SC&A RESPONSE TO NIOSH WHITE PAPER FOR GSI APPENDIX BB REVIEW

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November 8, 2008

On October 31, 2008, NIOSH issued a report titled "White Paper for GSI Appendix BB Review." The white paper updates the analyses originally presented in Battelle-TBD-6000 (Scherpelz 2006), as well as "Appendix BB: General Steel Industries" (Allen and Glover 2007) to that report. The white paper addresses two principal topics. One is the use of film badge dosimetry data to revise the exposure matrix for workers at the General Steel Industries (GSI) steel foundry at Granite City, IL, during the covered period of January 1, 1953 to June 30, 1964. The second is a critical review of the SC&A (2008) review of Appendix BB, first issued on March 17, 2008, with corrected pages issued on March 20, and a redacted version, cleared under the Privacy Act, issued on April 21.

Review of Film Badge Dosimetry Data

We have performed a limited review of the NIOSH analysis of the film badge dosimetry data obtained from Landauer, the vendor who supplied and processed the film badges. The dosimetry records furnished to us by NIOSH begin with a summary report for the first 3 months of 1964. This is followed by the first weekly report for the week that begins on Monday, January 6, 1964. There are presumably 130 weekly reports that span the period from January 6, 1964 to June 30, 1966, the end of covered activities. Each weekly report includes a control badge that is not assigned a badge number. This badge is normally stored in a location away from, or shielded from, any radiation sources. It is used to check on any accidental exposures of the badges for that week before they were issued to the monitored individuals or after they were retrieved from these individuals. Badge 1 is named "Betatron Ctl."

According to our observation of the film badge reports, as confirmed by a former official of Landauer, each badge number is unique to the monitored individual. An examination of the reports for the covered period at GSI shows the highest assigned badge was number 93. Thus, there were at most 92 monitored individuals during this period.[1]

According to the dosimetry reports, the program began in November 1963. However, no reports were furnished for the weeks prior to January 6, 1964. As it happens, the film badge dosimetry program began at approximately the same time that the new betatron was installed at the GSI Granite City foundry. According to the white paper, 6,999 badge readings were recorded through June 30, 1966.[2] The vast majority of these readings were reported as *M*, meaning that

[1] It is possible that the actual number was smaller, since some badges may never have been assigned to any workers.

[2] The authors of the white paper mistakenly interpreted the first quarterly report as a report for the week beginning January 1, 1964. They may have thus added these results to the total.

the results were below the reporting level of 10 mrem.[3] According to NIOSH, there are only 22 reported readings of 10 mrem or greater (all values are reported in increments of 10 mrem).

Because the PDF files containing the optically scanned reports furnished by NIOSH are of limited legibility (a number of the 1964 reports are totally illegible), we were not able to completely reproduce the NIOSH analyses of these data. We were able to perform a somewhat limited analysis, however, primarily based on the cumulative doses reported for each individual at the end of various monitoring periods. We did confirm that 22 individuals received cumulative doses of 10 mrem or greater during the covered period. We also determined that at least one individual received his dose during two or more separate weeks. In another case, a badge number first appears on the report for a given week, with no name and a 1-week dose of *M*. No cumulative doses are listed for any badge in that report. The same entries for this badge number appear on the reports for the next two weeks. The report for the following week lists a name for this badge number, but a blank field appears in place of the 1-week dose. The next week the individual has a 1-week dose of *M*, but a cumulative dose of 40 mrem for the calendar quarter, which is listed as the permanent lifetime dose on later reports on this worker. Consequently, based on this one individual, there is some question about the relevance of the reported cumulative doses to exposures at GSI.

According to the white paper, 89 individuals were monitored during the covered period. This is consistent with our observation that there were 92 badges, not including the betatron control, some of which may never have been assigned to individual workers. If this total is correct, we agree that 67 of these workers may not have received any recorded dose, since we found only 22 individuals with such doses. Our observation is based on spot checks of cumulative doses at various times, and may not include workers who were removed from the monitoring program between such times.

The white paper attempted to apply several statistical methods to the dosimetry data. In the one that was finally adopted, the authors assigned a dose of 10 mrem to every reading reported as *M*. They then calculated an average weekly dose for each of these individuals. Since only 10 monitored workers received doses greater than 10 mrem, the 79 other workers were assigned average weekly doses of 10 mrem. We calculated the maximum average weekly dose of the workers to be approximately 35 mrem.

The authors of the white paper calculated a mean weekly dose to the 89 workers of 10.35 mrem (listed as *mr* in the white paper) with a standard deviation of 2.75 mrem.[4] They then use these values to estimate a 95th percentile weekly dose of 14.87 mrem. We have reproduced the calculated values of the mean and the standard deviation. However, we note that the calculation of the 95th percentile dose is valid only for data that has a normal distribution.

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[3] In some cases, the field for reporting the weekly reading is blank. We do not know if these blank fields are included in the 6,999 reading cited by NIOSH.

[4] The dosimetry data is reported by Landauer in units of mrem, which is how the film badges were calibrated.

SC&A Analysis of Film Badge Dosimetry Data

To determine the goodness of fit of the data to a normal distribution, we constructed a normal score plot of the average weekly doses to the 89 individuals, as calculated by NIOSH. This plot is shown in Figure 1. The horizontal axis in this figure is the normal score or z-score, which measures the number of standard deviations the value is from the center of the distribution. The assigned values form a horizontal line at 10 mrem. The regression line fits closely to these values, due to the large leverage of values on the left side of the figure. The extreme high value on the right lies far from the regression line in this case. The red vertical line marks the location of the 95th percentile.

The R^2 for this regression is 0.096, indicating that the normal distribution provides a very poor fit to the distribution of values. In this case, a large majority of the data points lie close to the regression line, but the normal distribution provides a poor fit to the values in the upper tail of the distribution.

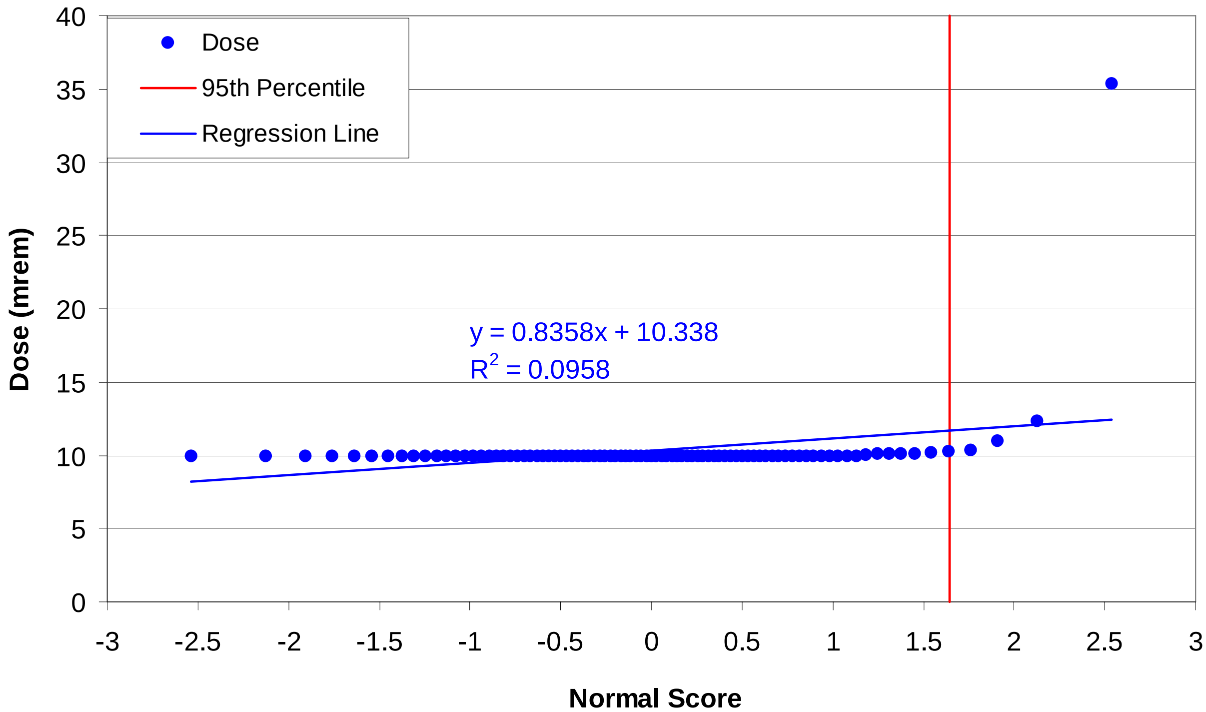

Figure 1. Normal Score Plot of Average Weekly Doses to Individuals

We next tried to fit a lognormal distribution to the same data, as shown in Figure 2. The R^2 for this regression is 0.115, which indicates that the lognormal distribution is a slightly better fit than the normal. However, neither fit satisfy the criterion specified by Brackett (2005) in OTIB-0019: "A value [of R^2] greater than 0.9 indicates a very good fit; however, values as low as 0.7 are acceptable, and even lower values may be acceptable if no better equation seems appropriate." Values of 0.096 or 0.115 are completely outside the acceptable range. This is despite the fact that a rank-ordered data, such as those used to construct these plots, yield an R^2 with an inherent upward bias. Consequently, neither an assumed normal nor a lognormal distribution appear to constitute a scientifically valid basis for assigning doses to GSI workers.

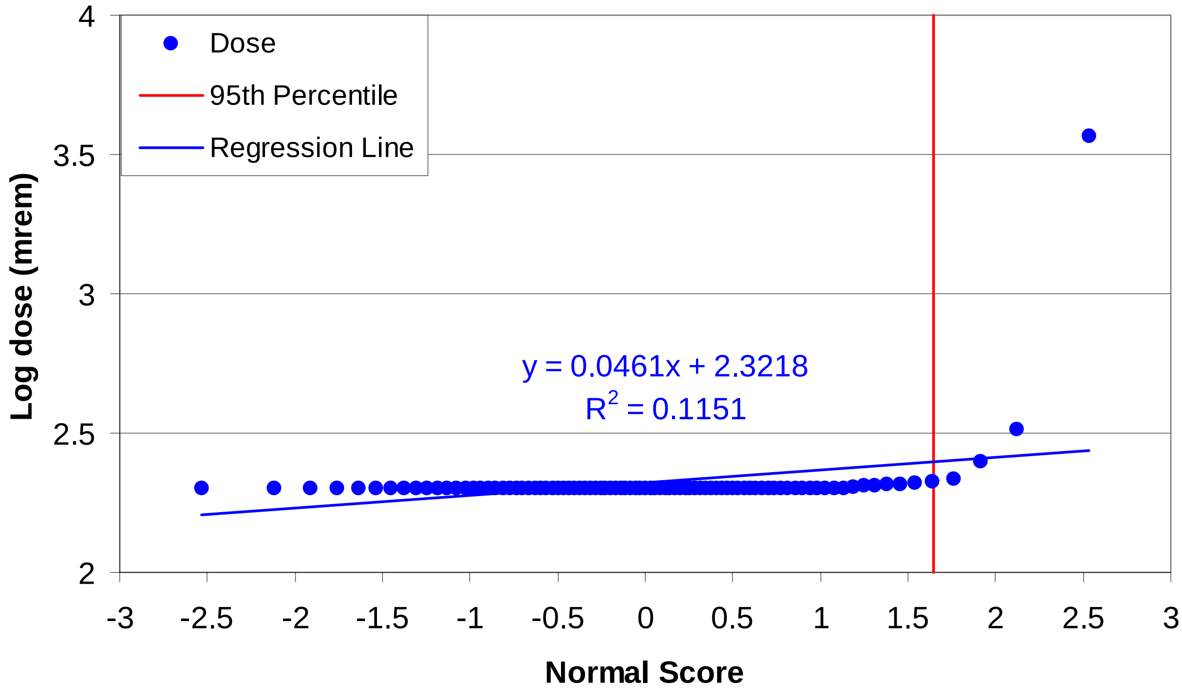

Figure 2. Lognormal Score Plot of Average Weekly Doses to Individuals

NIOSH Review of SC&A Report on Appendix BB

<u>Location of Betatron Operator</u>

In their review of the SC&A (2008) report on Appendix BB, the authors of the white paper point out inconsistencies which they have perceived in our analyses. The first perceived inconsistency is the location of the betatron operator in between radiographic exposures.[5] In calculating the exposure to residual radiation from the betatron apparatus, we assumed that, during the short shots, in which the betatron target was 6 ft from the casting, the worker was at a fixed distance of 3 ft—halfway between the internal betatron target and the casting—while during the long shots, in which the betatron was 9 ft from the casting, the worker moved over a range of 3–6 ft from the target. Although the actual movements of the operator were certainly more complex than represented by this simple model, we believe these to be reasonable, upper-bound assumptions. However, in calculating the radiation from the activated metal, we followed NIOSH/OCAS procedures regarding the distance from the metal. In OTIB-0004, Anderson and Bloom (2006)

[5] There were a number of betatron operators employed by GSI during the covered period. The betatron operator discussed in this report is a hypothetical construct used to model bounding exposures—it does not represent any actual individual.

provide guidance for estimating the maximum plausible dose to workers at Atomic Weapons Employers (AWEs). These authors assume that the worker is exposed for 8 h/d to uranium metal in the anteroposterior (AP) orientation at a distance of 1 ft. In Battelle-TBD-6000, Scherpelz (2006) recommends that an operator be assumed to spend 8 h/d at 1 ft from the metal, while a general laborer spends 8 h/d at a distance of 1 m. In Appendix BB, Allen and Glover (2007) assumed that the betatron operator spent one-half of the setup time at 1 ft from the metal and the other half at 1 m. We retained the last assumption in our original analysis.

While we certainly agree that the assumptions we used in calculating the exposures from the two sources appear to be inconsistent, they are not illogical. The assumptions about the distance from the betatron are reasonable and claimant favorable and should not be changed, absent more precise information. Changing the distance from the metal would make the dose reconstructions inconsistent with those used for other AWEs, raising issues of fairness. We wish to emphasize that our analyses represent bounding calculations—if the distances from the metal are reasonable for other AWEs, they should be also used in these instances.

However, the results of our analyses render these issues moot. As discussed in our report, the limiting weekly exposure is of a betatron operator exclusively occupied with radiographing steel. His exposure, based on a time-weighted average of long and short shots, is 33.5 mR/shift from all sources. If the exposure from the activated metal were completely ignored in the calculation, his exposure would be reduced to 33.0 mR/shift. Thus, if the exposure to the steel were recalculated to account for greater distances, the exposure would be between 33.0 and 33.5 mR/shift, an insignificant difference from the original calculation.

The distance from the metal takes on special significance in calculating the doses from beta radiation to the skin and other superficial organs. In these cases, the assumption that the worker was at a greater distance from the metal, even if it placed him nearer to the betatron, may not be claimant favorable. Since we do not know a priori which organs will be the targets of dose reconstructions, it is not possible to definitively state which worker location would be most claimant favorable. We therefore suggest that the apparently inconsistent positions are not unreasonable.

<u>Time of Onset of Exposure to Residual Radiation from Betatron</u>

The authors of the white paper take issue with our calculation of the time-integrated exposure to the residual radiation from the betatron, claiming that the assumption that the exposure starts at $t = 0$ is inconsistent with the calculation of the exposure to the activated metal, which starts 5 s after the beam is turned off. The reason for this apparent discrepancy is that the initial exposure rate of 15 mR/h at a distance of 6 ft from the betatron target, reported by Schuetz (2007), was measured under conditions similar to those experienced by the betatron operator. As stated in section 2.2.3 of our report, "[he] estimated . . . that [the] initial reading was taken within 5–10 s after the beam was turned off." Consequently, the initial exposure rate corresponds to the moment the operator reached the betatron, so no additional decay time needs to be considered. In the case of the activated metal, the exposure rates are based on MCNPX simulations, which begin at the moment the beam is turned off; therefore, the 5-s delay, which allows time for the operator to reach the casting, is appropriate in that case.

Railroad Track Exposure Scenario

The white paper questions the applicability of the scenario in which the casting was radiographed while on the railroad track and the limit switches on the betatron were overridden by reversing the head of the instrument. As stated in the white paper:

> *The operators went on to indicate that this was not done until the supervisor present in the early 1960s left the company and was replaced by another. This supervisor left the company on 6/30/1966 which is the last day of the uranium work. This information indicates the railroad shots occurred after the covered period.*

Although this supervisor did in fact remain at GSI until 1966, he had been promoted and moved to another division not involved with betatron operations at an earlier time. According to the workers interviewed at the meeting in Collinsville, IL, on October 9, 2007, a later supervisor ordered the betatron operator to override the limit switches. The Landauer film badge dosimetry reports for 1964 list the name of the earlier supervisor on weekly reports through the week of November 9. No listing of his name was found on any later report. Thus, it appears most likely that he was transferred to his new position by the end of that week, if not sooner. Having been issued a film badge, it is highly unlikely that he would continue being involved with betatron operation but not be monitored. Furthermore, the name of the later supervisor is first found on the report for the week of January 4, 1965. However, that report indicates that there were nine previous reports for this individual, beginning in November 1964. Thus, it would appear he started work in the betatron at about the same time the previous supervisor left that facility. Therefore, the practice modeled in our scenario may have taken place during at least part of the covered period (i.e., November 1964–June 30, 1966).

Output of Old Betatron

The next issue raised in the white paper concerns the output of the old betatron. The authors are incorrect in stating that "SC&A used a betatron output of 250 R/min from both the new and old betatron machines." As stated in section 2.1.3 of our report, we used MCNPX to calculate the electron beam current in the new betatron, based on a beam energy of 25 MeV and an output of 250 R/min. We then assumed the same current for the old betatron, which operated at 24 MeV, and used MCNPX to calculate the resulting photon and neutron emissions. These emissions are lower due to the lower beam energy. We recognize that the old betatron may have had a lower beam current. However, since the beam current of the old machine is not known and the actual exposure rate was not well documented and changed over the years of operation at GSI, we made the claimant-favorable assumption that the beam current was the same as in the new machine.

Different Assumptions for Beta and Photon/Neutron Dose Calculations

The white paper discusses an apparent inconsistency between the calculation of doses from beta rays and from photons and neutrons. The authors are correct in stating that the beta dose calculations took account of the uranium radiography, while the photon and neutron dose models did not. This apparent discrepancy is resolved in sections 2.6.2 and 3.2.9 of our report. As stated in the former section: "Since the Mallinckrodt purchase orders specified that the work was to be performed on the day shift Monday through Friday, we assume that the same operator could have performed all the uranium radiography during a given year." As stated in section 3.2.9: "Since we calculated a slightly higher exposure per shift for the radiography of steel than of uranium, the frequency of uranium radiography does not affect the maximum annual exposure, which we assumed to be that of an operator on the evening or night shift, when no uranium radiography was supposed to take place." Thus, the beta dose was to a worker on the weekday day shift, while the photon and neutron doses were to a worker on the evening or night shift. Depending on the organ in question, either the beta dose or the photon and neutron doses predominate; therefore, both scenarios are needed to perform a claimant-favorable dose reconstruction.

Verification of Rounded Values of Exposures to Uranium

The final comment in the white paper is on the exposure to uranium listed in table 16 in our report. The white paper cites the incorrect value of 0.66 mR/shift listed in the original March 17 version of our report. This error was due to a faulty link between the table and an Excel workbook, which we detected and corrected in an errata sheet sent out on March 20. The correct value is 6.8 mR/shift, as stated in our corrected report. The authors of the white paper attempted to calculate the exposure rate using the values listed in tables 8 and 9 of our report, and arrived at 6.56 mR/shift. The values listed in tables 8 and 9 were rounded to two significant figures so as not to imply a high degree of precision to our model, while table 16 displays all values with one decimal place; however, the actual calculation is based on the precise values. In the following verification, we show the values rounded to two decimal places:

$$R_u = \frac{r_{11} + r_{12} + r_{21} + r_{22}}{2}$$

R_U = total exposure to irradiated uranium
= 6.78 mR/shift

r_{11} = exposure to delayed radiation from irradiated uranium at 1 ft
= 11.46 mR/shift

r_{12} = exposure to delayed radiation from irradiated uranium at 1 m
= 1.38 mR/shift

r_{21} = exposure to aged natural uranium at 1 ft
= 0.64 mR/shift

r_{22} = exposure to aged natural uranium at 1 m
= 0.08 mR/shift

As can be verified from the above data, the rounded value of 6.8 mR/shift was correctly calculated.

Conclusions

As stated in our original report, the calculations of exposures and doses to betatron operators and other workers are bounding estimates. The film badge data indicate that, with two exceptions, the maximum dose during any one week is less than that predicted by our models. However, workers other than radiographers do not appear to have been issued film badges. Furthermore, it is not clear that workers using the ^{60}Co source in number 6 building wore film badges. That source was in use from at least 1951 (see footnote 5 on page 7), whereas the Landauer film badge program did not begin until November 1963.

Some of these issues are discussed in the SEC petition evaluation report for GSI (Buker et al. 2008). We read but did not formally review this report.

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[6] Mr. Schuetz was under contract with NIOSH for this project.