Draft

ISSUE RESOLUTION MATRIX FOR SC&A FINDINGS ON APPENDIX BB TO TBD-6000

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INTRODUCTION

The present document presents an update of the issues arising from the SC&A review of Appendix BB to "Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals" (Allen and Glover 2007). It is current as of the last meeting of the Advisory Board on Radiation and Worker Health (ABRWH) in Santa Fe, New Mexico, June 19-21, 2012. A separate issues matrix pertaining to SC&A findings on the General Steel Industries (GSI) Special Exposure Cohort (SEC) petition and the corresponding National Institute for Occupational Safety and Health (NIOSH) evaluation report (ER) was last updated on June 1, 2012. Although the two SC&A reports that form the bases of these matrices have different objectives, there is considerable overlap between the two sets of issues and hence the two matrices.

Time Line of Appendix BB Issues Matrix

- June 25, 2007: NIOSH issued Appendix BB to "Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals" (Allen and Glover 2007).
- March 17, 2008: SC&A (2008) issued a review of Appendix BB. Errata sheets correcting two tables in the report were sent out on March 20, and a revised version that complied with the Privacy Act was released on April 21.
- May 2, 2008: SC&A distributed the "Issue Resolution Matrix for SC&A Findings on Appendix BB" which listed 13 issues. These issues were taken from the list of 13 findings[1] presented in the executive summary of our review of Appendix BB (SC&A 2008).
- June 19, 2008: NIOSH responded to the 13 issues, inserting its responses in the boxes labeled "NIOSH Response."
- December 16, 2009: The ABRWH Work Group on TBD 6000/6001[2] met in Hebron, Kentucky, and recommended action items to NIOSH regarding the Appendix BB issues.
- April 24, 2010: Paul Ziemer, Chair of ABRWH Work Group on TBD-6000, issued a memo summarizing the action items from the December 16, 2009, work group meeting (ABRWH 2010). We have summarized each action item pertaining to Appendix BB in the box labeled "Board Action."
- October 08, 2010: Allen (2010) prepared the "Path Forward for GSI Appendix and ER Review" in which he presented the proposed NIOSH responses to several of the Appendix BB issues. We have summarized these responses in boxes labeled "Path Forward" in the appropriate locations in the matrix.

[1] The "findings" in the earlier report are presented as "issues" in the present document.

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

- October 12, 2010: The Work Group on TBD-6000 met in Hebron, Kentucky. The work group asked SC&A to update both the Appendix BB and the GSI SEC issues matrices to reflect work group recommendations and the NIOSH responses in the "Path Forward."
- July 25, 2011: SC&A updated the the Appendix BB issues matrix, appending an observation or reply to each relevant issue in the appropriate location in the matrix. We also listed the current status of each issue.
- August 10, 2011: Allen (2011b) prepared "Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Portable Radiography Sources."
- September 15, 2011: Anigstein (2011a) prepared "Review of NIOSH Report on Portable Radiography Sources at GSI—August 2011."
- September 17, 2011: SC&A updated the SEC issues matrix, incorporating our review of Allen 2011.
- September 20, 2011: The Work Group on TBD-6000, meeting in Hebron, Kentucky, tasked SC&A with interviewing two former GSI workers and a former GSI contractor.
- October 4, 2011: Macievic (2011) prepared a report entitled "Evaluation of the Response of Film Badges to High Energy Photons."
- October 20, 2011: Anigstein (2011b) prepared a white paper: "Update on the Use of Sealed Radioactive Sources at General Steel Industries."
- October 28, 2011: Anigstein et al. (2011) issued a memo reviewing Macievic 2011.
- January 13, 2012: Allen (2012a) prepared "Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations."
- March 12, 2012: Anigstein and Olsher (2012) prepared "Response to 'Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations'."
- March 15, 2012: The Work Group on TBD-6000 met in Hebron, Kentucky. The work group asked SC&A to update the SEC issues matrix to reflect Allen 2012a, Anigstein and Olsher 2012, and discussions of these reports at the meeting.
- March 22, 2012: SC&A updated the SEC issues matrix, incorporating all developments since September 15, 2011.
- March 23, 2012: Allen (2012b) prepared "Battelle-TBD-6000 Appendix BB General Steel Industries: Addendum to Dose Estimates for Betatron Operations White Paper."
- March 25, 2012: Anigstein and Mauro (2012a) issued a memo to the work group

entitled “Review of ‘Addendum to Dose Estimates for Betatron Operations White Paper’.”

- March 28, 2012: The Work Group on TBD-6000 met in Hebron, Kentucky and took two votes on recommendations to the full board regarding the SEC petition for various periods.

- May 30, 2012: Anigstein and Mauro (2012b) issued a memo to the work group updating SC&A’s review of occupational internal dose at GSI.

- June 1, 2012: SC&A updated the SEC issues matrix, incorporating all developments since March 22, 2012.

- June 8, 2012: Allen (2012c) responded to Anigstein and Mauro (2012b).

- June 11, 2012: Anigstein and Mauro (2012c) issued a memo to the work group, replying to Allen (2012c).

- June 14, 2012. The Work Group on TBD-6000 held a teleconference meeting, during which a work group member questioned the use of surrogate data from TBD-6000 (Allen 2011a) to characterize the airborne uranium concentrations at GSI. The work group voted not to recommend action on the GSI SEC petition to the full board, pending resolution of the surrogate data issue.

- June 20, 2012. The ABRWH, at its meeting in Santa Fe, NM, tasked SC&A with reviewing the use of Allen’s (2011a) surrogate data to characterize the airborne uranium concentrations during uranium handling operations at GSI.

- July 16, 2012. Anigstein (2012) transmitted a report reviewing the use of Allen’s (2011a) surrogate data to characterize the airborne uranium concentrations during uranium handling operations at GSI.

- July 25, 2012. Anigstein et al. (2012) transmitted a memo suggesting an alternative model for the calculation of uranium intakes at GSI.

- July 28, 2012: SC&A updated the matrix, including all developments up to the current date.

Status Summary

- Issue 1 (data sources): *Open.*
- Issue 2 (period of covered employment): *Open.*
- Issue 3 (betatron beam intensity): SC&A recommends that this issue be *Closed*.
- Issue 4 (underestimate of stray betatron radiation): *Open.*

- Issue 5 (other radiography sources): *Open.*
- Issue 6 (skin dose) : *Open.*
- Issue 7 (residual radiation from betatron apparatus): SC&A recommends that this issue be *Closed*.
- Issue 8 (work hours): *Closed* —Dr. Ziemer noted that the Work Group, NIOSH, and SC&A are in agreement.
- Issue 9 (work practices): SC&A recommends that this issue be *Closed*.
- Issue 10 (dose rates from uranium): *Open*.
- Issue 11 (doses to other workers): *Open*.
- Issue 12 (surface contamination and resuspension): *Open*.
- Issue 13 (incorrect units): *In Progress,* pending completion of revised Appendix BB.

Level of Importance

We have assigned four levels of importance to these issues, which we define in the following manner:

- **High**: Capable of having a significant impact on individual dose reconstructions and hence on the probability of causation (POC) for the claimants.
- **Medium**: Could alter the POC for some individuals.
- **Low:** Recommended technical improvements in the accuracy of dose reconstructions, but unlikely to have major impacts in most cases.
- **N/A:** Not applicable because issue was closed by action of the Work Group or SC&A recommends that the issue be closed.

We have assigned the following levels of importance to these issues:

- Issues 1, 4–6, and 11–12: *High*
- Issues 2 and 10: *Medium*
- Issue 13 (use of correct and consistent units of dose and exposure): *Low*
- Issues 3 and 7–9: *N/A*

Issue Resolution Matrix for SC&A Findings on Appendix BB to TBD-6000

Issue 1: Completeness of Data Sources

SC&A Finding: The authors of Appendix BB have not utilized some key information on the GSI Granite City site. For example, they failed to note the presence of two betatrons, housed in two different buildings, as indicated in the reports by Murray and Uziel (1992), and Murray and Brown (1994), and as was brought out at the General Steel Industries Worker Outreach Meeting on August 21, 2006. Other examples of incomplete utilization of available data are presented in the context of other findings discussed below.

NIOSH Response (6/19/08): The information was used in the preparation of the appendix though it was admittedly not well documented. The presence of a second betatron likely would not change the modeled exposure (since a worker could be in proximity to only one at a time), but information that has been refined since the earliest discussions might affect the modeled dose. However, NIOSH has obtained film badge results for the betatron operators and is in the process of comparing this data to the modeled doses.

Board Action (12/16/09): Discussed at meeting of the Work Group on TBD-6000/6001.

Action items: (4/24/10) (ABRWH 2010):

- Concerning Landauer report on Picker X Ray film badge records, NIOSH is still awaiting a report back from Landauer. (*Reference: p. 125 of the 12/[16]/09 transcript*.)
- NIOSH is to evaluate new source term information (that had been identified by the petitioner) to determine if Appendix BB needs to be updated/revised. (*Reference: p. 125 of the 12/[16]/09 transcript.)*

SC&A Observations (7/23/11)**:** During a telephone conversation with Robert Anigstein (SC&A), the late [redacted], former betatron supervisor, hypothesized that since GSI purchased x-ray film from Picker, they might have obtained their film badges from that company before switching to Landauer in November 1963. This hypothesis was buttressed by our learning that Picker had, in fact, offered film badge dosimetry services, and that there were currently one or more file cabinets labeled "Picker" at Landauer. However, the Atomic Energy Commission (AEC) licensing records indicate that film badges during 1962–1963 were provided by the Nuclear Consultants Corporation (no longer in business).

7/28/12**:** NIOSH should take note of information about external exposures prior to the Landauer film badge program that started in November 1963. Specific data include the exposure records for [redacted] that, together with information obtained by SC&A in interviewing [redacted], demonstrate that there was a film badge monitoring program as far back as 1957. Additional information is the report to AEC that AEC external exposure limits were never exceeded from 1953 onward.

In calculating internal exposures from intakes of uranium, NIOSH should take note of the contamination survey of the Old Betatron Building prior to the cleanup under FUSRAP in June 1993.

Status (7/28/12)**: Open.**

Issue 2: Period of Covered Employment

SC&A Finding: Appendix BB states that the covered activities took place in 1953–1966. It is plausible and claimant favorable to assume that this work began in 1952. We base this assumption on Atomic Energy Commission "Correspondence Reference Form," with a hand-corrected date of December 5, 1952, that has a summary titled, "Regarding ingots of uranium metal furnished to General Steel Castings Co. for betatron testing." Since the Army installed the first betatron in Granite City in January 1952, an event that was reported in a local newspaper, it seems likely that Mallinckrodt would have taken advantage of this facility at an early date.

NIOSH Response (6/19/08): NIOSH uses the official covered period established by the Department of Labor, and does not have the authority to amend that covered period. It is our understanding that this information was available at the time the period was established for GSI however, we will forward the information to the DOL for their consideration.

Board Action (12/16/09: Discussed at meeting of the Work Group on TBD-6000/6001.

Action item (4/24/10) (ABRWH 2010):

- NIOSH to confirm that DOL received information concerning a possible start date for the covered period (1952 rather than 1953). *(Reference: p. [151] of the 12/[16]/09 transcript*.)

SC&A Reply (7/23/11): We have not seen any further communication regarding receipt by DOL of information from NIOSH. We have since found an announcement by the U.S. Army on January 13, 1952, regarding the installation of a betatron at GSI in Granite City, Illinois, reported in the New York Times on the following day. The assumed 1953 starting date is based on a single AEC memo, which is cited by DOE in qualifying the site for inclusion in FUSRAP. DOE would have had no incentive to determine if the starting date could have been 1952, since that would not have affected the eligibility of the site for FUSRAP. DOL should be informed that it is at least equally likely that AEC started utilizing the GSI betatron in 1952 as in 1953.

Conclusion: An additional year of covered employment may affect the POC for some claimants.

Status (7/28/12)**: Open.**

Issue 3: Underestimate of Betatron Beam Intensity

SC&A Finding: The authors assume a betatron beam intensity of 100 R/min (without the aluminum beam-flattening compensator) at a distance of 3 ft from the target. They cite an interview with Jack Schuetz as the source of information that the betatron beam had a "design maximum" output of 100 R/min. This value is inconsistent with the material furnished by Schuetz (2007), which lists outputs of up to 282 R/min. It is also inconsistent with the Allis-Chalmers acceptance criteria for the betatron tubes, which required a minimum output of 220 R/min at 25 MeV. We find that assigning an uncompensated intensity of 250 R/min at 3 ft is reasonable and claimant favorable.

NIOSH Response (6/19/08): To be clear, Mr. Schuetz indicated

> *"Tubes manufactured in the early 1950s produced outputs between 125-150 R/M, the 1960s between 200-275 R/M and by the late 1970s, between 300-375 R/M @ 25 Mv. These levels were only obtainable in my laboratory machine with varying percent reductions depending on individual field locations and whether in-house maintenance personnel or my trained service engineers installed the tubes."*

Mr. Schuetz then went on to list the last 7 tubes purchased by GSI in a table. The shipping dates ranged from 12-29-1969 to 5-31-1973. The output at 25 Mv ranged from 260 to 282. At the 8/11/2006 worker outreach meeting, operators recalled values of 100 R/M from the old betatron and 250 R/M from the new betatron. Based on worker accounts, NIOSH concluded that the old betatron, which dated from the early 1950's could only develop 100 R/m in use at GSI, while the new betatron could develop 250 R/m. This information, along with other refined information and possible issues with uranium [activation], could affect the modeled dose, but NIOSH has obtained film badge results for the betatron operators and is in the process of comparing this data to the modeled doses.

However, as indicated in the SC&A review, NIOSH has obtained film badge results for betatron operators. We are in the process of comparing this data to the modeled estimates provided by both the appendix and SC&A.

Path Forward (10/08/10) (Allen 2010): NIOSH proposes using a value of 100 R/min for the old betatron machine and 250 R/min for the new betatron machine. This is in keeping with recollections of former GSI radiographers that indicate the old betatron had a lower output.

Board Action (10/12/10): Paul Ziemer, Chair of TBD-6000 Work Group, confirmed that NIOSH and SC&A agreed that the unmodulated output of the new betatron should be modeled as 250 R/min at 3 ft from the internal betatron target, which is reduced to approximately 160 by the aluminum beam-flattening compensator. It was also agreed that the output of the old betatron should be modeled as 100 R/min, with the compensator in place.

New Betatron Model (1/13/12 and 3/23/12): Allen (2012a and 2012b) updated the NIOSH betatron model, which utilized the higher output of the 25-MeV betatron as the limiting case for both the new and the old betatrons.

Status (7/28/12)**:** SC&A recommends that this issue be closed.

Issue 4: Underestimate of Stray Radiation from Betatron

SC&A Finding: Appendix BB understates the stray radiation during the operation of the betatrons. Our calculations show higher dose rates in the control rooms than the 0.72 mrem/h cited in the Appendix. We calculated effective dose rates of 208 mrem/h on the roof, which was occasionally occupied by maintenance workers, 22 mrem/h in a restroom, and up to 51 mrem/h in other areas accessible to workers while the betatron was in operation. The Appendix ignores neutrons generated in the betatron target, which make a minor but potentially significant contribution to the effective doses.

NIOSH Response (6/19/08): As indicated in the SC&A review, NIOSH has obtained film badge results for betatron operators. We are in the process of comparing this data to the modeled estimates provided by both the appendix and SC&A. The data includes an area dosimeter from the Betatron control room.

Path Forward (10/08/10) (Allen 2010):

<u>New Betatron Building:</u>

- Develop exposure scenarios for betatron x-ray examination, “shooting scenarios” (shooting angle, duration of exposure, time between exposures, etc.);
- Develop scenarios for potential worker exposures during betatron operations “worker scenarios” (working on the roof, occupying the rest room, etc.);
- Develop a model of the betatron building using new dimension information and “calibrate” the model using the 80 Ci Co-60 source survey;
- Determine dose rate at various locations associated with “worker exposure scenarios” from each of the “shooting scenarios” and include the betatron control room as one location; and,
- Combine dose rates from various combinations of “shooting scenarios” into realistic combinations consistent with a heavy utilization but not to exceed 10 mrem per 168 hours in the betatron control room.

<u>Old Betatron Building:</u>

Similar path forward for the Old Betatron except “worker exposure scenarios” change and there is no “calibration” survey.

SC&A Reply (7/23/11)**:** Before assuming that the dose inside the betatron control room did not exceed 10 mrem per 168 hours, NIOSH needs to establish the following:

- Was film badge No. 001, called "BETATRON CTL," in fact kept in the betatron control room?
- Since there were two betatrons operating at the time, in two separate buildings, do we know which of the two control rooms housed this badge?

Absent any records or worker testimony, we do not agree that this is a correct, claimant-favorable assumption on which NIOSH should base its exposure model.

We also question the assumed MDL of 10 mrem, based on the following observations by Joseph Zlotnicki, CHP (former Landauer official, currently member of SC&A staff):

> *Following is my opinion regarding the Landauer film dosimetry MDL for high energy photons. (>250 keV).*
>
> *While a film dosimeter can readily measure 10 mrem of low energy photons, it is a much more difficult task once the photon energy reaches a few hundred keV or above. The over-response of the film emulsion to x-rays around 40 keV by a factor of 30 was a blessing and a curse for film badge dosimetry and was one of the reasons that film has largely been replaced.*
>
> *It is very difficult to say what the MDL would be for high energy photons, but it almost certainly was higher than 10 mrem, even on a good day. Below are some of the factors that one would need to consider in deriving the MDL. Note that some items are systematic and some vary day to day and person to person:*
>
> - *Film type*
> - *Base fog (age since manufacture and storage conditions)*
> - *Processing*
> - *Storage during the issuance period*
> - *Background radiation levels*
> - *Storage and handling of background, calibration and control film*
> - *Densitometer calibration, sensitivity and step size per density unit*
> - *Calibration methods, energy and lowest dose point*
> - *Rounding and truncation preference*
> - *Film holder design*
> - *Wear location on body (backscatter)*
>
> *As can be seen, there are numerous sources of variation. Based on my experience, a single click (i.e. the smallest quantum of dose) on a good densitometer would have been on the order of 15 mrem for high energy photons. Remember, the assigned dose is determined by subtracting two numbers that are derived from the density on the user film and the density on the background or "blank." The subtraction was probably done in terms of dose, not density, however. In other words, the density on the two films being compared was converted to dose and subtracted in the dose, not density, domain.*
>
> *Other film system reviews have recommended using 40 mrem as the MDL, including the National Research Council report on atmospheric testing and ORAU reports on DOE sites. This might be a little high for Landauer's system, but 20 mrem to 30 mrem might be a better choice than 10 mrem for high energy photons.*

NIOSH Response (10/04/11): Macievic (2011) prepared a report entitled "Evaluation of the Response of Film Badges to High Energy Photons."

SC&A Reply (10/28/11): Anigstein et al. (2011) issued a memo reviewing Macievic 2011. We concluded that the Landauer film badge dosimetry reports for GSI during the 1963–1966 time period are comparable in accuracy to reports of other film dosimeters used at other facilities during that era, and are also comparable to current dosimetry practices.

NIOSH Response (1/13/12): Allen (2012a) assessed the exposures of the layout man working just outside the entrance to the New Betatron Building. The analysis utilized 15 betatron/object geometries, then selected two geometries that would result in a dose of 10 mrem/week at the assumed film badge rack location, assuming the use of a control badge.

SC&A Reply (3/12/12): Anigstein and Olsher (2012) observed that Allen (2012a) assumed a lead shield between the New Betatron Building and the No. 10 Finishing Building that might have not been present prior to 1968, the date of a GSI application to amend their AEC license to permit the use of an 80-Ci ^{60}Co source. We found that (1) the betatron radiographic geometries are unrealistic and not necessarily representative of GSI operations; (2) there is insufficient evidence for the assumption of a betatron control badge; (3) the location of the film badge storage rack was not consistent with worker testimony.

NIOSH Response (3/23/12): Allen (2012b) revised the previous analysis, removing the lead shield, but retaining a thick steel shield. He also moved the location of the film badge rack, but retained other aspects of the analysis.

SC&A Reply (3/25/12): Anigstein and Mauro (2012a) observed that the external exposures to photon, neutron, and beta radiation assigned by NIOSH to the layout man were 2- to 4-fold lower than the limiting exposures proposed by SC&A. We found that the revised NIOSH MCNPX model placed the film badge rack at a distance from the control room but separated by only an air-filled space, neglecting interior walls and intervening equipment. This would increase the exposure rate at the location of the rack and thus suppress the calculated exposures of the workers. We found a lack of realism in assigning doses to the layout man for 1953–1966 based on exposure to stray radiation from the new betatron, since this machine was first installed near the end of 1963.

Board Action:

Status (7/28/12)**: Open**

Issue 5: Failure to Assess Other Radiography Sources

SC&A Finding: The authors acknowledge the use of other radiography sources, notably ^{60}Co, but dismiss the doses from these sources, stating that the doses from the betatron would be more limiting. As shown in our analysis, an 80-Ci ^{60}Co source produced a dose rate of up to 960 mrem/h on the roof of the New Betatron Building, and rates of 12–16 mrem/h in other locations outside the building. Furthermore, stray radiation from a 250-mCi ^{60}Co source that was used in a lightly shielded structure could have produced dose rates in accessible areas of 9–17 mrem/h.

These rates are one to three orders of magnitude higher than the stray radiation cited in the Appendix.

NIOSH Response (6/19/08): As indicated in the SC&A review, NIOSH has obtained film badge results for betatron operators. We are in the process of comparing this data to the modeled estimates provided by both the appendix and SC&A. The data includes operators that indicated they used the sources.

Path Forward (10/08/10) (Allen 2010):

<u>GSI Co-60 sources (1962 on)</u>

- Develop worker exposure scenarios–both radiography room and open area radiography
- Radiographers reported to wear film badges when working with isotopes

- Divide film badge readings into normal and incident readings (assume over 100 mr in a week is an incident)
- Determine frequency and amount of incident exposures and distribution of remaining doses.
- Reconcile "normal" film badge readings with radiographer exposure scenarios
- Add incident exposure based on frequency and amount of incidents

X-ray Machines

- X-ray machine usage described as being infrequent.
- Radiographers wore film badges during betatron operations and source operations (when film badges were issued). A natural assumption is that they would have worn them for x-ray machine operations as well.
- Photon beam from an x-ray machine is directional and pointed at a piece of equipment being examined. It is not realistic to believe it would be routinely pointed at a nearby individual.
- Develop model to determine exposure rate from machine photon leakage and backscatter from steel. Compare dose rates to other sources to determine if further analysis is necessary.

Ra-226 sources

SC&A presented a model for exposure from a 500-mg Ra-226 source using a fishing pole technique. In the model it is assumed the radiographer holds the source for the duration of the exposure. The technique is sometimes performed in that manner but cannot be performed for very long durations because variance in the position of the source will affect the clarity of the radiograph. Therefore, the technique requires the radiographer to hold the source very steady for the duration of the exposure. The fishing pole technique can also be used as a technique to move the source from the shielded container and placing it in a location for the x ray. In both cases, a one minute duration is not unrealistic.

A former GSI worker remembered seeing a pole he believed to be the fishing pole for radiography and estimated its length to be 12 feet. The purpose of the pole is to increase the distance between radiographer and source. The estimate of the source being 1 meter from the radiographer leaves nine feet remaining and defeats the purpose of using a pole. It is more realistic to believe the radiographer is in the middle of the length of pole or near the opposite end from the source. The middle of the pole would represent a six foot distance and the calculation performed by SC&A would change from 28 rem per year to approximately 7 rem per year. Also, the calculation assumes one person performs all the radiography at the site. It is likely that duties were shared and this dose can be at least divided by two to represent at least two radiographers.

St. Louis Testing Sources

St. Louis Testing was contracted to perform some radiography at GSI. The individual that indicated he did this work discussed using a 10 curie Co-60 source outdoors to examine Westinghouse casings. He indicated the exposures took one week and a half a day (180 hours). He also indicated a boundary was delineated at the 2 mr/hr point and 2 radiographers kept the area under constant surveillance. Lastly, he indicated that 10 of these exposures were performed over a six month period. For a typical work week of 65 hours, a GSI employee would be on site for approximately 69.6 hours of each exposure. If at the radiography boundary the entire time, it would equal 139 mrem of dose per shot. Multiplying that by 10 shots equals 1.39 rem of dose over that six month period. The other radiography remembered by the St. Louis Testing employee was the use of a 50 curie Ir-192 source to perform some repair shots in the repair area. The individual indicated that the Ir-192 showed more detail than the betatron and implied this wasn't used a lot because it caused more castings to be rejected.

The 50 curie Ir-192 source would produce a dose rate approximately 1.8 times higher than a 10 curie Co-60 source reducing the duration of the exposure necessary to expose the film. Repair shots would concentrate on a particular area rather than the overall casting. This would allow the source to film distance to be reduced and further shorten the duration of the shot. Lastly, the St. Louis Testing employee implied few shots were performed with this source. Even though the source was stronger, the

2 mr/hr boundary would still be the standard used to delineate an area. Taken together, these pieces of information imply that number and duration of Ir-192 shots should be less than the Co-60 shots while the same 2 mr/hr boundary would be used. It should therefore be a bounding estimate to double the 1.39 rem estimate of the Co-60 source to account for dose from the Ir-192 source.

SC&A Reply (7/23/11): There are no data on radiation exposures from April 1962, when the two ^{60}Co sources were procured, until mid-November 1963, when the Landauer film badge monitoring began. Since the latter date coincides with the installation of the new betatron (transferred from the closed GSI facility in Eddystone, Pennsylvania), exposure conditions were most likely different during the Landauer period. For instance, the expanded use of the betatrons might have led to a *decrease* in the use of sealed sources and thus a lower frequency of incidents. Consequently, it would be inappropriate to apply a model based on the frequency of incidents during the Landauer period to an earlier time.

We agree that workers would not routinely be exposed to the direct beam from the x-ray machines. However, [redacted], a former GSI betatron operator, reported at least one incident in which the x-ray machine was activated with workers in the room (Anigstein 2010b). [Redacted], was presumably wearing his film badge, non-radiographers not wearing film badges could also have been accidentally exposed in this or other incidents of which neither NIOSH nor we have any knowledge.

Allen (2010) is incorrect in characterizing the calculation of exposures of radiographers from ^{226}Ra sources, performed by SC&A (Anigstein 2010a), as a *model*. As stated in our report, "Although we cannot construct a plausible bounding exposure scenario for the exposure of a worker performing ^{226}Ra radiography with the fishpole technique, we can perform a *sample calculation* [italics added] to indicate the potential exposure from such a source." We agree that one former worker recalled walking past the area used for the sealed-source radiography and seeing a pole leaning against the wall that he estimated to be 12-ft long, which he *assumed* was used in the fishpole technique. More reliable information was provided by [redacted], who performed such radiography. He stated that the pole was 4–6 ft long, and that the exposed source was 4–6 ft from his body (Anigstein 2010b). [Redacted] was interviewed after Anigstein (2010a) performed the sample calculation. Given the range of distances recalled by [redacted], we believe that a claimant-favorable distance would be 142 cm (122 [= 4 ft] + 10 [distance from skin to center of torso] = 142).

There is no basis for dividing the exposure among two radiographers. If 10 exposures were performed per shift, these could be accommodated by one worker using a single source if the average exposure was less than, say, 45 minutes. If the exposures were longer, the same worker could set up one exposure, then use the second radium source to set up another exposure in a different location. Distributing the work among two radiographers is not based on factual data and is not claimant favorable.

We do not agree with the estimated exposures of GSI workers from radiography performed by St. Louis Testing. As stated by Anigstein (2010a, PA-cleared version):

> *Mr. Sinn [of St. Louis Testing] later explained that he meant that there was one radiographer on each shift. . . With only one radiographer on duty, there would have thus been times when the area was unattended while he took necessary breaks. Some GSI workers could have intruded into the exclusion area and received exposures from these sources that were greater than those from the 260 and 280 mCi ^{60}Co sources possessed by GSI.*

NIOSH Report (8/10/11): Allen (2011b) calculated the radiation exposures of radiographers and nonradiographers to ^{226}Ra during 1953–1962. The assessment of doses to radiographers divided the radiography among two workers, and used the average distance and exposure duration cited by [redacted], a GSI radiographer from that era. The resulting dose rate was 3,573 mrem/y. A maximum dose of 1,353 was assigned to nonradiographers. For 1962–1966, a maximum annual dose of 2,671 mrem/y was assigned to GSI radiographers, based on their working with St. Louis Testing at the GSI site; a maximum dose rate of 1,348 mrem/y—from the use of GSI-owned ^{60}Co sources—was assigned to nonradiographers during the same time period.

SC&A Reply (9/15/11): Anigstein (2011a) estimated the annual exposure of a radiographer positioning and removing ^{226}Ra sources before and after each radiographic exposure to be 9.39 R/y. The analysis assumed that the ^{226}Ra radiography would be performed by a single radiographer. The shortest distance to the source and the longest exposure duration, based on information from [redacted], were used in the assessment. However, we had insufficient information to estimate the doses to the radiographer during the radiographic exposures, or to nonradiographers from the use of ^{226}Ra sources. We estimated an exposure of 2.8 R/y of GSI radiographers to St. Louis Testing sources at the GSI site, which is numerically similar to Allen's (2011b) 2.67 rem/y. However, we did not agree with the lower dose of 1.35 rem/y Allen assigned to nonradiographers.

10/20/11: Anigstein (2011b) interviewed two former GSI workers and two former GSI contractors. Based on the information acquired from these interviews, we updated our assessments of exposures to portable radiation sources. We used three independent approaches to estimate exposures of radiographers to ^{226}Ra sources. First, we extrapolated the 4.5 years of dose records of [redacted], who performed radiography only on weekends, to a full-time radiographer and derived annual doses of 9–20 rem/y, depending on how frequently [redacted] had worked. Next, we performed an MCNP analysis of the exposures inside the radiographers' office in the radiographic facility in No. 6 Building and added the results to the previously estimated exposure from handing the source before and after radiography, obtaining a total exposure of 9.69 R/y. Finally, we noted the statement in the initial GSI application for an AEC license, that the applicable AEC dose limits during the previous 10 years were never exceeded. These annual limits were 15 rem/y in 1953–54, and 12 rem/y after 1954. Since the AEC limits encompass or overlap the other two dose estimates, we recommend that these limits be used to bound the doses during these two respective time periods.

Board Action:

Status (7/28/12)**: Open**

Issue 6: Neglect of Skin Dose

SC&A Finding: Appendix BB ignores the skin dose from beta radiation from activated steel. Our analysis yielded doses of about 2 rads/y to bare skin from beta radiation from irradiated steel.

NIOSH Response (6/19/08): As indicated in the SC&A review, NIOSH has obtained film badge results for betatron operators. We are in the process of comparing this data to the modeled estimates provided by both the appendix and SC&A. The modeled beta dose and photon dose are linked and so the beta dose can adjusted to the film badge data by using the model.

SC&A Reply (7/23/11): Although Allen (2010) discussed plans for modeling the activation of steel, the "Path Forward" does not mention calculation of skin dose.

NIOSH Report (1/13/12): Allen (2012a) listed the dose rates from natural uranium metal, which were taken from SC&A 2008, and which included the contribution of activation and fission products. He also calculated skin doses to the betatron operator and the layout worker from residual activity in HY-80 steel following betatron irradiation, using the results of earlier SC&A calculations.

SC&A Reply (3/12/12): Anigstein and Olsher (2012) recalculated the doses from irradiated uranium, using the current version of MCNPX—SC&A (2008) had utilized an earlier beta version (26e) released in November 2007. Our new analysis indicated a slight decrease in the beta dose; the results cited by Allen (2012a) are claimant favorable and in sufficiently close agreement with our later analysis. However, we found that Allen's use of our earlier calculations of residual nuclides in HY-80 steel markedly underestimate these activities and the resulting doses to the skin when compared to results obtained with the current MCNPX version 27e.

Board Action:

Status (7/28/12)**: Open**

Issue 7: Underestimate of Exposure to Activated Betatron Apparatus

SC&A Finding: Appendix BB assigns an initial exposure rate of the betatron operator of 15 mR/h from activation products in the betatron apparatus, based on a measurement reported by Schuetz (2007) at 6 ft (183 cm) from the betatron target. This exposure rate would apply only if the operator were located 6 ft from the betatron during the setup period. Such an assumption is inconsistent with the calculation of dose rates from the handling of irradiated steel or uranium, which assumes that the betatron operator spent one half of the setup time at a distance of 1 ft (30 cm) from the metal and the rest at 1 m. Assuming, as we did, that his distance from the betatron target ranged uniformly between 3 and 6 ft (61–183 cm) would double his exposure rate.

NIOSH Response (6/19/08): As indicated in the SC&A review, NIOSH has obtained film badge results for betatron operators. We are in the process of comparing this data to the modeled estimates provided by both the appendix and SC&A.

Path Forward (10/08/10) (Allen 2010): A former Allis-Chalmers employee indicated that the betatron machine exhibited residual radioactivity causing an exposure rate of about 15 mr/hr in front of the machine six feet from the target. He further indicated that dose rate diminished to near zero within 15 minutes and that identical measurement behind the machine showed 1% of the forward readings. To investigate the source of this exposure, activation of several components was explored, as well as the possibility of some residual current in the accelerator causing this effect. No viable explanation for this phenomenon has yet been discovered. However, the Allis-Chalmers employee did not state the conditions that were associated with these measurements. If little air movement occurred it could be possible that the 15 mr/hr exposure rate was caused by air activation. Under those conditions, the activated air would exhibit the highest concentration where the beam was exposing the air and low concentrations behind the machine. The half-life of N-13 is approximately 2 minutes while that of O-15 is approximately 10 minutes. This does not necessarily correlate well with the dose rate diminishing to zero within 15 minutes. However, considering that some air movement would dilute the concentration and lower the dose rate, it appears to be a possible explanation for this dose rate measurement.

Air activation would cause an external dose from the air, not the machine. Operators exposed to this would be exposed in an isotropic geometry. The 511 keV photon would be easily detectable by the film badges worn by the operators. Therefore, residual radiation coming from the machine will not be considered a source of radiation exposure for the radiographers. Instead, air activation will be considered in the scenarios.

SC&A Reply (7/23/11): We do not agree that air activation can account for the residual radiation from the betatron after shutoff that was measured by Jack Schuetz when he was employed by Allis-Chalmers. As was discussed by Robert Anigstein (SC&A) at the October 12, 2010, work group meeting, SC&A had calculated the exposure of the betatron operator from air activation, obtaining an estimated exposure of 6 μR per shift. It is not plausible that the 15 mR/h reported by Mr. Schuetz could be due to air activation.

We disagree with the decision, reported by Allen (2010), not to consider the residual radiation from the betatron as a source of exposure of the radiographers. We note that Mr. Schuetz's account is corroborated by the betatron instruction manual (Allis-Chalmers 1951), which warns users not to touch the betatron doughnut for at least 15 min after the machine is turned off, stating that the tube becomes "intensely radioactive" while generating x rays. Although our MCNPX analysis could not replicate this phenomenon, our simplified model of the betatron most likely did not include all materials in the doughnut tube nor did it include the magnets and surrounding structures. Thus, the analysis does not invalidate Schuetz's data.

The fact that elevated exposures were, for the most part, not found in the film badge dosimetry data also does not invalidate these observations. SC&A (2010) stated:

> *The response of film badges worn by GSI workers was highly dependent on the energies and angles of incidence of the photon radiation. This issue assumes particular significance when the exposure is in the posteroanterior (PA) orientation, as was the case for at least part of the time that the betatron operator was setting up the exposure of a steel casting and was exposed to residual radiation from the betatron apparatus. He would have his back to the instrument when he was marking the casting, using the remote controls to adjust the position of the betatron, and measuring the distance to the casting. According to ICRP (1997, table A.22), the ratio between the directional dose equivalent at a depth of 10 mm at 180° to that at 0° [H'(10,180°):H'(10,0°)] ranges from zero (i.e., < 0.005) for photon energies E ≤ 30 keV to 0.62 at E = 10 MeV.*

NIOSH Report (1/13/12): Allen (2012a) examined various mechanisms that could explain the residual betatron radiation reported by Schuetz (2007) and concluded that the most likely cause was magnetic interference that could have caused a spurious reading on the survey meter.

SC&A Response (3/12/12): Anigstein and Olsher (2012) reexamined the possibility that the residual radiation consisted of low-energy x-rays that were partially shielded by the operator's body and would therefore not be registered on the film badge, normally worn in front, if his back was to the betatron apparatus. Our analysis showed that, in theory, the operator could have received an effective dose that was slightly higher than the MDA of the film badge, assumed to be 10 mrem/week. However, since the limiting photon dose was to either the layout man, in 1963–1966, or to the radiographer using ^{226}Ra in 1953–1962, the bounding photon exposures of GSI workers would not be affected by such radiation.

Status (7/28/12): SC&A recommends that this issue be closed.

Board Action:

Issue 8: Underestimate of Work Hours

SC&A Finding: The authors assume that the GSI employees worked an average of 2,400 h/y. This estimate is contrary to the recollection of the workers, who remember working 50–80 h/week. The consensus estimate was 65 h/week, or 3,250 h/y. Such a value is reasonable and claimant favorable, and should be adopted as a default value for dose reconstruction.

NIOSH Response (6/19/08): As indicated in the SC&A review, NIOSH has obtained film badge results for betatron operators. We are in the process of comparing this data to the modeled estimates provided by both the appendix and SC&A. Since the film badges measure the dose received over the course of a week, the amount of time taken to receive that dose would no longer be relevant.

Path Forward (10/08/10) (Allen 2010): Operators provided an estimate of typical work hours different than that utilized by the appendix (3250 hrs per year). The path forward addresses revising the model taking all new information into account and including the operator's estimate of work hours.

Board Action (10/12/10): Paul Ziemer, Chair of TBD-6000 Work Group, noted that there is agreement on the length of the work week among NIOSH, the WG, and SC&A.

Status (10/12/10)**: Closed**

Issue 9: Mischaracterization of Steel Work Practices

SC&A Finding: According to Appendix BB, "The overall estimate for Betatron x-ray of steel is: 30 minutes setup with no dose; one hour Betatron x-ray exposure due to skyshine at 0.72 mR/hr; and, 30 minutes takedown." Such a description is at variance with a report prepared by former GSI workers that indicates repeated exposures of the same casting, with 12–15 minutes between exposures. Since both the steel and the betatron were activated from previous exposures, there was no setup period with no dose. Furthermore, most exposures were of a few minutes' duration, which reduced the time in the control room, where the exposure rates were relatively low, and increased the number of times during the day that the operators were exposed to the steel and the betatron.

NIOSH Response (6/19/08): As indicated in the SC&A review, NIOSH has obtained film badge results for betatron operators. We are in the process of comparing this data to the modeled estimates provided by both the appendix and SC&A. Since the film badges measure the dose received while performing this work, the exact exposure scenario is no longer important.

Path Forward (10/08/10) (Allen 2010): The path forward states that NIOSH will revise the model using new exposure scenarios [see Issue 4, above.]

NIOSH Report (1/13/12): Allen (2012a) utilized a mix of long and short betatron radiographic exposures, as well as a layout-man exposure scenario.

SC&A Response (7/28/12): We agree that the timing and exposure durations are consistent with information furnished by former GSI workers.

Status (7/28/12): SC&A recommends that this issue be closed.

Board Action:

Issue 10: Errors in Calculating Dose Rates from Uranium

SC&A Finding: We have found errors in calculations that lead to a significant overstatement of the dose rates from uranium presented in Appendix BB. The Appendix lists a dose of 21.7 mrem during the first 30 min following irradiation. Our model yields a dose of 1.4 mrem, using the same assumptions regarding the duration of the radiographic exposure, the duration of the worker's exposure, and his distances from the metal. Since the dose rates in the Appendix are not scientifically correct, they should not be used as the basis of dose reconstructions of exposed workers.

NIOSH Response (6/19/08): To the extent modeled doses are used, any errors in this calculation will be corrected. However NIOSH has obtained film badge results for betatron operators. We are in the process of comparing this data to the modeled estimates provided by both the appendix and SC&A.

Path Forward (10/08/10) (Allen 2010):

Uranium activation and fission products

- Assume four one hour shots per uranium ingot or slice
- Determine dose rates from activation and fission products and add to natural activity of uranium metal

NIOSH Report (1/13/12): Allen (2012a) calculated doses from photon and neutron radiation from uranium following betatron irradiation, using an MCNPX input file furnished by SC&A.

SC&A Response (3/12/12): Anigstein and Olsher (2012) reviewed Allen's (2012a) results and found the following issues with his calculations: (1) failure to adjust the source to object distance, as we did in subsequent calculations (SC&A 2008); (2) the use of 1-minute time steps, which do not properly model the rapidly decaying residual nuclides; (3) the use of MCNPX version 26e, released as a beta version in November 2007, rather than the current version, released in March 2011. These calculations will not affect the bounding photon dose, since the betatron operator would still not be the maximally exposed individual, they could lead to an increase in the neutron dose, since the betatron operator is the only individual addressed by the analyses that was exposed to neutron radiation prior to 1963.

Board Action:

Status (7/28/12)**: Open**

Issue 11: Underestimate of Doses to Other Workers

SC&A Finding: Appendix BB states that workers who did not work in the betatron building and did not routinely handle steel or uranium within 2 h following the x-ray exposure should be assigned a "dose" rate of 0.72 mR/h. As discussed under Finding 4, there were many situations in which these other workers could have been exposed to much higher radiation levels.

NIOSH Response (6/19/08): This finding appears to be a included in finding #4. As noted, NIOSH is in the process of evaluating the affect of film badge data on the exposure models presented by both the appendix and SC&A.

Path Forward (10/08/10) (Allen 2010): The path forward addresses developing new exposure scenarios based on all the information that has come to NIOSH since the appendix was approved.

(1/13/12): Allen (2012a) stated that, in assessing doses from betatron operations, dose reconstructors will choose the most favorable exposure scenario (i.e., betatron operator or layout man) in each case.

SC&A Response (7/28/12): We agree that the most favorable exposure scenario should be applied in all dose reconstructions. The same procedure should be extended to reconstructing the doses from external exposure to sealed sources. If such instructions are included in the revised Appendix BB, we will recommend that this issue be closed.

Board Action

Status (7/23/11)**: Open**

Issue 12: Incorrect Calculation of Residual Surface Contamination and Resuspension

SC&A Finding: The Appendix uses the same methods of calculating surface contamination and resuspension as were used in the main report (Scherpelz 2006). In SC&A's review of that report, we pointed out that calculating surface contamination on the basis of a settling velocity of 5 μm AMAD aerosol particles ignores the sloughing off of much larger flakes of uranium oxide that fall directly onto the floor. We also showed that a resuspension factor of 10^{-6} m^{-1} might understate the airborne concentrations by one or more orders of magnitude.

NIOSH Response (6/19/08): This finding indicates it is a reiteration of a comment from the Battelle-TBD-6000 review. Therefore the finding should be addressed in that review rather than here.

Board Action (6/20/12): The ABRWH, at its meeting in Santa Fe, NM, voted to task SC&A with reviewing the use of Allen's (2011a) surrogate data to characterize the airborne uranium concentrations during uranium handling operations at GSI.

SC&A Response (7/16/12): Anigstein (2012) found that the use of Allen's (2011a) surrogate data to characterize the airborne uranium concentrations during uranium handling operations at GSI not meet the five ABRWH criteria for the use of surrogate data.

7/25/12: Anigstein et al. (2012) issued a memo suggesting an alternative model for the calculation of uranium intakes at GSI that does not rely on surrogate data from other sites.

Status (7/28/12)**: Open**

Issue 13: Use of Incorrect Units

SC&A Finding: The Appendix switches erratically between units of mrem and mR. The results of the skyshine calculations are stated as 0.72 mrem/h in Section BB.4.2, then as 0.72 mR/h in later sections. Dose rates are incorrectly stated in units of mR/h, which is an exposure rate. Uranium dose rates are stated in mrem, whereas our review of the output files from the Appendix BB analysis shows that the calculations were of air kerma, which is expressed in mrads. A notable misuse of units appears in the table in Section BB.4.5, where the dose to the skin from beta radiation is expressed as "R/yr." Beta radiation should not be expressed in roentgens, which only apply to photons.

NIOSH Response (6/19/08): We accept the comment and will correct the units in any future revisions to the appendix.

Board Action:

Status (7/28/12)**: In progress**, pending revision of Appendix BB.

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