (2014, Section BB.4.4), in describing the radiographic facility in No. 6 Building, refers to armor steel plates used for shielding. However, the drawing of this facility included in the report of the radiological survey of this facility, which shows the steel plates, includes the notation "shows additional shielding added June–July 1962" (NRC 2009b, p. 31). Furthermore, Anigstein (2011) reported an interview with a former radiographer who worked at GSI during part of the Radium Era, which spanned the years 1952–1962. This worker recounted that steel plates were added to the facility when GSI started using radiographic sources other than radium. Although the plates were not included in the MCNPX model of the facility, and therefore do not affect the dose calculations, the reference to the steel plates should nevertheless be corrected.

Allen (2014, Section BB.4.4) describes a triangular distribution that was adopted by the work group, NIOSH, and SC&A to characterize photon exposures of GSI plant personnel during the Radium Era. The distribution has a minimum of 6.279 R/y, a mode (the most likely value) of 9.69 R/y, and a maximum of 12 or 15 R/y, depending on the year. The mode has two components: the exposure of 9.40 R/y a radiographer received while placing and retrieving a $^{226}$Ra source, and the exposure of 0.295 R/y he received in the office inside the radiographic facility during the radiographic exposure. This exposure scenario is valid for the years 1956–1962. This time span includes the period 1957–1962 during which the former employee who furnished information on the use of $^{226}$Ra sources performed radiography at GSI, and reported being in the office during the exposures.[2] However, it appears that this facility did not exist until 1955. During the April 26, 2013, teleconference meeting of the Work Group on TBD 6000, the copetitioner cited accounts of two former GSI workers who reported that the radiographic facility was built in 1955. (Although the two workers were on the conference call, neither of them volunteered this information.) This account is further substantiated by an e-mail to the copetitioner from a former GSI betatron operator from a later era, who had spoken with one of these two workers on the telephone. The latter worker said he was directly involved in constructing the radiographic facility. In the absence of contradictory information, the site profile should assume that the building was not in existence until sometime in 1955. Absent such a facility, it should be assumed that the $^{226}$Ra sources were used in an unshielded area of the plant during the years 1952–1955.

This changed assumption requires a change in the external photon exposures assigned to radiographers and other plant personnel during 1952–1955. NIOSH should assume that the radiographer waited at the 2-mR/h isoexposure boundary for the exposure to be completed. This is a reasonable assumption, given the need to have someone present to prevent intrusion into this restricted area. In such a case, the exposure in the radiographer's office is replaced by an exposure at the boundary of 1.54 R/y. This is calculated by first noting that radiography using $^{226}$Ra sources took place 30% of the time. Thus, assuming 3,250 work hours per year, 975 hours were devoted to this activity. The estimate of 9.4 R/y from handling the sources assumed that it took 15 s to position the source and an equal time to retrieve it, for a total handling time of ~34 h/y (15 s × 2 × 10 exposures/shift × 406.25 shifts/y ÷ 3600 s/h ≈ 34 h/y). Thus, the radiographer can be assumed to have spent ~941 h/y (975 – 34 = 941) at the 2-mR/h boundary, incurring an additional exposure of 1.88 R/y (941 h × 0.002 R/h ≈ 1.88 R/y), for a total of 9.4 + 1.88 = 11.28 R/y. This value should be used as the mode of the triangular distribution during 1952–1955.

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[2] According to this employee's "Occupational External Radiation Exposure History" (Form AEC-4), he most likely began working with radioactive sources in 1957.

Allen (2014) refers to the small enclosed area inside the radiographic facility as a "control room." This implies that there were some mechanisms in this room that could be used to control the exposure, which was not the case. Allen's Figure 8 shows a drawing of the radiography room, in which the small inner enclosure is marked "operation room," while the radiographer who worked in that facility referred to it as the radiographer's office (Anigstein 2011). This term should be corrected to avoid confusion.

The third sentence of the second paragraph on p. 23 (Allen 2014) reads "An interview with the radiographer indicated he only performed radiography on a part time basis and estimated he did this between 40 to 90 shifts per year." The radiographer did not, in fact, provide an estimate of his annual shifts. He only recalled that he worked 80%–90% of the weekends, one or two shifts per weekend. Anigstein (2011) used this information to estimate the annual shifts. Given the importance of this information in determining external exposures to radium sources, this statement should be clarified so as not to incorrectly attribute our conclusion to the worker.

The copetitioner had several comments on the third full paragraph on p. 23 (Allen 2014). In response to one of these comments, the second sentence of this paragraph should be changed to "The most likely value will be . . . ." (Added text underlined and displayed in red) To resolve another comment, NIOSH should cite the references for the upper limits of the triangular distribution. NIOSH may choose to cite our previous report (Anigstein and Mauro 2013b), which discusses the sources of these exposure limits and provides the required documentation. In response to a third comment, a citation should be included to document the statement that applicable AEC limits were never exceeded. A suggested reference is NRC (2009c, p. 26).

### 1.8 Section BB.4.5: External Dose Estimate for Portable X-Ray Machines

As noted by the copetitioner, the last sentence in the first paragraph of Section BB.4.5 should be corrected as follows: " Nor would they have been used near other~~s~~ sources of radiation." (Extraneous text crossed out and marked in blue)

### 1.9 Section BB.4.7: External Dose Estimate Summary

We note an error in the maxima of the triangular distributions used to characterize photon exposures to plant personnel listed in Table 8 (Allen 2014). The values of the maxima, which are based on the AEC exposure limits in effect during each year of the Radium Era, are listed as 15 R/y for 1952–1961, and 12 R/y for 1962. However, the AEC lowered the exposure limit to a maximum of 3 R per quarter, or 12 R/y, effective January 1, 1961 (Anigstein and Mauro 2013b). The maximum of the distribution for 1961 should therefore be 12 R/y.

We disagree with the prescription for dose reconstruction presented by Allen (2014, Section BB.4.7). During the Radium Era, radiography using radium sources is assumed to have taken place during 30% of a given shift. The same radiographer could have been in the Old Betatron Building radiographing uranium during the time he was not working with radium. In fact, in recounting an interview with a former GSI radiographer who worked during the Radium Era, Anigstein (2011) reported: "During his weekend shifts as a radiographer, he did both radium and betatron radiography—perhaps 50%–60% of the time using the betatron, the remainder using radium." As listed in Table 3 of this memo, a maximum of 54.7 shifts/y were devoted to the radiography of uranium, which represent ~13% of the assumed 406.25 shifts in a work year, leaving ample time for both functions to be performed by the same worker.

To be claimant favorable, NIOSH should assume that a radiographer spent 70% of each shift in the Old Betatron Building during 1952–1962, during which time he participated in all the uranium radiography performed at GSI during any given year, and spent the remainder of his time in that building radiographing steel. He should be assigned all of the ß skin dose from uranium handling and a portion of the ß skin dose from handling irradiated steel, based on the hours available for the latter task. The average annual shifts spent on betatron radiography of steel can be calculated by taking 70% of 406.25 shifts/y and subtracting the shifts spent on uranium radiography—the results are shown in Table 5 of this memo.

Table 5. Annual Doses to Skin of Radiographers from Beta Radiation During 1952–1962 (rads)

| Year | Annual number of shifts | | Hands and forearms | | | Other skin | | |
|---|---|---|---|---|---|---|---|---|
| | Uranium | Steel[a] | Uranium | Steel | Total | Uranium | Steel | Total |
| 1952-1957 | 54.7 | 229.7 | 31.96 | 2.21 | 34.17 | 2.03 | 1.51 | 3.55 |
| 1958 | 45.8 | 238.5 | 26.79 | 2.29 | 29.08 | 1.70 | 1.57 | 3.28 |
| 1959-1960 | 42.2 | 242.2 | 24.66 | 2.33 | 26.98 | 1.57 | 1.60 | 3.16 |
| 1961 | 48.4 | 235.9 | 28.31 | 2.27 | 30.57 | 1.80 | 1.56 | 3.35 |
| 1962 | 35.2 | 249.2 | 20.55 | 2.39 | 22.94 | 1.31 | 1.64 | 2.95 |

[a] Adjusted for 70% of work hours devoted to betatron radiography

A similar approach should be used to calculate neutron ambient dose equivalents, shown in Table 6 of this memo, where we derived annual neutron doses by multiplying the neutron doses to the betatron operator from uranium and steel, listed in Table 1 of this memo, by the number of shifts devoted to the betatron radiography of uranium and steel, respectively.

Table 6. Annual Neutron Ambient Dose Equivalents, H*(10), to Radiographers (rem/y)

| Year | Annual number of shifts | | H*(10) | | | |
|---|---|---|---|---|---|---|
| | | | Uranium | | Steel radiography | Total |
| | Uranium | Steel[a] | Handling | Radiography | | |
| 1952-1957 | 54.7 | 229.7 | 0.043 | 0.080 | 0.197 | 0.320 |
| 1958 | 45.8 | 238.5 | 0.036 | 0.067 | 0.204 | 0.308 |
| 1959-1960 | 42.2 | 242.2 | 0.033 | 0.062 | 0.208 | 0.303 |
| 1961 | 48.4 | 235.9 | 0.038 | 0.071 | 0.202 | 0.311 |
| 1962 | 35.2 | 249.2 | 0.028 | 0.052 | 0.214 | 0.293 |
| 1963 | 9.6 | 396.7 | 0.008 | 0.014 | 0.340 | 0.361 |

[a] Adjusted for 70% of work hours devoted to betatron radiography during 1952–1962

For the years 1963–1966, the limiting external exposure scenario is the layout man, as stated by Allen (2014). However, the skin and neutron doses need to be reconciled with the values in

Table 4 of this memo. As stated earlier in this memo, the neutron doses should be expressed in terms of the ambient dose equivalent. These doses, calculated by SC&A, are shown in Table 6 of this memo.

## 1.10 Section BB.5.1: Intakes from Handling Uranium Metal

The first sentence of the third paragraph of Section BB.5.1 should be corrected as follows: "Twenty-five samples from three different sites were found to ~~be~~ represent the airborne activity . . .

## 1.11 Section BB.5.4: Summary of Intakes of Radioactive Material

The value of 1.47 dpm/cal. day for intake of uranium by inhalation during uranium-handling operations for the period 1/1/1966–6/30/1966, listed in Table 10 (Allen 2014), is in error. The author apparently multiplied the uranium work hours during the first 6 months of 1966 by the airborne activity of 68.7 dpm/$m^3$ (the consensus value accepted by the TBD-6000 work group) and the breathing rate of 1.2 $m^3$/h, and then divided by 365 d/y. The correct divisor is 181 days—the number of calendar days in the first 6 months. The corrected value is 2.96 dpm/cal. day.

We also question the method for calculating the ingestion rate. According to OCAS-TIB-009 (OCAS 2004), the ingestion rate—in units of dpm—during an 8-h day is numerically equal to 20% of the average air concentration in dpm/$m^3$. Allen (2014) apparently calculated the ingestion per 8-h day as 20% of the assumed concentration of uranium dust during uranium handling operations. then assigned this intake during each year of operations, regardless of the uranium work hours during a given year. This ignores the long periods in between uranium handling operations, when the only airborne uranium was from resuspension.

While this method is claimant favorable, it does not appear to be consistent with the methodology of OCAS-TIB-009. We believe that the ingestion rate should be based on the average air concentration over the course of the work year. Since the daily inhaled intake is 9.6 times the average air concentration (1.2 $m^3$/h [assumed breathing rate] × 8 h/d = 9.6 $m^3$/d), the ingested intake should be 2.08% of the inhaled intake ($0.2 \div 9.6 \approx 0.0208$) during any 8-h work shift. The ingestion rates during the operational period would thus range from 0.06 to 2.38 dpm/calendar day, rather than having the fixed value of 15.45 dpm/calendar day listed by Allen (2014, Table 10). Finally, we suggest revising the title of Table 10 to indicate that the intakes are of uranium, for the benefit of the casual reader.

## 1.12 Section BB.6: Residual Contamination

We found two problems with the ingestion rates presented by Allen (2014, Table 11), who lists uranium intakes during the residual period. First, if we were to accept Allen's method of calculating the rates based on the airborne uranium concentration during metal handling, the value for 7/1/1966–12/31/1967 would be 15.45 dpm/cal. day rather than 15.88. The latter value was apparently copied from the total daily inhalation rate for 1966 in Table 10, rather than the ingestion rate for that year. However, as we stated in Section 1.11, we believe that the ingestion rate should be calculated as 2.08% of the average inhalation rate in a given year.

The remaining data in Table 11 (Allen 2014) are consistent with the agreed-upon methodology of calculating inhalation rates and external exposure rates. Repeating our comment on the title of Table 10, we suggest that the title specifies that the intakes in question are of uranium.

## 1.13 Section BB.7: References

It would be helpful to include live links to web pages, when available, in all references.

### 1.13.1 Reference "AEC 1962"

The citation for Reference "AEC 1962" should be changed to the title listed by NRC (2009d, Appendix A): "General Steel Industries Byproduct Materials License for Cobalt-60 Sealed Source not to exceed 1 curie." The correct date is 04/30/1963. The title and date cited by Allen (2014, Section BB.7) refer to a document inside this parent document; however, the page number cited by Allen is from the parent document, so the reference should be to the parent document.

### 1.13.2 Reference "AEC 1962a"

The citation for Reference "AEC 1962a" should be changed to the title listed by NRC (2009d, Appendix A): "Compliance Inspection Report from General Steel Industries for License Number 12-8271-1." The correct date is 11/6/1962.

### 1.13.3 Reference "Kleber 1962"

The citation for Reference "Kleber 1962" should be changed to the title listed by NRC (2009d, Appendix A): "Letter to James Mason from L. A. Kleber enclosing an application for two Cobalt-60 radiographic sources."

### 1.13.4 Reference "NCC 1962"

The citation for Reference NCC 1962 should be changed to the title listed by NRC (2009d, Appendix A): "Letter to James Mason from L. A. Kleber regarding an area radiation survey that was made of the Radiographic Exposure Facility in Granite City, Illinois." The correct date is 9/7/1962. The title and date cited by Allen (2014, Section BB.7) refer to an attachment to this parent document. The author of the parent document should be listed as L. A. Kleber, Vice-President-Manufacturing, General Steel Industries.

### 1.13.5 Reference "ORAU Collection"

The citation for Reference "ORAU Collection" should be revised to read: "Oak Ridge Associated Universities (ORAU) 2011, Radium Industrial Radiography Source (ca. 1940s)," http://www.orau.org/ptp/collection/Sources/radiumradiog.htm. (We retain the punctuation style used by Allen, 2014).

#### 1.13.6 Reference "SC&A 2014"

The full title of Reference "SC&A 2014" is "Update of Doses from External Exposure at General Steel Industries" (not "GSI"). The three SC&A references (2008, 2011, and 2014) should be listed in chronological order, earliest first.

#### 1.13.7 Reference "MCNP"

Reference MCNP is not listed in alphabetical order. A more suitable form of this reference is "Los Alamos National Laboratory (LANL). 2011. MCNP5/MCNPX: Monte Carlo N–Particle Transport Code System Including MCNP5-1.60 and MCNPX 2.7.0 and Data Libraries, RSICC Code Package CCC-740 [Computer software and manual]. Oak Ridge, TN: Oak Ridge National Laboratory."

### 1.14 Attachment A

Attachment A (Allen 2014) shows a drawing of the radiographic boundary. This boundary is intended to be circular, all points lying at an equal distance from the center. Instead, it appears to be oval, most probably the result of the width and height of the original figure not being kept in a fixed ratio.

## 2 Conclusions

The revised Appendix BB (Allen 2014) represents a major advance over the original version (Allen and Glover 2007) and is the culmination of nearly 7 years' work on the part of the Work Group on TBD-6000 and its predecessor, the Work Group on Procedures; DCAS; and SC&A. However, our review of the appendix produced a number of findings that still need to be resolved.

### 2.1 Summary of Findings

**Finding 1: Neutron Dose Rates**

Allen (2014) cites values of neutron dose rates without specifying which dosimetric quantities were calculated. Based on the similarity of his numerical values to neutron effective doses calculated by SC&A for the same scenarios, we conclude that these are effective dose rates, which are incompatible with the dose conversion factors listed in OCAS-IG-001 (OCAS 2007). All the neutron doses need to be recalculated—we suggest that DCAS uses neutron ambient dose equivalent, H*(10), rates.

**Finding 2: Beta Skin Dose**

Allen (2014, Table 5) lists annual ß doses to the skin of the betatron operator, other than the skin on the hands and forearms, that are 11%–26% lower than our currently calculated values. The ß doses to the skin on the hands and forearms are 3.6%–13.4% lower than our values for the years 1963–1966. These differences need to be resolved.

**Finding 3: No Dedicated Radiographic Facility in No. 6 Building Prior to 1955**

The copetitioner has presented persuasive evidence that the dedicated radiographic facility in No. 6 Building was constructed in 1955. The mode of the triangular distribution of photon exposure rates during 1952–1962 is based on the use of that facility. Assuming that the radiographer remained at the 2 mR/h boundary of the controlled area during the radiographic exposures rather than in the not-yet-constructed radiographer's office increases the mode from 9.69 to 11.28 R/y during 1952–1955.

**Finding 4: Maximum of Triangular Distribution of Photon Exposures for 1961 Should Be 12 R/y**

Because AEC lowered the exposure limit to a maximum of 3 R per quarter, or 12 R/y, effective January 1, 1961, the maximum of the triangular distribution of photon exposures for 1961 should be 12 instead of 15 R/y.

**Finding 5: Combined Exposures to $^{226}$Ra and Betatron Operations during 1952–1962**

Since radiography using $^{226}$Ra sources occurred during only 30% of a given shift, it is plausible that the same radiographer would have worked in the betatron building, performing radiography on uranium and steel, during the remainder of his shift. It is plausible and claimant-favorable to assume that the radiographer participated in all the uranium work during a given year and spent the balance of his time on the betatron radiography of steel. He should thus be assigned a ß dose to the skin as well as a neutron dose in addition to a triangular distribution of photon exposures during 1952–1962.

**Finding 6: Beta Skin Dose to Layout Man**

The ß doses to the skin of the hands and forearms as well as to the skin on the rest of the body listed by Allen (2014, Table 6) are significantly lower than those calculated by SC&A. These differences need to be resolved.

**Finding 7: Uranium Inhalation from Metal Handling in 1966**

Due to an apparent calculational error, the inhalation of uranium dust during the handling of the metal during the first 6 months of 1966 is understated by a factor of 2.

**Finding 8: Ingestion Intakes Not Consistent with OCAS-TIB-009**

The intakes of uranium particulates via ingestion listed by Allen (2014, Table 10) are significantly higher than the rates derived by applying OCAS-TIB-009 (OCAS 2004) to the airborne uranium dust concentrations, averaged over the work year. Although Allen's rates are claimant favorable, they should be corrected for the sake of consistency with other site profiles, or an explanation given why these rates are valid.

**Finding 9: Ingestion Intakes during Residual Period**

The intakes of uranium particulates via ingestion during the residual period listed by Allen (2014, Table 11) are inconsistent with OCAS-TIB-009 (OCAS 2004), as discussed in Finding 8. Furthermore, they are inconsistent with Allen's methodology for the operational period, since the rate for the first year is equal to the inhalation, rather than ingestion, rate during the last year of AEC operations.

## 2.2 Observations

We have made a number of comments throughout the present memo intended to correct or clarify statements in the text which, although they do not affect the prescribed methods of dose reconstruction, do not accurately represent the GSI site or its activities. Furthermore, there are some errors in wording that should be corrected, and some references that should be cited more precisely to aid the reader in understanding the background of the report. The report could benefit from further editorial improvements, such as consistent use of initial caps in section headings.

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