Draft

Issue Resolution Matrix for SC&A Findings on the General Steel Industries Special Exposure Cohort (SEC) Petition-00105 and the NIOSH SEC Petition Evaluation Report

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Original Date: October 6, 2009
NIOSH Responses: October 9, 2009
SC&A Reply: October 12, 2009
Updated: July 25, 2011
Second Update: September 17, 2011
Final Update: March 22, 2012

INTRODUCTION

The present document presents a cumulative update of the issues arising from the SC&A review of the General Steel Industries (GSI) Special Exposure Cohort (SEC) Petition-00105 and the National Institute for Occupational Safety and Health (NIOSH) SEC Petition Evaluation Report. It is current as of the last meeting of the Advisory Board on Radiation and Worker Health (ABRWH) Work Group on TBD-6000 in Hebron, Kentucky, on March 15, 2012. A separate issues matrix pertaining to SC&A findings on Appendix BB to "Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals" (Allen and Glover 2007) was originally issued on May 2, 2008.[1] 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 SEC Issues Matrix

- February 25, 2008: NIOSH received SEC petition from Patricia Coggins (2008) on behalf of herself and former GSI employees and their survivors.
- May 15, 2008: Petition SEC-00105 qualified for "[a]ll individuals who worked in any location at the General Steel Industries site, located on 1417 State Street, Granite City, Illinois, from January 1, 1953 through December 31, 1966, and/or during the residual period from January 1, 1967 through December 31, 1992 (Buker et al. 2008)."[2]
- October 3, 2008: NIOSH issued an SEC petition evaluation report (Buker et al. 2008).
- July 24, 2009: SC&A (2009a) prepared a review of the SEC petition and the NIOSH evaluation report (ER) and submitted it for Department of Energy (DOE) review and approval. This report was distributed on August 7, 2009, following DOE approval.
- October 2, 2009: SC&A distributed the SEC issues matrix which listed 10 issues. These issues were taken from the list of 10 findings[3] presented in the executive summary of our review of the SEC petition and ER (SC&A 2009a).
- October 9, 2009: NIOSH responded to the 10 issues, inserting its responses in the boxes labeled "NIOSH Response."
- October 12, 2009: SC&A replied to the NIOSH responses in a revised, restricted version of the SEC issues matrix.

[1] Three versions of the matrix were previously distributed to the ABRWH Work Group on TBD 6000/6001: (1) the initial matrix on May 2, 2008, (2) NIOSH responses to the issues, distributed by NIOSH on June 19, 2008, and (3) an edited version with the revision history on the cover, issued December 8, 2009.

[2] Buker et al. (2008) amended the covered period as ending June 30, 1966, and the residual period as beginning July 1, 1966.

[3] The "findings" in the earlier report are presented as "issues" in the present document. Several of these issues overlap those in the Appendix BB issues matrix.

- December 16, 2009: The Work Group on TBD 6000/6001, Appendix BB,[4] met in Hebron, Kentucky, and recommended action items to NIOSH regarding the SEC 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 the SEC issues 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 SEC issues. We have summarized these responses in boxes labeled "Path Forward" in the appropriate locations in the matrix.
- 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 23, 2011: SC&A updated the GSI SEC 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 (2011) 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 matrix, incorporating our review of Allen 2011.
- January 13, 2012: Allen (2012) 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, 2015: The Work Group on TBD-6000 met in Hebron, Kentucky. The work group asked SC&A to update the matrix to reflect Allen 2012, Anigstein and Olsher 2012, and discussions of these reports at the meeting.
- March 22, 2012: SC&A updated the matrix, incorporating all developments since September 15, 2011.

[4] 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

Status Summary

- Issue 1 remains *Open*, according to the work group. There is inadequate information about radiation exposures during 1953–1956.
- Issue 2 is *Open*, according to the work group. Once NIOSH updates its dose assessments of unmonitored workers during 1964–1966, SC&A recommends that this issue be closed.
- Issue 3 is *Open*, according to the work group. Once NIOSH updates its dose assessments of workers exposed to sealed sources, SC&A recommends that this issue be closed.
- Issue 4 (residual radiation from betatron) is *Open*, according to the work group. NIOSH and SC&A concur that this is not a significant source of worker exposures. SC&A recommends that this issue be closed.
- Issue 5 (lack of validation of models) is *Open*, according to the work group. SC&A recommends that this issue be closed.
- Issue 6 is *Open*, according to the work group. Based on Allen's (2012) directions to dose reconstructors, it is our understanding that NIOSH will assign the bounding doses for each time period to all GSI workers. SC&A believes that bounding doses can be developed for the period 1957–1966, but not for earlier years.
- Issue 7 (scientific errors in Appendix BB to be addressed by NIOSH): The work group directed that the issue be closed when NIOSH corrects the errors. Until such a time, the issue is *In Progress*. SC&A finds that NIOSH has made progress in correcting these errors, but that some discrepancies still need to be resolved.
- Issue 8 (incomplete model used for exposure assessments): NIOSH asserts that this is an Appendix BB issue. SC&A finds that NIOSH has made progress in correcting these errors, but that some discrepancies still need to be resolved. Until such a time, the issue should remain *Open*.
- Issue 9 (underestimate of beta dose): NIOSH based its revised estimates of beta dose from natural and irradiated uranium and from irradiated steel on the SC&A (2008) analyses. However, the results for steel were based on a developmental version of MCNPX; the current, publicly released version yields higher skin doses for this scenario. Until NIOSH resolves this discrepancy, this part of the issue should remain *Open*.
- Issue 10: *Closed*, according to the work group.

Level of Importance

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

- **High:** NIOSH has not demonstrated that it can calculate doses with sufficient accuracy.

- **Medium:** NIOSH has not described the methods that it will employ to calculate doses with sufficient accuracy; however, such methods can most likely be developed.

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

- Issue 1 and 6: *High.* SC&A finds that there is insufficient information to assign bounding doses during the 1953–1956 period.
- Issues 2, 3, 7–9: *Medium*
- Issues 4, 5: SC&A recommends that these issues be closed.
- Issue 10 (closed): Level of importance irrelevant

Issue Resolution Matrix for SC&A Findings on the General Steel Industries Special Exposure Cohort (SEC) Petition-00105 and the NIOSH SEC Petition Evaluation Report

Issue 1: Lack of Radiation Monitoring Data for 1953–1963

SC&A Finding: The lack of radiation monitoring data for the 11-year period 1953–1963 precludes a bounding assessment of external exposures to direct penetrating radiation. There were four reported incidents during this period: (1) a worker who was not a radiographer mistakenly took home a ^{60}Co source; [5] (2) [REDACTED], who was not a radiographer, remained inside an Army tank being radiographed with the betatron; (3) [Worker A], a betatron operator, reported he was involved in an incident with "Betatron II" (presumably the new betatron) just prior to the beginning of the Landauer film badge monitoring program; (4) an employee of St. Louis Testing, a GSI contractor, reported finding an unsecured ^{60}Co source that may have exposed GSI employees. These incidents, especially the worker's taking home a ^{60}Co source, indicate a serious breakdown of radiation controls.

NIOSH Response (10/9/09): The incidents mentioned are specific events from years ago based on recent memories of operators. This specific nature of the descriptions provided by the operators indicates that they have clear recollections of these events. This implies that these events were likely to be unusual occurrences, rather than an indication of systemic breakdown of radiological controls. Regardless, there has been little or no credit given to any radiological controls in the appendix or the ER in mitigating radiation exposures.

As with all dose reconstructions, NIOSH accommodates known incidents into the individual dose reconstruction based on information specific to the case. One of the events described above has already been incorporated into an individual's dose reconstruction.

SC&A Reply (10/12/09): There were thousands of workers employed at GSI and its predecessor, General Steel Castings, during 1953–1963. To the best of our knowledge, approximately 40 former workers or their family members have participated in meetings or have been interviewed, a very small fraction of the total work force. There could have been numerous incidents that were unknown to or forgotten by these individuals from over 50 years ago. For instance, NIOSH would not be able account for an incident involving a deceased worker if the claimant were one of his children who might have been born after the incident occurred.

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

Action items (4/24/10) (ABRWH 2010): Agreed to hold the issue of FB records and source terms open until NIOSH completes the evaluation of the new documents identified by the petitioner *(Reference: p. 181 of the 12/[16]/09 transcript.*)

NIOSH Path Forward (10/08/10) (Allen 2010): SC&A pointed out that several incidents were verbalized by workers and without film badge data, other incidents could be unknown. The handling of incidents is discussed in the Co-60 section of the path forward [below]. A preliminary review indicates a consistent frequency through the years that monitoring data is available.

GSI Co-60 sources (1962 on)

- 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.

[5] Based on more recent information, it now appears that the source consisted of ^{226}Ra.

- Add incident exposure based on frequency and amount of incidents

SC&A Comment (7/23/11): The film badge reports furnished by Landauer list only two weekly readings >100 mrem during the covered period (i.e., up to June 30, 1966) (Anigstein 2009). It is not possible to construct a meaningful distribution based on these two readings. Allen (2010) might intend to include additional film badge records for the period July 1966 through December 1977, during which there were several more weekly readings >100 mrem.

We do not believe that it is correct to extrapolate data from that period to the 1962–1963 period, because operating conditions were significantly different during the two periods. The Landauer film badge monitoring began in mid-November 1963. Since this 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.

NIOSH Report on Betatron Operations (1/13/12): Allen (2012) performed MCNPX analyses of the external exposures of a layout man to direct penetrating radiation from the betatron. These exposures were higher than the exposures he assigned to the betatron operators, based on film badge data and MCNPX simulations. He proposed assigning the highest reasonably bounding exposures to all workers, regardless of job category.

SC&A Comment (3/22/12): Anigstein and Olsher's (2012) analyses result in significantly higher exposures to the layout man than those reported by Allen (2012). Limitations of the DCAS analyses include the assumption that a lead-shielded door separated the New Betatron Building from No. 10 Finishing Building, where the layout man was assumed to be stationed. Another limitation is the assumption that the total weekly exposure in the betaron control room was monitored by means of a film badge assigned to "betatron ctl." In light of the uncertainty regarding both the presence of the lead door during the covered period and the location of the "betatron ctl" badge, DCAS indicated they will revise their analyses. The neutron doses to the betaron operators and the layout men likewise need to be revised. Furthermore, we found that Allen's (2012) use of 2007 MCNPX version 26e results significantly understated the doses to the skin of the hands and forearms of the betatron operators.

In summary, we believe that it is possible to reconstruct the doses during the years 1957–1962 by assigning the bounding exposures of the radiographer using ^{226}Ra to all workers. Doses during 1963 can be based on the exposures to the layout man, once the issues raised by our recent analyses (Anigstein and Olsher 2012) are resolved. Since the date of the start of operation of the new betatron is uncertain, the claimant-favorable assumption would be to assign those doses for all of 1963.

Due to scarce data and no first-hand accounts for the 1953–1956 period, it is not clear that bounding exposures can be assigned during that time period.

Status (3/22/12): Open

Issue 2: Incomplete Monitoring of Workers: 1964–1966

SC&A Finding: The film badge dosimetry records for 1964–1966 list the names of 89 workers, who are believed to have been members of the betatron teams or radiographers who used sealed sources. Former workers have reported that the badges were stored in a rack just outside the New Betatron Building, and that they were required to take off their badges whenever they left the betatron buildings. Consequently, the monitoring of even these workers was incomplete, since it did not cover exposures they might have received outside the betatron building. Areas in 10 Building, including the restroom, were potentially exposed while the betatron was in operation. Furthermore, some of these workers may have worked as layout men who were in intimate contact with castings immediately after betatron radiography. They would not have been wearing their badges while performing such duties. The monitored workers represent a small fraction of the total GSI workforce. One incident that occurred during this period involved a worker who was inside a casting while it was radiographed with a betatron.

He was in the plant engineering department and was therefore not monitored.

NIOSH Response (10/9/09): While information has come to light that the radiographers took off their film badges when they left the Betatron building, testimony and affidavits indicate radiographers did wear their film badges when performing radiography outside the betatron buildings. The dose to layout men was modeled by SC&A in the Appendix BB review and found to be less than the dose to betatron operators. The dose to other areas outside the betatron building was addressed in the ER. NIOSH does acknowledge, however, that there was a misconception about when the practice of "flipping the betatron head" began. It appears it could have occurred as early as November 1965, leaving about 19 to 20 months of covered period where this could be an issue. Operators have indicated this was not a frequent practice but it does require further analysis.

SC&A Reply (10/12/09): We agree that the exposure of nonradiographers in proximity to the New Betatron Building in 1965–1966 needs to be studied further.

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

Action items (4/24/10) (ABRWH 2010): Similar to Issue 1; keep this issue open. (*Reference: p. 184 of the 12/[16]/09 transcript.*)

NIOSH Path Forward (10/08/10) (Allen 2010): SC&A pointed out that betatron operators removed their badges when leaving the betatron building but scenarios exist where they could have been exposed outside that building. The path forward addresses developing new exposure scenarios based on all the information that has come to NIOSH since the appendix was approved.

SC&A Comment (3/22/12): The dose assessments of unmonitored workers are discussed under the subheadings Allen (2012) and "SC&A Comment" under Issue 1, above. Allen examined the exposures of unmonitored workers to stray radiation from the betatron, and concluded that the layout man would receive the highest external exposures to penetrating radiation. Dose reconstructors will be instructed to use the most bounding assessments for each case. We do not agree with the bounding exposures estimated by Allen. However, we believe that, using reasonably bounding, claimant-favorable assumptions and the latest calculational tools, it is possible to reconstruct the doses to GSI workers during the period January 1, 1964–June 30, 1966. This issue needs to be addressed by NIOSH in a revision to Appendix BB. Once that is done, SC&A recommends that this issue be closed.

Status (3/22/12): Open

Issue 3: Lack of Documentation

SC&A Finding: There are few contemporary records to document operations at GSI during the operational period. The available records comprise purchase orders for uranium radiography spanning the period 1958–1963, correspondence between General Steel and Mallinckrodt regarding payment of a single invoice for radiography prior to February 1958, a December 1953 memo referring to betatron radiography at General Steel Castings (as GSI was then known), and Landauer film badge dosimetry reports for 1964–1973. There is no information on the extent of uranium radiography at GSI prior to March 1, 1958, except for a February 28, 1958, memo requesting payment for an earlier invoice (Brownfield 1958). Consequently, it does not appear to be possible to determine the exposure of workers to uranium from January 1, 1953, the assumed start of uranium handling operations, to March 1, 1958.

There are no records regarding the radioactive sources used for radiography. For example, the "small" ^{60}Co source used in 6 Building was variously described as having an activity of less than one curie or 0.25 Ci. The large source was described as 80 Ci; however, we could not determine when it was acquired. Given the 5.27 half-life of this nuclide, the date of acquisition would affect its activity at various times during the operation of GSI. Given the paucity of documentation, it is difficult to establish suitable parameters for dose reconstruction.

NIOSH Response (10/9/09): The first part of the issue indicates there is no indication of the extent of uranium radiography prior to 1958. However, the SC&A review of appendix BB estimated that

radiography operations of steel produced higher doses to operators than operations with uranium. It therefore appears to be a favorable assumption to assume no uranium work occurred prior to 1958.

The only record of the use or the existence of these sources is that of worker testimony. The radiographer testimony also indicated they wore their film badges when using these sources.

SC&A Reply (10/12/09): The question remains: Is it possible to perform dose reconstructions with "sufficient accuracy" in the absence of documentation on sources of radiation?

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

Action items (4/24/10) (ABRWH 2010): Keep this issue open pending review of the new documents. (*Reference: p. 196 of the 12/[16]/09 transcript*.)

NIOSH Path Forward (10/08/10) (Allen 2010): SC&A indicated that the amount of uranium work is unknown prior to 1958 and that there is no record of the type of radiography sources used at GSI. The path forward addresses developing new exposure scenarios based on all the information that has come to NIOSH since the appendix was approved. This includes information about the radiography sources used at GSI.

NIOSH Report on Portable Sources (8/11/11) (Allen 2011): Allen (2011) identified the two 500-mCi ^{226}Ra sources used at GSI prior to May 1962, and the two "small" ^{60}Co sources (260 mCi and 280 mCi) procured at that time, as well as the 10-Ci ^{60}Co source and the 50-Ci ^{192}Ir source used at GSI by St. Louis Testing. He also described the operating characteristics of the two 250 kVp x-ray machines used for radiographing steel castings and derived their output. Allen estimated the exposures of radiographers and of other workers to the ^{226}Ra sources, based on safety practices that he assumed were used in later years and which he projected backwards to the "radium era" (prior to May 1962). He cited the results of a radiation protection survey of the radiography room performed after the procurement of the "small" ^{60}Co sources, and used the highest exposure rates in a potentially occupied area to estimate the annual exposures of GSI workers, including both radiographers and nonradiographers. He also estimated the exposures of GSI employees to the St. Louis Testing sources.

SC&A Review of NIOSH Report (9/15/11) (Anigstein 2011a): We have confirmed the information about the characteristics of the portable radiography sources used at GSI during the period of AEC operations presented by Allen (2011). We found that the fundamental assumption regarding the safety practices employed by GSI during the use of ^{226}Ra sources during the radium era was based on a misinterpretation of information furnished by a former worker and then projected backwards to an earlier time period. Absent any information about the whereabouts of the radiographer and other workers during the employment of the ^{226}Ra sources, absent any radiation monitoring data, and absent any evidence of an effective radiation safety program during this time, we do not believe there is a sufficient basis for estimating worker exposures during this time period. A glaring failure of radiation safety is evidenced by the unauthorized removal of a ^{226}Ra source from the premises.

We do not agree with Allen's method of assigning bounding doses to GSI workers during the post-radium era. We have proposed a modification of Allen's exposure scenario to the St. Louis Testing sources, which results in a slightly higher exposure of radiographers (due to their intrusion into the exclusion boundary during the temporary absence of St. Louis Testing personnel), and in over twice the exposure to nonradiographers, whom Allen assumes are exposed for only one-half their workday. However, we believe that these are tractable problems which can be resolved.

These questions need to be addressed by NIOSH in a revision to Appendix BB. Once this is done, we recommend that this issue be closed.

Status (3/22/12): Open

Issue 4: Film Badge Dosimetry Dependence on Photon Energies and Exposure Geometry

SC&A Finding: The response of a film badge dosimeter is highly dependent on the angle of the incident radiation, especially if the radiation source is behind a person wearing a film badge on the front of his body. To a smaller extent, the film badge response varies with the energy of the incident photons. Consequently, given the complex exposure conditions at GSI, the film badge records are at best an approximate measure of the radiation doses received by their wearers.

NIOSH Response (10/9/09): The film badges response is relatively uniform for energies beyond a few hundred keV. They tend to over respond to energies below that. The angle of incident radiation is not an issue specific to GSI, it is an issue that has been discussed [in] a number of other settings. In general, an assumed AP geometry is favorable for most organs. However, if the dose on a film badge is assumed to be caused by a PA exposure, it can be accounted for using ICRP or NCRP standards.

SC&A Reply (10/12/09): The issue here is that corrections for the attenuation of incident radiation in the PA orientation when the badge is worn in front are dependent on photon energy. Since the energy spectrum of the residual radiation from the betatron apparatus is unknown, it would be difficult to correct for the exposure geometry.

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

Action items (4/24/10) (ABRWH 2010): SC&A to provide an analysis relating to this issue. (*Reference: p. 231 of the 12/[16/]09 transcript.*)

SC&A Analysis (5/9/10): We performed an analysis of the betatron apparatus and its electrical circuitry to develop three possible exposure scenarios. We then calculated the radiation exposure from the most probable of these three scenarios. We could not find a physical explanation for the residual exposure rate reported by Schuetz (2007). Absent an understanding of the mechanism by which the reported residual radiation was generated, we cannot determine the quality of the radiation (i.e., the photon energy spectrum). Thus, the underresponse of the workers' film badges to radiation incident in the posteroanterior (PA) orientation cannot be quantified. (SC&A 2010)

Board Action (5/12/10): Discussed at meeting of the Work Group on TBD-6000. According to Paul Ziemer, chair of the work group, "In part, the burden will be on NIOSH again to figure out what do we do with this information."

SC&A Reanalysis (3/22/12): Former betatron operators reported that for most of the time they were setting up a radiographic exposure, their backs were to the betatron. Despite the fact that neither NIOSH nor SC&A could find a physical explanation for the phenomenon reported by Schuetz (2007), Anigstein and Olsher (2012) examined the possibility that betatron operators could have been exposed to residual radiation from the betatron that was incident on the body in the PA orientation. Using the female breast as a surrogate for the film badge worn on a worker's breast pocket, we found that the greatest disparity in the effective dose and the dose to the breast for the PA orientation was for 30-keV photons—the lowest-energy photons addressed in NIOSH dose reconstructions. Making the bounding assumption that all of the exposure of the film badge was due to such radiation, and using 10 mrem (the stated MDL of the film badge) as the weekly dose to the badge, the maximum weekly effective dose would have been 26 mrem, or 1.3 rem/y. Allen (2012) estimated the external exposure of the layout man to penetrating photon radiation to be over 2 R/y, and stated that this exposure should be assigned to all GSI workers. Anigstein and Olsher, using different assumptions about shielding and betatron orientation, derived an exposure rate of the layout man of 9.2 R/y. During the discussion at the work group meeting on March 15, 2012, David Allen indicated that NIOSH would revise some of the assumptions and repeat the analysis. Whichever set of assumptions is used, it is clear that the betatron operator would not receive the bounding exposure.

We recommend that this issue be closed.

Status (3/22/12): Open

Issue 5: Lack of Validation of Models of Radiation Exposure of Betatron Operators

SC&A Finding: Even for the period of time for which film badge dosimetry reports are available, there is no agreement between the measured and the modeled exposures. In SC&A 2008, we have presented a detailed critique of the models of external exposure developed by Allen and Glover (2007). We have performed an independent analysis to demonstrate that the exposures to betatron radiation and to activated steel could be higher than those predicted by the NIOSH model. However, we do not claim that our model is definitive, based as it is on a limited set of exposure scenarios and extensive conjectures on exposure durations and geometries.

The film badge data indicate that the vast majority of weekly reports list doses of less than the reporting level of 10 mrem. These results call both the NIOSH and SC&A models into question. Conversely, neither model explains how one worker received a dose of 2,470 mrem in one week during the period of covered operations, or how another worker was reported to have received a dose of 7,590 mrem in one week after the end of AEC operations at GSI. Although the latter dose is, strictly speaking, outside the scope of this review, it does call into question the exposure conditions at GSI. Since there is no basis for believing that the operating conditions were significantly different in the later years, except for the absence of uranium, such a dose report should be considered in evaluating the models of external exposure.

In short, neither the film badge data nor the modeled exposures can be used to establish an upper bound to the external exposures of betatron operators that is claimant favorable and scientifically correct.

NIOSH Response (10/9/09): Appendix BB attempted to be a bounding estimate. In a number of places in the SC&A review of that Appendix, there is indication of the modeled dose being conservative. Both imply that if successful, real data such as the film badge data should be lower. That appears to be the case.

The few reported high doses could be indicative of an incident or as some workers reported, dropping their badge in the shooting room or intentionally putting someone else's badge in the shooting room. A NIOSH white paper presented to the WG analyzed the film badge data which included some of these values. In that manner, it is assumed they are related to real incident exposures and the dose as well as the likelihood of an incident are accounted for.

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

Action items (4/24/10) (ABRWH 2010): Keep this issue open pending analysis of the new documents. (*Reference: p. 250 of the 12/[16]/09 transcript*.)

NIOSH Path Forward (10/08/10) (Allen 2010): SC&A indicated there is no agreement between the appendix model and the film badge results. The path forward addresses developing new exposure models and reconciling them with the film badge data.

NIOSH Report on Betatron Operations (1/13/12): Allen (2012) constructed an MCNPX model of the New Betatron Building and used it to calculate the exposure rates from an 80-Ci ^{60}Co source that was used in that building after the covered period. Despite some discrepancies in the source strength and other details, he was able to confirm the measurements made during a radiation protection survey of that building performed in 1971, thus validating the MCNP model of the building.

SC&A Observations (3/22/12): Anigstein and Olsher (2012) performed an independent MCNPX analysis of the exposure rates inside and near the New Betatron Building from the nominal 80-Ci ^{60}Co source (after accounting for radioactive decay), and validated the model of the building by comparing the calculated exposure rates to the GSI survey results. The major source of discrepancy between the earlier SC&A models of the exposure of betatron operators (SC&A 2008) and the film badge dosimetry reports was the assumed exposure of the betatron operators to the residual radiation from the betatron immediately following a radiographic exposure. This discrepancy is now resolved (see Issue 4). We believe that appropriate models, utilizing MCNPX simulations, can be used to bound the external

exposures of GSI workers. The rare instances of high film badge exposures were most likely due to singular occurrences, perhaps involving accidental or even deliberate exposures of film badges when they were not actually being worn by workers.

We recommend that this issue be closed.

Status (3/22/12): Open

Issue 6: Underestimate of External Exposure of Unmonitored Workers

SC&A Finding: Allen and Glover (2007) make a seemingly arbitrary distinction between two classes of workers. Betatron operators and workers who handle metal within 2 hours of irradiation are assigned a higher exposure, ranging from 2.1 to 6.3 R/y, depending on the calendar year, while all other workers are assigned a dose of about 1.7 R/y. The latter exposure rate is based on a calculated exposure rate of 0.72 mR/h in shielded areas of the plant. SC&A (2008) has calculated exposure rates far in excess of this value in locations accessible to workers not involved in radiography, including a rate in excess of 1 R/h on the roof while the 80 Ci ^{60}Co source was in use. Given the lack of any systematic program of radiation protection to bar access to these areas during betatron or ^{60}Co radiography, and the fact that the exposures of these other workers were not monitored, it does not appear to be possible to bound their radiation exposures in a manner that is scientifically correct and claimant favorable. Thus, the distinction between the external exposures assigned to these two classes of workers is not adequately justified and could result in a significant underestimate of the external exposures of some of the workers that are assigned the lower exposures.

NIOSH Response (10/9/09): Two models were developed to provide a distinction between plant personnel and office personnel and others clearly not routinely exposed. The 2 hour cut-off was based on the method used to develop that model and provides the dose reconstructor with some guidelines when reviewing an individual case. Most are assigned the radiographer dose in dose reconstruction.

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

Action items (4/24/10) (ABRWH 2010): Keep this issue open pending analysis of the new documents. (*Reference: p. 263 of the 12/[16]/09 transcript*.)

NIOSH Path Forward (10/08/10) (Allen 2010): SC&A points out again that there are other exposure scenarios not addressed in the appendix. The path forward addresses developing new exposure scenarios based on all the information that has come to NIOSH since the appendix was approved and using those scenarios to revise the dose estimates.

NIOSH Report on Portable Sources (8/11/11) (Allen 2011): Allen (2011) developed several new scenarios for deriving bounding estimates radiation exposures of nonradiographers. During the "radium era" (prior to May 1962), he assumed that such workers would remain at the boundary of the "safe area" roped off during radiography using ^{226}Ra sources, where he estimated the exposure rate to be 0.89 mR/h, but would occasionally intrude into this area while the radiographer was away. For the later period, Allen assigned limiting exposures of 1.348 R/y to nonradiographers to two ^{60}Co sources (260 mCi and 280 mCi), based on the highest exposure rates measured during a 1962 radiation safety survey of the radiographic room in No. 6 Building (NRC 2009). Allen estimated the exposures of nonradiographers to sources used on the GSI site by St. Louis Testing to be 1.336 R/y. This was based on the assumption that they remained at the 2-mR/h boundary established by St. Louis Testing for one-half of their work-hours during the time that radiography by St. Louis Testing was in progress, and that they prevented from crossing the boundary by the St. Louis Testing radiographers who were assumed to be continuously on duty.

SC&A Review of NIOSH Report (9/15/11) (Anigstein 2011a): As we discussed under Issue 3 of this matrix, we do not believe that there is any basis for assuming that a "safe area" was roped off during radiography with ^{226}Ra sources. Consequently, we do not believe that NIOSH has sufficient information to estimate the doses to nonradiographers (nor to radiographers) during the radium era. We found that

the limiting exposure of nonradiographers to portable sources following the radium era to be from sources used by St. Louis Testing. We do not agree that the limiting exposures of nonradiographers should be based on their spending only one-half their time at the 2 mR/h periphery. Since St. Louis Testing only had one radiographer on duty at any time, working a 12-h shift, there were obviously times he left his post, so a GSI employee, especially a nonradiographer, could have crossed the boundary. We believe that a bounding scenario should assume that any GSI worker could been at the 2 mR/h periphery when the source was in use , and that once during his shift he could have crossed the area inside this perimeter. We estimate the bounding exposure to these sources to be 2.8 R/y to all GSI plant workers.

SC&A Update on Use of Sealed Sources (10/20/11): Anigstein (2011b) developed plausible bounding exposures of radiographers employing ^{226}Ra. If NIOSH adopts the strategy of assigning the bounding doses to all GSI workers, as indicated by Allen (2012) in the case of betatron operators, we believe that bounding doses can be assigned to all GSI workers for years beginning in 1957. Prior to 1957, we do not have enough information to assign limiting doses that are plausible and claimant favorable. Although we find that NIOSH needs to update their estimates of limiting doses during the period 1957–1962, we believe that this is a tractable issue.

SC&A Recommendation (3/22/12): These questions need to be addressed by NIOSH in a revision to Appendix BB. Once this is done, this issue can be closed.

Status (3/22/12): Open

Issue 7: Dose Reconstructions Not Based on Best Available Science

SC&A Finding: SC&A (2008) has documented a number of scientific errors in Appendix BB. Most notable is a 20-fold error in calculating the dose rate from irradiated uranium, which we found in the computer program files used by NIOSH. Although this error increases the dose rate and is therefore claimant favorable, it is not scientifically correct. The calculated values are therefore not acceptable for use in dose reconstructions.

NIOSH Response (10/9/09): The comment appears to be discussing the accuracy of the dose estimate rather than the ability to estimate the dose. As such, it would be more appropriate to remove this from the SEC review matrix and add it to the Appendix BB review matrix.

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

Action items (4/24/10) (ABRWH 2010): This is not an SEC issue. NIOSH is correcting the error. Action to be confirmed at next meeting and the issue will be closed. (*Reference: p. 264 of the 12/[16]/09 transcript.*)

NIOSH Path Forward (10/08/10) (Allen 2010): Determine dose rates from activation and fission products and add to natural activity of uranium metal.

SC&A Reply (7/23/11): NIOSH has not yet reported a correction to the errors cited above.

NIOSH Report on Betatron Operations (1/13/12): Allen (2012) utilized updated MCNPX models developed by SC&A to calculate exposures and doses from betatron operations.

SC&A Observations (3/22/12): Anigstein and Olsher (2012) reviewed Allen's (2012) report. We questioned several of Allen's assumptions, as well as his use of results for residual nuclides obtained with MCNPX 26e, an early beta version, rather than version 27e, which is the same as the current official release. The latter code leads to significantly higher skin doses to both the betatron operators and the layout men from beta-emitting nuclides in irradiated steel. However, we believe that these are tractable issues which need to be addressed in a revision to Appendix BB, at which time this issue can be closed.

Status (3/22/12): In Progress

Issue 8: Incomplete Model Used for Exposure Assessments

SC&A Finding: It would appear that the model used by NIOSH for the 208 dose reconstructions completed by October 3, 2008, the date of the ER, is incomplete. We base this conclusion first on the response by NIOSH to some findings in the "Issue Resolution Matrix for SC&A Findings on Appendix BB to TBD-600[0]," dated June 19, 2008. In response to Issue 10: "Errors in Calculating Dose Rates from Uranium," NIOSH wrote:

> *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.*

Our review of Case [B] indicates that NIOSH did use doses modeled by Allen and Glover (2007). To the best of our knowledge, NIOSH has not revised this model. NIOSH made similar comments in response to other SC&A findings regarding the scientific validity of the Appendix BB models.

Other indications that the NIOSH model is incomplete are given by Buker et al. (2008). In section 7.3.4.1, under the heading "Neutron Dose," is the statement, "A study is in place to determine the photon-to-neutron ratio." As we found in our audit of Case [B], NIOSH has neglected the neutron dose in performing dose reconstructions.

Given the undetermined status of the model, we find that the dose reconstructions performed by NIOSH to date do not meet the standard of scientific accuracy.

NIOSH Response (10/9/09): The comment appears to be discussing the accuracy of the dose estimate rather than the ability to estimate the dose. As such, it would be more appropriate to remove this from the SEC review matrix and add it to the Appendix BB review matrix.

SC&A Reply (7/23/11): We believe that this should remain an SEC issue until NIOSH demonstrates that it can calculate external doses with sufficient accuracy. One issue cited above is the neglect of neutron doses. Allen (2010) states that NIOSH will include neutron exposures in its revised model. However, NIOSH has not described any approach to calculating neutron doses other than one cited by NIOSH (2008), which proposed to use a neutron:photon ratio, based on SC&A's calculations of betatron doses and exposures, scaled to photon doses taken from the Landauer film badge dosimetry reports. We continue to object to such an approach for several reasons.

First, SC&A did not attempt to model the typical worker exposures over the course of a year. The purpose of our analyses of the 25-MeV betatron was to demonstrate that under a limited set of exposure conditions, the hourly dose rates in various locations were significantly higher than those calculated by NIOSH. Although we then extrapolated the hourly dose rates to estimate annual exposures and contrasted these with the annual exposures/doses presented by Allen and Glover (2007), we do not claim that our estimates correspond to average exposure conditions, nor that they represent a plausible upper bound. To do either would have required us to perform much more extensive analyses which would have exceeded our authorized scope of work.

Our second objection to the NIOSH approach is to the manner in which NIOSH (2008) calculated the neutron:photon ratio. They used our estimated annual neutron dose, which was the dose to a betatron operator in the control room from neutrons emitted from the betatron target during radiography of a steel casting. They then calculated a ratio using our estimated annual photon exposure of the betaron operator from all sources, notwithstanding that 80% of this exposure was from the reported (Schuetz 2007) but unexplained radiation from the betatron after the beam was shut off. The fact that the average film badge dosimetry reports indicated lower photon doses than we estimated, based on our MCNP model of the betatron and the reported residual radiation from the betatron, does not justify decreasing the neutron doses by the same proportion.

NIOSH Report on Betatron Operations (1/13/12): Allen (2012) utilized updated MCNPX models developed by SC&A to calculate exposures and doses from betatron operations, including doses from neutrons emitted by the betatron target and by irradiated uranium.

SC&A Observations (3/22/12): Anigstein and Olsher (2012) reviewed Allen's (2012) report and questioned several of his assumptions. We performed an independent analysis which resulted in significantly higher neutron doses. However, we believe that these are tractable issues which need to be addressed in a revision to Appendix BB, at which time this issue can be closed.

Status (3/22/12): Open

Board Action:

Issue 9: Underestimate of Beta Dose

SC&A Finding: The beta dose assigned to GSI workers may be underestimated. Freshly cast uranium ingots may have enhanced concentrations of the short-lived progeny of ^{238}U on the surface, leading to a significant increase in the beta dose over aged natural uranium metal. Furthermore, uranium ingots were handled not only by the betatron workers but also by chainmen who transferred the ingots from the trucks or railway cars on which they arrived at the plant to the plant's own railway system. Such workers would also have been exposed to the beta rays from the uranium, but they are not assigned such exposures in the guidance for dose reconstruction of Allen and Glover (2007).

NIOSH Response (10/9/09): The comment appears to be discussing the accuracy of the dose estimate rather than the ability to estimate the dose. This issue has been raised in the Battelle-TBD-6000 review and appears on that issues matrix. Any revisions [to] Battelle-TBD-6000 will also result in revisions to applicable appendices.

SC&A Reply (10/12/09): The NIOSH response does not address the workers who may have handled uranium on its way into and out of the betatron facilities but were not assigned the dose to radiographers and consequently were not assigned *any* skin dose.

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

Action items (4/24/10) (ABRWH 2010): This issue is being addressed under the TBD-6000 issues matrix (relating to the [Putzier] Effect). SC&A will provide a write-up withdrawing their comment (e.g., the [Putzier] Effect is really not involved in this situation). (*References: pp. 266–268 of the 12/[16]/09 transcript*.)

SC&A Response (5/9/10): As stated above, this issue has two components:

1. Underestimate of skin dose to betatron operators due to neglect of the Putzier Effect.

2. Failure to account for the skin dose to chainmen and other workers who handled uranium but who were not categorized as "betatron operators" (i.e., they did not operate the betatron nor did they handle metal within 2 hours of irradiation).

As stated by Robert Anigstein (SC&A) at the May 12, 2010, work group meeting, we believe that the Putzier Effect is relevant to GSI, since there was most likely some recasting of ingots at Mallinckrodt and Weldon Spring, some of which may have been sent to GSI. We agree with the NIOSH response that the first part of issue 9 is also being addressed in the SC&A review of TBD-6000. We also agree with NIOSH that this part of issue 9 concerns the accuracy of the reconstruction of doses to the skin, rather than the ability to reconstruct the doses. However, we used the context of the SEC petition issues matrix to bring it to the attention of the Board because NIOSH has not addressed this and other dose reconstruction issues in the 2 years since the issuance of the original SC&A review of Appendix BB.

NIOSH did not respond to item 2, above. To address this issue, NIOSH needs to expand the category of workers who receive doses to the skin from contact with uranium metal to include all workers who may have handled uranium before or after betatron irradiation, regardless of the time elapsed after irradiation.

In the case of employees for whom precise job descriptions are not available, this could result in assigning doses to the skin to all employees who worked in the plant, with the likely exception of office or administrative personnel. Until we know how NIOSH will address this concern, we cannot judge if it is feasible to reconstruct doses to the skin of such workers. (SC&A 2010)

SC&A Observation (7/23/11): Allen (2009) indicated that although TBD-6000 did not explicitly incorporate the Putzier Effect in its dose estimates, comparisons of the derived 95th percentiles of deep and shallow doses[6] with maximum annual doses recorded at Fernald indicate that these estimates are claimant favorable. SC&A (2009b) concurred. However, it is not clear if these generic dose estimates will be applied to exposures from uranium handling at GSI. Allen and Glover (2007, Section BB.4) stated, "Since this estimate relies on estimates of exposure times and dose rates, the dose rates for specific types of work in table 6.4 [TBD-6000] do not apply." They consequently base their dose estimates on the dose rates from a rectangular uranium ingot, listed in table 6.1 of TBD-6000. We have two issues with that procedure: (1) the Putzier Effect is not included, and (2) the doses are from bremsstrahlung x rays and ignore the significant contribution of gamma radiation and the smaller contribution of characteristic x rays. That said, issue 2 is moot in terms of the doses from the uranium shapes handled at GSI, since the calculated doses from the rectangular ingot are twice the doses from the cylindrical ingot listed in table 6.1, and are larger still than the dose rates from a uranium slice calculated by SC&A (2008).[7] Thus, the neglect of the gamma and x-ray doses is fortuitously compensated for by the claimant-favorable choice of the rectangular ingot.

NIOSH Report on Betatron Operations (1/13/12): Allen (2012) utilized results presented by SC&A (2008) to estimate doses to the skin from beta rays emitted by natural and irradiated uranium and by irradiated steel.

SC&A Observations (3/22/12): Anigstein and Olsher (2012) reviewed Allen's (2012) report. We questioned his use of results for residual nuclides obtained with MCNPX 26e, an early beta version, rather than version 27e, which is the same as the current official release. The latter code leads to significantly higher skin doses to both the betatron operators and the layout men from beta-emitting nuclides in irradiated steel. However, we believe that these are tractable issues which need to be addressed in a revision to Appendix BB, at which time this issue can be closed.

Issue 10: Lack of Consistency in Assigning External Exposures

SC&A Finding: Because of an error in calculating the external exposure to irradiated uranium, Allen and Glover (2007) assign a disproportionately high exposure rate to workers handling uranium following radiography while underestimating (in modeling terms) exposures to the betatron and to irradiated steel. This results in exposure rates that vary from year to year. By contrast, SC&A (2008) estimated that the bounding external exposures to direct penetrating radiation did not vary significantly over the duration of AEC operations. The dose reconstruction approach prescribed by NIOSH can inappropriately assign a dose to a betatron operator working in 1961 that would be 3 times the dose to one working in 1965.

NIOSH Response (10/9/09): The comment appears to be discussing the accuracy of the dose estimate rather than the ability to estimate the dose. As such, it would be more appropriate to remove this from the SEC review matrix and add it to the Appendix BB review matrix.

[6] It is not clear if "deep dose" corresponds to personal dose equivalent, $H_p(10)$, or ambient dose equivalent $H^*(10)$—organ DCFs based on both these quantities are listed in OCAS-IG-001.

[7] Information furnished by former GSI workers after the preparation of the SC&A (2008) report indicates that some cylindrical ingots were radiographed at GSI as well as the uranium slices cited by Westbrook and Bloom (2010) and previously confirmed by the workers.

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

Action items (4/24/10) (ABRWH 2010): Agreed to close the issue here and deal with it in the Appendix BB Issues Matrix.

Status (9/17/11): Closed

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