DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

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Dear

Thank you for your comments on the Appendix BB (General Steel Industries) to Battelle-TBD-6000. We have carefully considered your comments and provide the following in response to your concerns. Your comments and our responses have also been made available to the Advisory Board on Radiation and Worker Health.

The purpose of the Appendix BB and Technical Basis Document 6000 is to serve as general guidance for dose reconstructors to use in preparing dose estimates for General Steel Industries claims. These documents, and specifically Appendix BB, serve as an exposure/dose model which presents a worst-case exposure scenario for radiation exposure across all GSI workers from non-destructive testing of metal components using an x-ray source (Betatron). Information gaps are filled in with claimant-favorable assumptions often representing the bounding condition of a range of credible possibilities. The Appendix is not designed nor intended to provide fundamental tutorials in scientific concepts or to itemize all available information pertaining to a facility or a source of exposure, nor is it intended to provide a detailed and highly accurate estimate of the dose where a bounding estimate will suffice for compensation purposes. With that in mind, there are often many documents reviewed that are not used in preparing the Appendix and thus not included in the list of supporting references. You have pointed out several references (e.g., LAMS-2064, Kuttemperoor's papers, Sugarman, and Duffield) that were not cited in the Appendix but you thought they should have been. While these and others were carefully examined, they did not offer any specific detail or additional guidance for dose reconstructors nor did they contradict the approach presented in the Appendix; therefore, they were not listed in the Appendix references. If you feel this is in error, we would need you to point out what specific portions of a reference you feel contradicts the idea that the Appendix is a bounding estimate.

In reading your comments, we get the impression you believe any change will result in an increase to the assigned dose. In many cases the opposite is actually true, and a change based on many of the issues you have raised would cause the estimated dose to decrease. After carefully reviewing and considering your comments, we do not feel a revision of Appendix BB is necessary at this time.

You have raised several technical-based perceptions that require a technical discussion. In the following commentary we have attempted to provide enough technical background to address

these perceptions. Since a number of your perceptions can be addressed with one general response, we have tried to do so in the following with an itemized response at the end.

The first perception is that all of the uranium metal produced at Mallinckrodt was x-rayed at GSI. NIOSH is in possession of no information that this was indeed the case. The average monthly production of uranium billets at Mallinckrodt exceeded 150 tons as early as 1950. The design capacity of plant 6E was originally 150 tons per month but was expanded to 265 tons per month in the third quarter of 1951. In your comments, you indicate your belief that each 3300 pound ingot was x-rayed with four two-hour shots plus 15 minutes between shots. This totals nine hours of work on each ingot. At that pace, a little less than 134 tons of uranium per month could be x-rayed. That does not allow for any maintenance time and more importantly, does not allow for any time to x-ray any other components such as steel castings. It is clear from the operators that other components were indeed x-rayed and, in fact, were the largest part of their work. Therefore, it does not appear to be feasible that all uranium metal produced at Mallinckrodt was x-rayed at GSI.

The second general perception we would like to address is the belief that the Appendix only addresses one Betatron machine. The Appendix addresses exposures at a Betatron whether it is the new or the old machine. The exposure rates came from transcripts of the operators as described in the Appendix. This was increased to the rated output of the old Betatron but is not intended to imply it is only specific to the old Betatron Machine. Also, the difference in the maximum output energy (24 MeV or 25 MeV) was considered small so all models assumed a 25 MeV maximum output energy.

The third general perception to address is the dimension, shape and content of the uranium and steel described in the Appendix. GSI x-rayed several different shapes and sizes of uranium metal. Some were referred to as ingots, dingots, and Betatron slices. It is also very clear that GSI also x-rayed many different sizes and shapes of castings made from steel and other alloys. As you indicated in your comments, it can take a very long time for the Betatron x-rays to penetrate thick uranium or steel castings. This is due to the fact that these materials stop much of the x-ray energy in the first few inches. This implies that once the material exceeds some thickness, little additional interaction will occur because the beam has been almost entirely attenuated. Also, Betatron machines are known for their narrow beam and that is the reason the components being x-rayed had to be set several feet from the machine in order to obtain an x-ray of reasonable size. The model used in the Appendix was large enough to encompass the entire beam and thick enough to absorb most of the energy. Any dimensions beyond that of the Appendix model will have no effect on the dose rate from induced radioactivity. This was used as a claimant-favorable assumption in order to bound all the possible sizes and shapes of material x-rayed by the Betatrons.

The last general perception we would like to address is that exposing the materials to x-rays from the Betatron for longer durations will produce higher dose rates from the material. The primary misconception here appears to be that the increase in dose rates is linear. That is, doubling the x-ray time will double the dose rate. This is incorrect.

The induced radioactivity doesn't wait for the x-ray to turn off before it begins to decay. The decay rate is proportional to the amount of radioactive atoms in the material at any point in time. This causes a constant production term and an increasing removal term which leads to a buildup of an equilibrium value while the Betatron is on. In more general terms, the dose rate coming from the material increases at a decreasing rate until it reaches an equilibrium level at which point it does not increase any further.

The rate at which this buildup occurs is related to the half-life of the radioisotope being created. It will reach one-half of the equilibrium value after a time equal to one half-life of the radioisotope being produced. After another half-life, it will increase to the point that is half way between that level and the equilibrium level. That is, it will be at 75% of the equilibrium level after 2 half-lives. After 3 half-lives, it will be at 87.5% of the equilibrium level and so on.

The equilibrium level is the level achieved when the decay rate of a radioisotope is equal to the production rate of that isotope. The production rate from a photo-neutron reaction is essentially proportional to the abundance of the parent isotope. The parent isotope is the material being irradiated to produce the radioactive isotope. That means the decay rate at the equilibrium level of any isotope will be essentially proportional to the abundance of the parent isotope.

Therefore, the decay rate (and thus the dose rate) depends on the abundance of the parent isotope and the half-life of the radioactive isotope as well as the time the Betatron is irradiating the material. The half-life of iron-53 is 8.51 minutes. A one-hour x-ray would equal approximately 7 half-lives which means iron-53 is at a little over 99% of its equilibrium level. Continuing to irradiate the iron will not increase the dose rate beyond the equilibrium value. If we consider something with a very long half-life such as Cobalt-60 which has a 5.27 year half-life, even after an 8-hour x-ray, this would only reach about 0.012% of its equilibrium level. Therefore, the important isotopes to consider for alloys of steel are those with a half-life within an order of magnitude of the shot time and which have an abundance greater than or close to that of iron-54 (parent of iron-53).

Steel comes in many alloys, and some common elements alloyed with iron to make steel are carbon, chromium, and nickel. Carbon is usually a very low percentage of the alloy which produces a very low equilibrium value. Radiation from chromium would come from the photo-neutron reaction with Cr-50 to create Cr-49. Cr-50 is a lower fraction of chromium than Fe-54 is for iron. Thus, replacing iron with chromium reduces the isotopes available to become radioactive. Cr-49 has a half-life of 42.3 minutes compared to 8.51 minutes for Fe-53. Therefore, it takes longer to reach that equilibrium level but both would reach a reasonably high fraction of that level within the time of a credible x-ray exposure. The conclusion here is that the dose rates would be lower for stainless steel due to replacing iron content with chromium.

Radiation from nickel would be caused by the photo-neutron reaction of Ni-58 to create Ni-57. Ni-58 can be more abundant than Fe-54 in nickel alloys (such as Inconel) causing a higher equilibrium activity. However, the half-life of Ni-57 is 35.6 hours. Therefore, it would take a 35.6 hour x-ray exposure for Ni-57 to reach half of its equilibrium activity.

As mentioned earlier, the Betatrons are known as a narrow beam x-ray machine. Basically, the beam of photons that are emitted from these machines is narrower than many other types of x-ray generating devices. This means the equipment being x-rayed has to be set at an appropriate or nominal distance from the machine in order to obtain a reasonably-sized image. A distance of about 9 feet is required to obtain a 14" x 17" image. The discussion above about production and decay of radioisotopes assumes the material is being irradiated by Betatron x-rays. While a large casting can require hundreds of x-ray exposures, the same spots are not usually x-rayed over and over. Therefore, once the beam is turned off, the activity in that shot area begins to decrease as the radioactivity decays. Even while a new shot is being taken in another area of the casting, the original area continues to decay. Therefore, shot times are not additive.

One additional point needs to be made concerning the Appendix exposure model. While Betatron operators and other workers are exposed to skyshine during the x-ray shot, this dose rate is normally lower than what they will be exposed to while working in close proximity to the irradiated material. Obviously, this is assuming the material was irradiated long enough to achieve a detectable dose rate. Even if the material is still emitting radiation after the next shot begins, the radiation is not exposing anyone since once they leave the area, the operators are shielded from this radiation.

In summary, the highest doses from the Betatron operation would be achieved when the material is exposed just long enough to build up a dose rate near its equilibrium level before the operators are exposed to that radiation by working in close proximity to the x-rayed material. The longer the operators are exposed to that radiation, the more radiation dose they receive (until it decays to a low level). The dose rate from a piece of iron after a 1-hour x-ray exposure will not increase if the exposure were to last 2 hours, or 4 hours, or more. In actuality, the operators are not being exposed to that piece of irradiated iron while the x-ray shot is taking place. Thus, for the long x-ray exposure scenarios, there are many more hours of work time in which they are not being exposed (other than the skyshine), and the dose would in reality decrease.

Shortening the time between shots also reduces the time they are being exposed and thus reduces the dose. For example, a person exposed to an 8 mrem/hr radiation field for one hour would receive 8 mrem of radiation dose. A person exposed to the same radiation field for 15 minutes would receive a 2 mrem radiation dose.

The exposure scenario in the Appendix has been created to use bounding values (i.e. those that would result in the highest exposure) for most parameters while still being credible. For example, a 15-minute turn-around time is credible but so is a 30-minute turn-around time. People exposed to the irradiated material for 30 minutes will receive more dose than those exposed for 15 minutes. Also a 2-hour shot time is credible as is a one-hour shot time. However, if pure iron is assumed, the saturation dose rate is reached within the one-hour time frame, and adding time to the shot only reduces the amount of time an operator can be exposed to the irradiated material. Lastly, pure iron causes a dose rate from irradiating iron-54. In other steel alloys, some of this iron is replaced with elements that will produce a lower dose rate due to the abundance of the alloyed material and the half-lives of the radioactive products formed.

Admittedly, using pure iron is not a credible scenario, since we know other iron alloys were irradiated, but it is a bounding scenario producing higher doses than alloys.

We hope that this addresses all of your technical comments. The following will address the specific questions you raised by referencing the sections of the Appendix.

Comments on Section BB.2

The comment pertaining to two Betatron machines is addressed above. Basically, the exposure model prescribed in Appendix BB provides guidance to a dose reconstructor and presents a worst-case exposure scenario applied to all GSI workers whether they were a Betatron operator or not.

Your comment implying a GSI employee may have interpreted the x-ray film of uranium metal adds no value to the guidance in the Appendix. The purpose of the statement in the Appendix – "The x-ray films were processed, but not interpreted, at GSI." was to indicate that GSI personnel would not have corrected flaws in the uranium metal by grinding or any other means. It is expected that GSI radiographers reviewed the film to insure it was of good quality.

Your comment that purchase orders for 1953 to 1957 have not been retrieved is addressed in detail in the next section. Your point here appears to be that without these, the amount of uranium, the size and shape of that uranium and the composition of that uranium can not be determined. The derivation of the estimate of the amount of uranium x-rayed is discussed in the Appendix. We believe this is a reasonably bounding estimate. As discussed in the next section, there appears to be little or no evidence that uranium was x-rayed at GSI between 1953 and 1957. In the general responses above, we indicated that the size and shape of the uranium was modeled using enough uranium to completely absorb the x-ray beam and thus maximize the possible photo-interactions and the dose estimate. The general responses also discussed how the composition of the material being x-rayed can reduce the dose rate. The examples used were all for iron alloys but the principle also applies to uranium. The primary source of radiation from uranium irradiated with a Betatron machine is the photo-fission of the uranium. Reducing the amount of uranium in the material by alloying it with other material reduces the amount of photo-fission that occurs and thus reduces the dose rate.

You made a long comment indicating the Appendix sentence that states "The use of the facility for these services was on an as-needed basis … " is not accurate. The rest of the comment appears to attempt to justify this by pointing out that the Betatron machines were used around the clock to x-ray various components including tank hulls, tank turrets, nuclear power plant components and missile tubes. However, the "services" the sentence in Section BB.2 is referring to are described in the paragraph as x-raying uranium metal. We clearly understand that all radiation exposures during the covered period of an AWE must be addressed in a dose reconstruction. Thus, the examples don't appear to show any inaccuracy or inconsistency in our understanding as the Appendix BB addresses the exposures at GSI.

Comment (d)[1] indicates there are worker comments to this fact without being specific as to which comment you refer. From examples in (d)[2], it appears that would be the comments pertaining to a lot of work on the components mentioned above. As stated above, this doesn't appear to imply the statement in the Appendix is inaccurate.

Comment (d)[3] indicates not all the sources of radiation at GSI were considered. The Appendix is intended to represent a bounding estimate of radiation exposures at GSI. The use of the radiography sources mentioned is common in the steel industry as well as other industries. Thus, the typical exposures are well known and lower than estimates in the Appendix for Betatron operations. Thus it was favorable to assume radiographers were always involved in Betatron operations. This is mentioned in the second paragraph after the table in section BB.4.5.

Comments on Section BB.2.1

Regarding the question of who owned the Betatron buildings, the designation of a facility as AWE or DOE is provided by the Department of Energy. Under the EEOICPA law, there are only two types of facilities, AWE and DOE facilities. The definition of these facilities are documented in the law, and essentially an AWE facility is privately owned while a DOE facility is owned by the DOE or one of its predecessors (the AEC or the Manhattan Engineer District). Facilities owned by other government agencies are not covered under EEOICPA; for example, see the following Web page pertaining to the National Bureau of Standards (a Department of Commerce agency). http://www.cdc.gov/niosh/ocas/nbs.html Any questions or information you have regarding the AWE facility designation for GSI should be directed to the Department of Energy as it is their responsibility to establish such designations.

You point out that purchase orders for 1953 to 1958 were not retrieved. February 1958 through 1966 is the only period where the documentation indicates that the facility was x-raying uranium. The only other indication that has been uncovered to date of operations outside of that period was a correspondence cover page pertaining to x-raying uranium in 1953. However, there is no indication this was work actually accomplished or was simply a consideration of a future project. Even if this work was performed in 1953, there is no indication that this continued until 1958. There is actually information indicating no purchase orders were in existence prior to February of 1958. This information was a request for payment for services rendered without purchase order in February 1958. This request for payment was apparently not paid immediately because a second request for this payment was sent on July 10, 1958. This request indicated the amount of the request was $48.00 equating to 3 hours of work at the charge rate of $16 per hour specified in later purchase orders. Also the non-standard start date of March 1958 rather than the beginning of a fiscal year implies the March 1958 purchase order was the beginning of the use of purchase orders for this work. This is also implied by the extensions to the first purchase order until the pattern settled out to providing purchase orders covering each fiscal year. Thus, it does not appear any work that may have occurred from 1953 to 1958 was covered by purchase orders.

The comments pertaining to the size of the uranium metal were addressed in the general comments above; the size, shape, and content of the irradiated components have been modeled to reflect the worst-case exposure scenario.

As discussed earlier, we do not believe all the uranium metal types and alloys that went through Mallinckrodt were x-rayed at GSI. Therefore, indications of types of uranium at Mallinckrodt are not necessarily pertinent to the GSI Appendix.

Comments on Section BB.2.2

The comment indicating the 1953 to 1958 work must have been covered by purchase orders was discussed in the previous section of this letter. There is no evidence of this work occurring between 1953 and January of 1957 but there is evidence that the use of purchase orders began in March of 1958.

You commented that it was common practice to change purchase orders. Indeed several of the GSI purchase orders were modified to include an agreed-to price for different sizes of film and to change the people who could authorize the work. Other modifications extended the allowed time frame of the purchase order as indicated in the Appendix. With this modification uncovered, it is believed we have all the modifications that occurred. Also, the value of these purchase orders was reasonably consistent from year to year. If they were exceeded in a given year, the next year's purchase order would be increased.

You made a comment that the sentence "For the remainder of the year, it is assumed that various alloys of steel were x-rayed" is a "gross misleading estimate". The examples you provided indicate that GSI facility produced "tank hulls and turrets, railroad trucks, NY rail cars, nuclear submarine missile launch tubes, nuclear power plant channel heads and other huge industrial castings made of multiple types of steel alloys". This does not appear to contradict the Appendix. All those examples are various alloys of steel.

Comments on Section BB.3

Telephone interviews for dose reconstruction claims do have a specific question pertaining to the frequency of medical x-rays. These interviews were reviewed for over 200 claims NIOSH has with GSI employment. The vast majority indicated either a) x-rays were performed less frequently than annually (such as pre-employment only), b) were not performed during the contract period, or c) did not know. ORAU-OTIB-0006 provides a claimant-favorable assumption of an annual chest x-ray.

Comments on Section BB.4

The statement in this section that no exposure data was found refers to none being found in our Site Research Database for GSI workers. You commented that dose records exist at Landauer and that you recovered data from 30 workers. We have not yet recovered any data from Landauer but if it is recovered in the future, it will be considered in a revision to the Appendix. If you provide the records of the 30 workers you claim to have, NIOSH will consider the records in a revision to the Appendix.

The effect of the size and shape of materials being x-rayed were previously discussed in this letter. The statement that the rectangular ingot produces the highest dose rate is referring to table 6.1 of Battelle-TBD-6000.

Comments on Section BB.4.1

You made several comments indicating there was no "cooling off" period, that operators "swarmed" over the material as soon as the shot ended and that there was no gap between take down of one shot and setup for the next shot. The Appendix is consistent with these statements and, as noted previously, the Appendix presents an operation cycle without a cool down period as a worst-case exposure scenario. Also, as indicated earlier, we would not normally reference material we did not use to develop the Appendix. Since we did not assume there was a cool-down period, the reference to Professor Kuttemperoor would add no value to the Appendix.

You commented indicating it is necessary to know exposure times, and the size and shape of the material being x-rayed in order to calculate the radiation dose rate. As addressed earlier, the exposure time in the Appendix produces a favorable dose to the operators as does the size and shape used in the model.

While a large casting can require hundreds of x-ray exposures, the same spots are not usually x-rayed over and over. Therefore, once the beam is turned off, the activity in that shot area begins to decrease as the radioactivity decays. Even while a new shot is being taken in another area of the casting, the original area continues to decay. Therefore, shot times are not additive.

You indicated that a 3-D CAD program front end to MCNP5 must be used to accurately model the doses. The use of the CAD front end with MCNP5 is a simplifying tool. It is not significant to the dose calculations and thus does not lead to a deficiency. This is similar to stating what mathematical calculations were performed without stating the type of calculator used to perform the calculations.

Comments on Section BB.4.2

You commented that the description of the shielding was inadequate. There appears to be a misconception here. In order for shielding to be effective, it needs only to be placed in a direct line between source and area of interest. The design of the new Betatron building, as well as the old, is commonly referred to as a labyrinth design. That is, it allows an open access to the area while providing direct line of sight shielding. The calculations referred to as skyshine in the Appendix are the calculated dose rates outside the shielded area when the beam is pointed in various directions. This inherently accounts for radiation scattered through the roof, the unshielded second story, the floor, the walls, and down the labyrinth. It also accounts for any radiation penetrating the 10- foot-thick walls.

The source and program version of Attila is provided in the reference section of the Appendix. Attila is capable of modeling neutrons but as you pointed out, this was not done. The skyshine calculation was simplified by pointing the beam in various directions without attenuating it with castings or other material being x-rayed. No neutrons would be produced in this setup. This represents a large overestimate of the photon dose and thus the neutron dose was omitted.

The use of the CAD front end with Attila is a simplifying tool. It is not significant to the dose calculations and thus does not lead to a deficiency. This is similar to stating what mathematical calculations were performed without stating the type of calculator used to perform the calculations. Attila is capable of modeling neutrons; however, as indicated above, the neutron dose contribution to skyshine was omitted by providing a favorable estimate of the photon dose. Since neutron production ceases when the beam is turned off, there is no neutron dose when the individuals are in close proximity to the irradiated material.

You mention that SC&A is using MCNP to model Betatron doses at Fernald and that NIOSH should obtain and use this data. Fernald did not have a Betatron, did not do non-destructive testing, thus this comment is not relevant to Appendix BB.

You asked about the floor plans that were used to model the skyshine. Both buildings were modeled using the floor plans. Referencing the floor plans is a good suggestion that will be applied in the next revision of the Appendix.

You asked what the term "built up" roof means. It is a common term in construction referring to building up layers of tar and tar paper on top of the structural element of a roof.

You indicated electricians had to access the second floor above the control room. The worker comments indicated the electricians would change capacitors in that area and presumably at times work on the "Mag" equipment. This was the power supply for the Betatron. Any elevated dose rates in this area would occur while the Betatron is operating. Operators indicated they had to power down the Betatron to change capacitors so electricians should not routinely have been exposed to elevated radiation in this area.

You also asked what source documents or calculations were used to state the highest modeled dose rate was 0.72 mrem/hr. The source was the model calculated with Attila as discussed previously.

Comments on Section BB.4.3

You ask what "machine value" means. The term is meant to refer to the maximum exposure rate output for which the machine was rated.

You made a number of comments in a paragraph mentioning Jack Schueltz and Professor Kuttemperoor. Some of the paragraph appears to simply discuss some of the efforts you went through to gather information without agreeing to or disagreeing with anything in the Appendix. Information from Mr. Schueltz was referenced in the Appendix because it was useful in completing the Appendix. Information from the operators was also used. Professor Kuttemperoor's papers indicated that components in steel can become activated when they are exposed to the beam from a Betatron. It was not useful in quantifying that activation and was, therefore, not used in preparing the Appendix. You also mentioned that Picatinny Arsenal was

recently removed from coverage as an EEOICPA site. That site was removed because it was a Department of Defense facility and thus does not meet the definition of DOE facility or AWE facility.

You also indicated that the 100 R/min was on the low side. As discussed earlier, the 100 R/min used in the Appendix was based on statements from the operators. These values were increased to the 100 R/min rated output of the old Betatron as a claimant-favorable assumption.

Comments on Section BB.4.4
The majority of comments in this section are addressed previously in this letter or later in the Appendix. The referenced documents indicate the fission yield curve from photo-fission is similar to that from any type of fission. This is not a few isotopes; it is a mix of hundreds of isotopes. The exact mixture changes over time as fissions occur and after fission ends. This was modeled using MCNP as described and equations for the dose rate decay over time are given in the Appendix.

Comments on Section BB.4.5
You make a number of comments in this section most of which have been addressed earlier in this letter. You raise the issue that all sources of radiation were not accounted for in the Appendix. The Appendix is intended to represent a bounding estimate of radiation exposures at GSI. The use of the radiography sources mentioned is common in the steel industry as well as other industries. Thus, the typical exposures are well known and lower than estimates in the Appendix for Betatron operations; consequently, it was favorable to assume radiographers were always involved in Betatron operations. This is mentioned in the second paragraph after the table in section BB.4.5.

Comments on Section BB.5
The Appendix states that "Since no cutting, machining, or abrading of uranium was involved, there was a low potential for producing elevated air concentrations of uranium". You indicate this statement is not true. We are not aware of any statements by the operators indicating uranium was cut, machined or abraded. Also, the documentation on the work GSI performed under contract to AEC was for non-destructive testing with the Betatron; therefore, we have no indication that GSI workers cut, machined, or ground the uranium ingots from Mallinckrodt.

Comments on Section BB.5.3
You list several weaknesses that appear to be a summary of previous comments. As such, they have been addressed earlier.

Comments on Section BB.6
Your comments in this section appear to be general observations that do not require a specific response.

Again, we hope this has addressed your general technical comments and specific questions raised in your review.

Sincerely,

Larry J. Elliott
Director
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cc:

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