TO: Advisory Board on Radiation and Worker Health, Work Group on TBD-6000
FROM: Robert Anigstein and John Mauro, SC&A
SUBJECT: Review of NIOSH Response Paper No. 1
DATE: Monday, January 26, 2015

Review of "Responses to Sanford Cohen & Associates Review of Battelle-TBD-6000 Appendix BB (General Steel Industries, Rev. 1)," Response Paper

On January 8, 2015, David Allen (NIOSH/DCAS) issued two "Response Papers," responding to our review of a revision of Appendix BB to TBD-6000 (Anigstein and Mauro 2014b). The present memo is our reply to the first of these Response Papers (Allen 2015a). We will comment only on those finding that require further discussion.

Finding 1: Neutron Dose Rates

In referring to the fact that Appendix BB, Rev. 1 (Allen 2014), lists effective doses from neutrons, Allen (2015a) stated:

> The values in Appendix BB match the numbers agreed to during an exchange of files between SC&A and NIOSH prior to the drafting of the appendix revision. Both SC&A and DCAS neglected to realize at the time that calculating effective dose was not appropriate.

To understand the genesis of the use of effective dose from exposures to neutrons, we need to understand what transpired between SC&A and NIOSH during and prior to the January 16, 2014, meeting of the Work Group on TBD 6000, when NIOSH and SC&A, with the approval of the work group, agreed on the assignment of doses from penetrating external radiation. We first need to return to the initial SC&A (2008) review of Appendix BB, Rev. 0 (Allen and Glover 2007). At that time, we noted that Allen and Glover did not include exposure to neutrons in their GSI site profile. We calculated photon exposures in roentgens since at least some of the photon exposures (referred to as "doses" by Allen and Glover) were listed in those units. In order to demonstrate the significance of neutron exposures in comparison to photons, we elected to express the effects of the two types of radiation in terms of effective dose, the most commonly used quantity for radiation protection. Our purpose was to critique the NIOSH model, not to prescribe a methodology for future dose reconstructions.

To help SC&A and NIOSH explain differences in the results of the exposure assessments, the two organizations exchanged MCNPX input and output files used in their respective analyses. Allen (2012a, 2012b) presented dose rates from neutrons emitted during betatron operations at GSI. The results were listed in mrem, but the dosimetric quantity was not specified. However, an examination of the MCNPX input files used for these analyses, which David Allen transmitted to the senior author of this memo, show that the results are reported as effective dose. (In fact, the input files were based on the files previously furnished to NIOSH by SC&A, which contained neutron-fluence-to-effective-dose conversion coefficients listed by ICRP, 1997.)

In late 2013, we revised our neutron dose calculations, using a more recent version of MCNPX and improved code parameters. To maintain continuity with previous analyses, we again expressed the results in terms of effective dose. As requested, we shared our MCNPX input and output files with NIOSH. NIOSH agreed with our method of deriving doses based on the output of our MCNPX analyses. It was our understanding at the time that the purpose of the information exchange was to agree on the models used to calculate the doses, not to prepare a prescription for dose calculations.

Following the exchange of MCNPX files and subsequent calculations of ß skin doses, we realized that NIOSH was planning to use our MCNPX output files as the bases of their dose calculations for GSI. We also realized that NIOSH would need a dosimetric quantity other than effective dose to calculate organ doses from neutron radiation. By this time, however, we had started the final set of MCNPX computer runs to calculate neutron doses. We would have had to perform a new set of MCNPX simulations to calculate neutron ambient dose equivalents (one of the quantities that could be used for such assessments), which we anticipated would require several days of running time. There was not enough time to perform these analyses prior to the next work group meeting, which was scheduled for January 16, 2014. Furthermore, to quote from our earlier report, "During the December 19, 2013, meeting of the ABRWH Work Group on TBD-6000, SC&A was asked to provide an update to our previously calculated doses to GSI employees from external exposure to penetrating radiation (Anigstein and Mauro 2014a)." The calculation of neutron ambient dose equivalents was not part of that assignment. We did perform these analyses as part of our review of Allen (2015a) to determine the numerical differences between effective doses and ambient dose equivalents and to demonstrate that the two quantities could not be used interchangeably. (We found that each of these runs required between 96 and 158 hours of computer time, confirming our previous expectations).

We concur with the DCAS decision to "revise the [neutron dose] calculations to use either ambient dose equivalent or deep dose equivalent conversions [Allen 2015a]." DCAS may choose to use the MCNPX files that we used to calculate the neutron ambient dose equivalent, which we furnished to DCAS on September 29, 2014. The input files included in that set were based on the MCNPX neutron dose calculations performed during December 2013–January 2014—the only significant differences were the substitution of ICRP (1997, Table A.42) neutron-fluence-to-ambient-dose-equivalent coefficients for neutron-fluence-to-effective dose coefficients (ICRP 1997, Table A.41). These earlier MCNPX input files were developed in close collaboration with John Hendricks, one of the authors of the MCNPX code, and are considered to be reliable.

Finding 2: Beta Skin Dose

Allen (2015a) is correct in stating that "DCAS and SC&A exchanged files and reconciled differences late in 2013 prior to the drafting of the revision to Appendix BB." However, it appears that DCAS did not blindly accept the annual ß doses to the skin of the betatron operator that were listed in our memo of December 5, 2013 (Anigstein and Mauro 2013, Table 5), since all the ß doses to the skin on the whole body and on the hands and forearms listed by Allen (2014, Table 5) were higher than those in our memo. Whatever changes Allen made to our doses do not appear to have included the dose rates at 1 m from irradiated steel. We had presented the dose rates at 1 m from irradiated steel as millirads per shift (Anigstein and Mauro 2013, Table 2), but neglected to include them in the annual summaries in our Table 5, which we obtained by multiplying the doses per shift by the number of shifts per year devoted to the radiography of steel.

The intent of our finding was to recommend that DCAS and SC&A reconcile the differences in their assessments of annual ß doses to the skin of betatron operators, since agreement had been previously reached on assumptions and methodology. However, Allen (2015a) stated that

> DCAS intends to correct this in the next revision to Appendix BB. However, the original calculations assumed the steel was irradiated for 30 continuous hours. DCAS intends to adjust the initial dose rate to account for the intermittent irradiation as described in a white paper that recalculates the layout man's beta dose.

We cannot come to closure on this issue until we have had the opportunity to review the planned DCAS assessment of ß skin doses to the betatron operator. We will examine the revised DCAS assumptions and methodology, as well as the results of their calculations of ß skin doses to the layout man, in our upcoming review of the second NIOSH Response Paper (Allen 2015b).

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

DCAS decided to assign the value of 11.34 R/y to the mode of the triangular distribution used to characterize the external exposures of plant personnel to direct photon radiation during the period 1952–1955. This is approximately 0.5% higher than the value of 11.28 R/y proposed in our memo (Anigstein and Mauro 2014b). We would like to take this opportunity to share our evolving understanding of the exposure scenarios that led to this small difference in the two assessments.

Our value was based on an annual exposure duration of 941 h at the 2-mR/h exclusion boundary, while DCAS assumed that the duration of the radiographic exposures was 975 h/y. These values are based on different interpretations of a statement in the initial AEC license application: "A maximum of 30% of each shift is used for actual exposure [NRC 2009, p. 12]."

In an earlier report, Anigstein (2011) performed a bounding assessment of the annual exposure of a radiographer inside the radiographer's office—a small room inside the radiographic facility—during radiography using ^{226}Ra sources. We assumed he remained there for 30% of each shift, or 975 h/y. This calculation, initially intended to be an example of exposures that should be considered as part of the GSI site profile, was later adopted by the Work Group on TBD 6000 with the concurrence of NIOSH and SC&A. In performing the analysis of the radiographer's exposure at the 2-mR/h exclusion boundary, we observed that the AEC license application further stated: "This means the source is seldom exposed for a total of more than 2 or 3 hours for each 8 hour shift." Thus, the 30% can be interpreted to refer to the time the *source* is exposed, rather than the time the film is exposed. Since the source would have been exposed during the 15 s the radiographer needed to position and retrieve the source, it was reasonable to subtract that time from the total time he spent at the exclusion boundary.

The exposure duration assumed by DCAS in deriving exposures at the 2-mR/h boundary during the 1952–1955 period is consistent with the previously adopted exposure duration in the radiographer's office during the 1956–1962 period, as well as being slightly more claimant favorable. We therefore do not object to the DCAS decision to assign the value of 11.34 R/y to the mode of the triangular distribution for 1952–1955.

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

In our recent memo (Anigstein and Mauro 2014b), we recommended that plant personnel employed during the Radium Era (1952–1962) be assigned neutron and ß doses that they could have received while working in the Old Betatron Building, performing radiography of steel and uranium. Previous discussions during meetings of the Work Group on TBD 6000, as well technical reports produced by NIOSH and SC&A, did not address combined exposures to photons, neutrons, and ß rays during this era. Our recommendation is meant to fill the gap in previous discussions—it is not "clearly a change from what had already been discussed and resolved [Allen 2015a]." We made this recommendation upon noting that Allen (2014, Table 8) listed neutron and ß doses of zero to organs other than the skin on the hands and forearms of "operators" during this period. Allen (2014, Table 9) assigned photon doses of 1,300 mrem/y, along with ß and neutron doses, to betatron operators to be used in calculating doses to the skin on the hands and forearms during this period.

Allen (2015a) argued that a radiographer working with radium sources would not have had any spare time to work in the betatron building, asserting that the setup time for radium exposures would be even longer than the 15 min assumed for the betatron.

We disagree for several reasons. The betatron was used to radiograph large, thick castings. The initial shots were set up by the betatron operator and a helper. Since the betatron beam was directional and strongly focused, it was necessary to precisely align the position and direction of the head of the betatron apparatus with the film that was placed behind the casting. In contrast, the radium sources were used for relatively thin castings. Since the radiation was isotropic, there was no directional orientation and the position of the source was less critical.

Allen's (2014) assumption that a radiographer working with radium could not also work with the betatron is also negated by the recollections and dosimetry records of the one GSI radiographer who worked during the Radium Era and provided information about the work practices during that time. A summary of an interview with this worker was presented in an appendix to one of our earlier reports (Anigstein 2011):

> I called [Worker A] again on September 27, 2011 to ask some follow-up questions. The following are his responses.

> 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. He worked 80–90% of the weekends, one or two shifts per weekend. Sometimes there was one person per shift (in the beginning), later increased to two or three per shift, since it made the work go faster and they got more shots.

In the main body of the same report, Anigstein (2011) stated:

> Another approach to estimating the doses to radiographers from ^{226}Ra sources is based on [Worker A's] "Occupational External Radiation Exposure History." . . . We note that he received a whole-body dose of 9.1 rem over 18 calendar quarters, or an average annual dose of 2.02 rem. We also note that [he] performed radiography only on weekends—during the week he worked in the testing laboratory, where he was not knowingly exposed to radiation and would therefore not have been wearing his film badge. We can prorate his doses to those of a full-time radiographer. According to [Worker A], he worked one or two shifts per weekend, 80%–90% of the time. To derive a high-end dose, we assumed [he] performed radiography one shift per weekend, 80% of the time. Thus, he would have worked approximately 40 shifts per year. A full-time radiographer working 406 shifts per year would thus have received an annual dose of 20.5 rem (2.02 rem × 406 shifts/y ÷ 40 shifts/y = 20.5 rem). A low-end estimate is based on the assumption that [he] worked two shifts each weekend, working such weekends 90% of the time. He would have thus worked 90 shifts per year, and the prorated dose to a full-time radiographer would be 9.1 rem/y, which is close to the [mode of the triangular distribution for 1956–1962].

Thus, this worker's dosimetry record and work history indicate that he received a full-time-equivalent photon dose of 9.1–20.5 rem/y, which spans and indeed exceeds the agreed-upon triangular distribution, which has a maximum of 12 rem/y during Worker A's period of employment.[1] Thus it is entirely plausible that a radiographer using radium could have received a dose derived from the triangular distribution and could have also worked with the betatron during the same period.

Finally, we note that, as quoted in the discussion of Finding 3, "A *maximum* of 30% of each shift is used for actual exposure [NRC 2009, p. 12, italics added]." Thus, the radium exposures may have taken less than 30% of the time on some shifts, allowing the radiographers more time to work on the betatron.

We therefore believe that, for the purpose of assigning limiting neutron doses and ß skin doses, radiographers working with radium should be assumed to have also worked in the betatron building. Given the limited number of hours devoted to uranium radiography, it is plausible and

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[1] According to the AEC regulations in effect at this time, in the case of x-ray and γ radiation, 1 R = 1 rem = 1 rad (AEC 1960).

claimant favorable that the same radiographer could have participated in all of the uranium radiography, as well as some of the betatron radiography of steel, during the Radium Era.

Finding 6: Beta Skin Dose to Layout Man

Allen (2015b) presented a detailed discussion of new methodology and assumptions used by DCAS to calculate the ß skin dose to the layout man. We will review this report in a separate memo devoted to this topic.

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

Allen (2015a) agreed that the uranium ingestion intake should be derived from the annual average air concentration, but suggested that it be based on the highest annual average concentration, rather than using the calculated average concentration for each year, which varies with the duration of uranium handling operations in each year. We do not object to DCAS' adopting such an ingestion rate, which, for most years, is intermediate between the one presented by Allen (2014) and one based on our recommendation (Anigstein and Mauro 2014b) and is claimant favorable.

Finding 9: Ingestion Intakes During Residual Period

Allen (2015a) agreed that the uranium ingestion intake during the first year of the residual period should be based on the ingestion rate during the operational period, as discussed under Finding 8 of this memo.

Finding 10: External Exposure of Betatron Operator (New Finding)

Allen (2014, Table 9) lists dose estimates for the skin of the hands and forearms of the betatron operator during 1952–1963 as 1,300 mrem/y. This value is 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 dose conversion factors listed in OCAS-IG-001 (OCAS 2007).

We suggest an alternative estimate of the residual photon radiation from the betatron apparatus, employing assumptions and methods similar to those used to derive the estimate of 26 mrem/week effective dose presented by Anigstein and Olsher (2012). That estimate utilized 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). Again using this value—0.0489 Gy/Gy—we derive a value of 204.5 mrem/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 suggest that NIOSH uses the maximum dose conversion factor (DCF) listed in OCAS-IG-001 for <30 keV photons in the PA orientation.

References

Allen, D. 2012a. "Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations."

Allen, D. 2012b. "Battelle-TBD-6000 Appendix BB General Steel Industries: Addendum to Dose Estimates for Betatron Operations White Paper." http://www.cdc.gov/niosh/ocas/pdfs/dps/dc-btronadd-0312.pdf

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/tbd/b-6000-apbb-r1.pdf

Allen, D. 2015a. "Responses to Sanford Cohen & Associates Review of Battelle-TBD-6000 Appendix BB (General Steel Industries, Rev. 1)," Response Paper. http://www.cdc.gov/niosh/ocas/pdfs/dps/dc-gsiappbbr1-010815.pdf

Allen, D. 2015b. "General Steel Industries Layout man Beta Skin Dose," Response Paper. http://www.cdc.gov/niosh/ocas/pdfs/dps/dc-gsilaybeta-010815.pdf

Allen, D., and S. Glover. 2007. "Site Profiles for Atomic Weapons Employers That Worked Uranium and Thorium Metals - Appendix BB: General Steel Industries," Battelle-TBD-6000, Appendix BB, Rev. 0.

Anigstein, R. 2011. "Update on the Use of Sealed Radioactive Sources at General Steel Industries." http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-gsiradsrc.pdf

Anigstein, R., and J. Mauro. 2013. "Review of Skin Dose Calculations for General Steel Industries." Memo to Advisory Board on Radiation and Worker Health Work Group on TBD-6000. http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-gsiskindose-120513.pdf

Anigstein, R., and J. Mauro. 2014a. "Update of Doses from External Exposure at General Steel Industries." Memo to Advisory Board on Radiation and Worker Health Work Group on TBD-6000." http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-gsiexdose-011214.pdf

Anigstein, R., and J. Mauro. 2014b. "Review of 'Site Profiles for Atomic Weapons Employers that Worked Uranium Metals Appendix BB – General Steel Industries,' Revision 1." http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-gsiapbbr1-121014.pdf

Anigstein, R., and R. H. Olsher. 2012. "Response to 'Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations'." http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-gsibeta-r0.pdf

Atomic Energy Commission (U.S.) (AEC). 1960. "Title 10—Atomic Energy; Chapter 1—Atomic Energy Commission: Part 20—Standards for Protection Against Radiation." *Federal Register, 25*(224), 10914–10924.

International Commission on Radiological Protection (ICRP). 1997. “Conversion Coefficients for use in Radiological Protection against External Radiation,” ICRP Publication 74. *Annals of the ICRP*, *26* (3/4). Tarrytown, NY: Elsevier Science, Inc.

Nuclear Regulatory Commission (U.S.) (NRC). 2009. “General Steel Industries Byproduct Materials License for Cobalt-60 Sealed Source not to exceed 1 curie.” ADAMS acquisition number ML093431334.

Office of Compensation Analysis and Support (OCAS). 2004. “Technical Information Bulletin: Ingestion Intakes,” OCAS-TIB-009, Revision No. 0. http://www.cdc.gov/niosh/ocas/pdfs/tibs/oc-t9-ro.pdf

Office of Compensation Analysis and Support (OCAS). 2007. “External Dose Reconstruction Implementation Guideline,” OCAS-IG-001, Revision No. 3. www.cdc.gov/niosh/ocas/pdfs/dr/oc-ig-001-r3.pdf

S. Cohen & Associates (SC&A). 2008. “Review of ‘Site Profiles for Atomic Weapons Employers That Worked Uranium and Thorium Metals - Appendix BB: General Steel Industries,’ Battelle-TBD-6000, Appendix BB, Rev. 0.” http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-gsisp-r1.pdf