MEMORANDUM

TO: Advisory Board on Radiation and Worker Health Work Group on TBD-6000
FROM: Robert Anigstein and John Mauro, SC&A, Inc.
DATE: September 6, 2016
SUBJECT: Review of Appendix BB, Revision 2

Review of "Site Profiles for Atomic Weapons Employers that Worked Uranium Metals Appendix BB – General Steel Industries," Revision 2

On May 26, 2016, David Allen (NIOSH/DCAS) issued Revision 2 of Appendix BB to TBD-6000 (Allen 2016). In an email message on June 13, 2016, Ted Katz, Designated Federal Official to the Advisory Board on Radiation and Worker Health (ABRWH), asked SC&A to review this report.

Revision 1 of Appendix BB to TBD-6000 was issued on June 23, 2014 (Allen 2014). On December 10, 2014, Anigstein and Mauro (2014) issued a review of this document that included nine findings. On January 26, 2015, Anigstein and Mauro (2015a) issued a review of the first NIOSH response paper (Allen 2015a). In the process of preparing our replies, we found another issue, which became Finding 10. In a series of reports spanning the period January 8, 2015–July 10, 2015, NIOSH responded to the SC&A findings. The NIOSH responses and our replies to the NIOSH reports were discussed at meetings of the Work Group on TBD-6000 held by teleconference on February 5, 2015, and November 3, 2015. In the course of the reports and memos issued by NIOSH and SC&A, and the discussions during the work group meetings, NIOSH and SC&A reached agreement on resolving all 10 findings. The work group concurred with the resolution of these findings.

1 Resolution of SC&A Findings on Appendix BB, Revision 1

The first step in the present review is to verify that Allen (2016) correctly implemented the agreed-upon resolutions of the 10 findings on Appendix BB, Revision 1, which are discussed below in numerical order. We first state the original finding, and then follow it with a discussion of the NIOSH response to the finding and its final resolution in the revised appendix.

1.1 Finding 1: Neutron Dose Rates

Allen (2014) cited 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 concluded that Allen's values represented effective dose rates, which are incompatible with the dose conversion factors (DCFs) listed in OCAS-IG-001 (OCAS 2007). To resolve this finding, Allen (2015a) stated that "DCAS will revise the calculations to use either ambient dose equivalent or deep dose equivalent conversions."

In reviewing the revised appendix, we find that Allen (2016) lists revised values of neutron doses, but does not identify the dosimetric quantity. Such information is needed by dose reconstructors for selecting the appropriate DCFs in OCAS-IG-001. Based on the similarity of the numerical values listed by Allen to neutron ambient dose equivalent, H*(10), rates calculated by SC&A for the same scenarios, we conclude that these doses are stated in terms of H*(10).

Allen (2016) states that the neutron doses derived from MCNPX simulations should be assumed to originate from neutrons with energies of 100 keV to 2 MeV in calculating organ doses. To see if this assumption was claimant favorable, we chose the lung as a representative organ and calculated the neutron dose rates to the lungs of the betatron operator and of the layout man. We first followed the method prescribed by NIOSH, multiplying the total neutron H*(10) rate at each location by the H*(10)-to-organ-dose-equivalent (HT) conversion factor for 100 keV to 2 MeV neutrons listed in OCAS-IG-001. We compared these results to the neutron doses to the lungs determined by multiplying the H*(10) rates in each of the energy intervals listed in OCAS-IG-001 at each location by the corresponding DCF and summing the results. The results are shown in Table 1.

Table 1. Comparison of Neutron Dose Rates to Lungs Calculated by Two Methods (mrem/shift)

Energy range	Lung DCF	Betatron operator						Layout man	
		Uranium radiography	Uranium handling	Uranium total		Steel radiography		Steel radiography	
		H*(10)	H*(10)	H*(10)	Lung	H*(10)	Lung	H*(10)	Lung
0–10 keV	1.523	0.574	0.003	0.577	0.879	0.160	0.244	0.106	0.162
10–100 keV	0.751	0.100	0.047	0.147	0.111	0.058	0.044	0.084	0.063
0.1–2 MeV	0.579	0.731	0.795	1.526	0.884	0.588	0.340	1.413	0.818
2–20 MeV	1.004	0.063	0.006	0.069	0.069	0.051	0.051	0.234	0.235
Total	—	1.469	0.851	2.319	1.942	0.857	0.679	1.837	1.278
NIOSH[a]	0.579	1.469	0.851	2.319	1.343	0.857	0.496	1.837	1.064
Δ[b]	—	—	—	—	45%	—	37%	—	20%

[a] Lung dose calculated using lung DCF for 0.1-2 MeV neutrons

[b] Δ = Total ÷ NIOSH − 1

The table shows that using the more exact method results in a 45% higher neutron dose to the lungs of the betatron operator during the betatron radiography of uranium and the subsequent handling of uranium metal, a 37% higher dose during the radiography of steel, and a 20% higher neutron dose to the lungs of the layout man. We recommend that NIOSH assigns doses based on the actual neutron energies, which is more claimant favorable and scientifically accurate, and consistent with OCAS-IG-001, which is itself a simplification of ICRP publication 74 (ICRP 1996).

1.2 Finding 2: Beta Skin Dose

Allen (2014, Table 5) listed annual beta doses to the skin of the betatron operator, other than the skin of the hands and forearms, that were 12%–33% lower than the values calculated by SC&A. The beta doses to the skin of the hands and forearms were 3%–14% lower than our values for the years 1963–1966. In a paper responding to Anigstein and Mauro (2014), Allen (2015c) listed revised beta doses to the skin of the betatron operator. In our review of Allen's response paper, we listed our recalculated doses from handling uranium metal and noted that Allen's doses were higher. In Appendix BB, Revision 2, Allen (2016, p. 17) cites doses to the skin of the whole body and of the hands and forearms of the betatron operator as 32.4 and 506 mrad per shift, respectively. These are identical to doses calculated by SC&A. Allen discusses the general methodology used to derive doses to the skin from exposure to freshly irradiated steel, but does not present detailed results of these calculations. Allen (2016, Table 5) lists the annual doses to the skin of the betatron operator during the covered period. We note that these are consistently higher than the SC&A values, the differences ranging from 0.2% to 3.4%. The differences increase with increased annual work shifts spent on radiographing steel, which indicates that the differences in the skin doses are due to differences in calculating the doses from steel, given the agreement on skin doses from uranium metal. As will be shown later in this review, the betatron operator represents the limiting exposure scenario for doses to the skin of the hands and forearms during 1952–1966, and to the skin of the rest of the body during 1952–1962. Allen's skin doses from these exposure scenarios are within 2.5% of the SC&A values. Since these differences are small and claimant favorable, the NIOSH values are acceptable for use in dose reconstructions. We thus conclude that NIOSH has resolved Finding 2.

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

The GSI copetitioner presented credible 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 listed by Allen (2014, Table 8) 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 exposure rather than in the radiographer's office, SC&A calculated the mode to be 11.28 R/y during 1952–1955. In a response paper, Allen (2015a) recalculated the annual exposure to be 11.34 R/y, using a slightly longer exposure duration at the boundary of the controlled area, which is consistent with the exposure scenario based on use of the radiographic facility. Allen (2016, Table 8) lists the mode of the triangular distribution to be 11.345 R/y for 1952–1955. NIOSH has thus resolved Finding 3.

1.4 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 (Allen 2014, Table 8). Allen (2016, Table 8) lists the maximum of the triangular distribution to be 12 R/y for 1961–1962. NIOSH has thus resolved Finding 4.

1.5 Finding 5: Combined Exposures to ^{226}Ra and Betatron Operations During 1952–1962

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

In the first NIOSH response, Allen (2015a) argued that radiography using ^{226}Ra took up an entire shift. However, during a meeting of the Work Group on TBD-6000, held by teleconference on February 5, 2015, three of the four work group members agreed with or leaned towards the SC&A position. In a subsequent response, Allen (2015c) proposed adding 38.75% of the values listed by Allen (2014, Table 1) to the radium radiography dose. During a meeting by teleconference on November 3, 2015, the Work Group on TBD-6000 recommended that the radiographer using radium be assumed to have spent 50% of his shift in the betatron building, and that he likewise be assumed to have performed 50% of the uranium radiography in any given year. NIOSH and SC&A concurred with these recommendations.

Allen (2016, Table 8) shows that the annual exposure of the operator for organs other than the skin of the hands and forearms during 1952–1962 consists of the triangular distribution from ^{226}Ra radiography plus one-half of the air kerma from the residual betatron radiation. Also included is one-half of the beta dose to the skin of the whole body and one-half of the total neutron dose for each year that are listed in Table 5. The combined doses listed in Table 8 comply with the work group's recommendation for this scenario for the time period in question. However, as discussed under Finding 1, above, separate neutron doses should be specified for each energy interval.

1.6 Finding 6: Beta Skin Dose to Layout Man

The beta doses to the skin of the layout man listed by Allen (2014, Table 6) were significantly lower than those that had been calculated by SC&A. In response, Allen (2015b) developed a new model of the exposure of the layout man to irradiated steel, taking into account the intermittent nature of the betatron radiographic exposures. In our reply to Allen's proposed model, Anigstein and Mauro (2015b) agreed that the scenarios, although not realistically describing the operations at GSI, were physically possible and appeared to be conceptually bounding. We disagreed with the assumption that it would take the same amount of time to mark the defects on a thin casting as on a thick one. We proposed a ratio of 3:1, which resulted in 25% of the layout man's time being spent on long shots, and listed the beta doses resulting from this modified scenario. During a meeting of the Work Group on TBD-6000, held by teleconference on November 3, 2015, NIOSH agreed to adopt the assumption that the layout man spent 25% of his time on long shots. The work group unanimously concurred that NIOSH had agreed to resolve the issue reflected in Finding 6 and that this finding can therefore be closed. The beta doses to the skin of the layout man listed by Allen (2016, Tables 8 and 9) are about 1% higher than our calculated values (Anigstein and Mauro 2015b, Table 4), the differences being attributable to differences in calculating the betatron beam intensity. These differences are small and claimant favorable; NIOSH has thus resolved Finding 6.

1.7 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 was understated by a factor of 2. The corrected value is listed by Allen (2016, Table 10). NIOSH has thus resolved Finding 7.

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

The intakes of uranium particulates via ingestion listed by Allen (2014, Table 10) were 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 were claimant favorable, we believed that they should be corrected for the sake of consistency with other site profiles, or an explanation given why these rates are valid. Allen (2015a) responded that DCAS agreed that it would be more appropriate to use the average airborne activity for the year. However, DCAS suggested using the average annual airborne activity for the highest year rather than changing the ingestion rate based on the amount of uranium work for a particular year. During a meeting by teleconference on February 5, 2015, the Work Group on TBD-6000 unanimously concurred that NIOSH had agreed to resolve the issue reflected in Finding 8 and that this finding can therefore be closed. The value of 2.38 dpm/day listed by Allen (2016, Table 10) complies with the agreed-upon resolution of this issue. NIOSH has thus resolved Finding 8.

1.9 Finding 9: Ingestion Intakes During Residual Period

The intakes of uranium particulates via ingestion during the residual period listed by Allen (2014, Table 11) were inconsistent with OCAS-TIB-009 (OCAS 2004), as discussed in Finding 8. Furthermore, they were inconsistent with Allen's methodology for the operational period, since the rate for the first year is the inhalation, rather than ingestion, rate during the last year of the period of AEC operations. Allen (2015a) responded that DCAS intends to use the ingestion rate for the highest operational year for the beginning of the residual period in the next revision to Appendix BB. Allen (2016, Table 11) lists 2.38 dpm/day as the ingestion rate for the period July 1, 1966–December 31, 1967, decreasing by ~21.7% per year in subsequent years, which is consistent with the recommendation in ORAUT-OTIB-0070, Rev. 01 (Sharfi 2012, Table 4-2). The date range for the initial ingestion rate spans 18 months and thus is slightly more conservative than the recommendation in ORAUT-OTIB-0070, which stated that the depletion adjustment factor for Year 1 of the residual period should be 1.00. However, it is consistent with the NIOSH procedure of assigning intakes by calendar year (except for the need to split the year 1966 between the operational and residual periods). This procedure is claimant favorable and is not likely to have a significant impact on dose reconstructions. NIOSH has thus resolved Finding 9.

1.10 Finding 10: External Exposure of Betatron Operator

Allen (2014, Table 9) listed estimates of doses to the skin of the hands and forearms of the betatron operator during 1952–1963 as 1,300 mrem/y. This value was based on the hypothetical 30-keV residual photon radiation from the betatron apparatus after shutdown and was calculated in terms of effective dose rates, which are incompatible with the DCFs listed in OCAS-IG-001 (OCAS 2007).

We proposed an alternative method of deriving doses to the skin as well as to other organs from the residual photon radiation from the betatron apparatus (Anigstein and Mauro 2015a). Our estimate employed assumptions and methods similar to those used to derive our earlier estimate of 26 mrem/week effective dose (Anigstein and Olsher 2012). That dose was based on the ratio of absorbed dose to the female breast from 30-keV photons in the posteroanterior (PA) orientation to air kerma listed by ICRP (1997, Table A.5). Using this value—0.0489 Gy/Gy—we derived a value of 204.5 mrad/week air kerma that corresponds to the MDA of the film badge dosimeter of 10 mrem (10 mrem/week ÷ 0.0489 = 204.5 mrem/week). Since OCAS-IG-001 does list air-kerma-to-organ-dose conversion factors, this quantity can be used for dose reconstructions. Since the radiation is assumed to have an energy of 30 keV, we recommended that NIOSH uses the maximum DCF listed in OCAS-IG-001 for photons with energy (E) < 30 keV in the PA orientation.

Allen (2015c) accepted our proposed value of 204.5 mrad/week air kerma in the PA orientation. Allen proposed using this air kerma rate, together with the air-kerma-to-skin-dose conversion factor for photons, E < 30 keV, to calculate the dose to the skin on the back and sides. However, he assigned only one-half of this dose to the skin of the hands and forearms, since he assumed that the worker's hands were at the side of the body only one-half of the time and in front of the body the rest of the time. He assigned an additional dose of one-half the MDL of the film badge—5 mrem/week or 0.25 rem/y—to account for the time the hands were in front of the body. He assigned a dose of 0.5 rem/y to the skin on the anterior portion of the body, other than the skin of the hands and forearms .

We agreed that the worker would not always have his hands at his sides; however, we did not agree that his hands and forearms would have been completely shielded by his torso during one-half of the time he was working (Anigstein and Mauro 2015b). That would happen only if his hands and forearms were held close together, which cannot be assumed to occur during one-half of his activities. Although some shielding of the hands and forearms by the torso may have occurred during some unknown portion of the setup period, in the absence of more specific information, we recommended that NIOSH assign bounding doses to the skin of the hands and forearms of 6.687 rem/y (10.225 rad air kerma × 0.654 rem/rad = 6.687 rem). Ziemer (2015) reported these proposed values to the ABRWH and stated that the Work Group on TBD-6000 voted to accept the SC&A assumption and that NIOSH had agreed.

Allen (2016, Table 9) includes a “gamma dose” to the skin of the hands and forearms of the betatron operator of 10.225 rad/y, but does not identify it as air kerma. A footnote to the table identifies the energy as E < 30 keV in the PA geometry, but does not specify which DCF value should be used in dose reconstructions. The footnote should be revised to specify a DCF of

0.654 rem/rad, as cited above. Allen (2016, Table 8) likewise includes a contribution of 5.112 rad/y to the "gamma dose" to all organs except the skin of the hands and forearms during 1952–1962. This is based on the agreed-upon scenario of the radiographer's dividing his time equally between betatron operations and radiography using ^{226}Ra. Footnotes to Tables 8 and 9 identify the photons as having E < 30 keV in the PA geometry, but do not specify which DCF value should be used in dose reconstructions. Since the residual radiation from the betatron is hypothesized to have an energy of 30 keV, the maximum rather than the average DCF that corresponds to E < 30 keV should be used for dose reconstructions. These footnotes need to be revised before NIOSH can be deemed to have resolved Finding 10.

2 Limiting Exposure Scenarios

Because of the changes in doses to both the betatron operator and the layout man from the previous version of the appendix for the years 1963–1966, we need to review the selection of the limiting exposure scenario for each of these years.

In the first paragraph under the subheading "Operators," Allen (2016) states: "After 1962, the bounding estimate is the layout man dose estimate for most cases. In the case of the skin ~~to~~ of the hands or forearms, the betatron operator dose estimate is limiting." A minor wording error is shown by the crossed out word in blue and the inserted word in red. More important, this statement is inconsistent with Allen's Table 9, which lists the betatron operator as the limiting exposure scenario for doses to the hands and forearms in 1963, but the layout man for 1964–1966. To resolve this ambiguity and to confirm the assignment of limiting doses to the skin of the hands and forearms, and to the skin of the rest of the body, we calculated the doses to the skin of a worker in each of these two positions during the years 1963–1966.

Table 2. Annual Doses to Skin of Betatron Operator[a]

Year	Neutron: H*(10)	DCF: neutron H*(10)[b]	Neutron dose	Air kerma (mrads)	DCF: air kerma[c]	Photon dose	Beta dose (WB)[d]	Skin dose (WB)[d]	Beta dose (H&F)[e]	Skin dose (H&F)[e]
1963	365	0.879	321	10,225	0.654	6,687	1,530	8,538	6,630	13,638
1964	356	0.879	313	10,225	0.654	6,687	1,350	8,350	3,590	10,590
1965	354	0.879	311	10,225	0.654	6,687	1,320	8,318	3,110	10,108
1966[f]	176	0.879	155	5,112	0.654	3,344	650	4,148	1,320	4,818

[a] All doses are in units of mrem unless otherwise noted.
[b] DCF for neutrons 0.1 MeV ≤ E ≤ 2.0 MeV
[c] See discussion in section 1.10 of the present review
[d] Skin of the whole body (excluding hands and forearms)
[e] Skin of the hands and forearms
[f] Six months of operations

Table 2 lists the annual doses to the skin of the betatron operator from neutrons, photons, and beta rays for each year from 1963 to 1966. We first list the estimated external dose rate from each type of radiation, followed by the appropriate DCF taken from OCAS-IG-001, followed by the product of the DCF and the dose rate, which is the annual skin dose from the radiation in question. (No DCF is listed for beta dose, since the factor is implicitly equal to unity.) The columns headed "Skin dose (WB)" and "Skin dose (H&F)" list the total dose—the sum of the contributions from each type of radiation—to the skin on the indicated portion of the body.

Table 3. Annual Doses to Skin of Layout Man (1963–1966)[a]

Year	Neutron: H*(10)	DCF: neutron H*(10)[b]	Neutron dose	Exposure (mR)	DCF: exposure[c]	Photon dose	Beta dose (WB)[d]	Skin dose (WB)[d]	Beta dose (H&F)[e]	Skin dose (H&F)[e]
All[f]	751	0.879	660	9,002	0.892	8,030	226	8,916	408	9,098

[a] All doses are in units of mrem unless otherwise noted.
[b] DCF for neutrons 0.1 MeV ≤ E ≤ 2.0 MeV
[c] DCF for photons 30 keV ≤ E ≤ 250 keV
[d] Skin of the whole body (excluding hands and forearms)
[e] Skin of the hands and forearms
[f] Years 1963–1966; 6 months of operations in 1966.

Table 3 lists the same quantities for the layout man for the years 1963–1966. As shown in Tables 2 and 3, the layout man constitutes the limiting scenario for the dose to the skin, other than the skin of the hands and forearms, during the years 1963–1966. Since the beta dose makes little or no contribution to organs other than skin, the layout man also constitutes the limiting scenario for doses to other organs. Although the neutron doses to both the betatron operator and the layout man will increase if the doses are calculated separately for each energy range, as recommended in section 1.1 of the present review, such changes are not likely to alter this conclusion. As shown in these tables, the betatron operator constitutes the limiting scenario for doses to the skin of the hands and forearms for each year 1963–1966. This is consistent with Allen's (2016) statement in the text of section BB.4.7, but not with Table 9, which lists the layout man as the limiting exposure scenario during 1964–1966. The last three rows of Table 9 should be revised to list doses to the skin of the hands and forearms of the betatron operator instead of the layout man as the limiting exposure scenario during 1964–1966.

3 Observations

In our review of Appendix BB, Revision 1 (Allen 2014), Anigstein and Mauro (2014) made a number of comments intended to correct or clarify statements in the text which, although they did not affect the prescribed methods of dose reconstruction, did not accurately represent the GSI site or its activities. The comments also identified errors in wording in order to improve the next revision of Appendix BB. During a meeting of the Work Group on TBD-6000, held by teleconference on February 5, 2015, James Neton (NIOSH/DCAS) stated that editorial comments in the SC&A review of Appendix BB, Revision 1, would be addressed in Revision 2. In our present review, we found instances where revisions or clarifications would lead to a more accurate and defensible presentation of the site profile; we also found errors in wording in the revised text. These are discussed in the same sequence of as they were presented by Allen (2016). Unless otherwise specified, the section numbers are from Allen 2016.

3.1 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, 1966, as stipulating estimates or limits on monthly expenditures for the radiography of uranium metal shapes. 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 the use of Mallinckrodt's estimated expenditures to derive the hours of uranium exposure during the March 1, 1958–June 30, 1961, period. However, we recommend that for the period October 1, 1952–June 30, 1961, NIOSH should refer to the uranium work hours derived from these estimates as "best estimates," rather than "maximum" hours, so as not to overstate the degree of conservatism in the exposure assessments for that period.

3.2 Section BB.4.1: Betatrons

The description of the shooting room in section BB.4.1 described it as surrounded by 10-ft thick walls consisting of 8 ft of sand sandwiched between two 1-ft-thick concrete walls. However, Allen (2016, Figure 3) indicates 10 ft of sand between the shooting room and the control room, and 9 ft on the other three sides. These dimensions, as well as the 1-ft-thick concrete walls containing the sand, were incorporated in the MCNPX model of the New Betatron Building. The text should be revised to reflect these dimensions.

Expanding on a comment by the copetitioner, we recommend 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 cited by Allen (2016) 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.

3.3 Section BB.4.3: Betatron Operations External Dose Estimate

In section BB.4.3, Allen (2016) stated: "While shooting steel, the betatron was assumed to always be shooting a large steel object on a railcar. *This angle* produced the highest dose rate for the layout man location… [italics added]" "This angle" is not identified—the revised appendix should state that the beam was oriented in a horizontal direction, perpendicular to the casting.

In discussions of the beta skin dose, Allen (2016) refers to dose rates at a distance of 1 cm from the surface of the metal and states that this was essentially in contact. In fact, the beta dose rates were calculated in actual contact with the surface of uranium and of irradiated steel—this should be corrected in the revised appendix.

The sixth line of the second-to-last paragraph on p. 19 should be corrected by inserting the text shown in red: "only one casting is worked per shift."

[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.

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

In describing the triangular distribution of exposures from radium radiography, Allen (2016, p. 25) states: "The maximum will be the AEC limit (15 rem/yr or 12 rem/yr depending on the year) (AEC 1960, NBS 1949)." The reference "AEC 1960" is to a 1957 issue of the *Federal Register* in which AEC prescribed a limit of 300 mR/week, the same as in NBS Handbook 41, cited by Allen as "NBS 1949." The notice that lowered the maximum annual exposure to 12 R/y is found at "*Federal Register 25*(224), 10914–10924." The *Federal Register* citation should be corrected in the list of references.

3.5 Section BB.4.7: External Dose Estimate Summary

The sixth sentence in the first paragraph of section BB.4.7 reads: "If it is assumed at least 10 minutes is necessary for setting up and removing the film and other tasks associated with radium radiography to would total 100 minutes per shift." There appears to be some text missing after the word "to."

3.6 References

Allen (2016) listed five new references that did not appear in the previous version of this Appendix (Allen 2014). We have already commented on the reference "AEC 1960" in section 3.4 of the present review. Corrections are needed to three other references, as discussed below.

3.6.1 AEC 1963

The reference "AEC 1963" refers to "Amendment 5," and lists a date of February 14, 1968. The document which contains the cited information is Amendment 1, dated April 22, 1963.

3.6.2 AEC 1968

The reference "AEC 1968" lists a date of February 15, 1963. The correct date is February 14, 1968.

3.6.3 MCNPX

The reference "MCNPX," which is to the MCNPX user's manual, version 2.7.0, has an incorrect document number and date. The document number is LA-CP-11-00438; it was issued in 2011.

4 Conclusions

NIOSH has resolved Findings 2–9. Finding 1 remains unresolved until NIOSH addresses the use of energy-dependent DCFs to calculate neutron doses. Finding 10 would be resolved if NIOSH identifies the "gamma doses" listed by Allen (2016, Tables 8 and 9) as air kerma and specifies the use of the maximum DCFs for photons with E < 30 keV to convert these air kerma values to organ doses. Table 9 should be revised to indicate that the betatron operator constitutes the limiting exposure scenario for doses to the skin of the hands and forearms.

References

Allen, D. 2014. "Site Profiles for Atomic Weapons Employers that Worked Uranium Metals: Appendix BB – General Steel Industries," Battelle-TBD-6000, Appendix BB, Revision No. 1. http://www.cdc.gov/niosh/ocas/pdfs/arch/b-6000-apbb-r1.pdf

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