**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.1
LAMS-2064 appears to be classified because of references and picture of specific components of nuclear weapons. Since these components did not exist at GSI, the fact that the report is classified is not relevant to this Appendix. You also ask "why major, scientific facts regarding exposures and procedures are not included in the GSI Appendix". After reviewing the LAMS-2064 document and your comments, we have not been able to determine what "major scientific facts" you are referring to; perhaps you could be specific as to which parts of this document you feel contradict the GSI Appendix and why.

You indicated that non-destructive testing appears to have been overlooked in other EEOICPA-covered facilities. This is not true. Radiography using sources such as Co-60, Ir-192 and portable x-ray machines are common in many industries. Doses received by radiographers in industry are well documented. Betatrons, on the other hand, are not that common and may require special consideration to insure doses are accounted for from operating Betatrons. You provided a list indicating a number of EEOICPA sites with Betatrons. This has been reviewed to determine if additional considerations need to be addressed for these sites. Some DOE sites had these machines but they also had much more powerful particle accelerators which would overshadow the Betatron dose. The dose received from Betatrons at these and some other sites are accounted for by dosimetry badges worn by the personnel. Some of the AWE sites on your list did have Betatron machines but these were installed after the period of time covered by EEOICPA. One example of this is Allis-Chalmers itself which is a covered facility only for 1943 and 1944. This is prior to the time Allis-Chalmers began producing Betatron machines. Also worth mentioning is Picatinny Arsenal and the Naval Research Laboratory. These two sites were removed from the list of facilities covered under the EEOICPA program because they were Department of Defense owned facilities.

Comments on Section BB.2
Several issues were raised in over two pages of comments to this paragraph. As far as the name of the facility, the covered facility for which NIOSH has attempted to reconstruct doses, has always been the facility at 1417 State Street regardless of the name. If there are questions as to the qualification of an individual claimant, those questions should be brought to the attention of the Department of Labor. NIOSH will provide a dose reconstruction for all the claimants DOL has verified to be employed at GSI. We will also request that DOL return those claims previously completed so that we can revise the dose reconstructions in accordance with the Appendix.

You raise the issue that all sources of radiation were not accounted for in the Appendix including the second Betatron. As mentioned earlier, the Appendix addresses exposures at a Betatron whether it is the new or the old machine. As to the other sources, the Appendix is intended to represent a worst-case exposure scenario and provides a bounding estimate of all 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 the estimate in the Appendix for Betatron operations. Thus it was most claimant-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 of the Appendix.

You commented that "numerous and copious amounts of information regarding GSI" have been provided by you and ask why very little of it was included in the Appendix. As discussed earlier, there are often many documents reviewed that are not used in preparing the Appendix and thus not included in the list of supporting references. While the information you provided was carefully examined (including the CATI interview and the workbook), it did not offer any specific detail or additional guidance for dose reconstructors nor did it contradict the approach presented in the Appendix; therefore, these documents are 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. All the documentation gathered, including that provided by you is accessible to the Advisory Board on Radiation and Worker Health to be considered during their review.

You mention again that the new Betatron was not considered and then point out that the Appendix mentioned the Betatron power was 25 MeV (the power rating of the new Betatron). As discussed earlier, 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 thus all models assumed a 25 MeV maximum output energy.

You also comment that there are no 10-foot-walls between the Betatron machine and the occupied building. 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 the 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 remaining comments in this section indicate castings were taken into buildings 8, 9, and 10, there was no radiation cooling-off period, and that this was an around-the-clock operation. The second paragraph after the table in section BB.4.5 indicates the dose estimate applies to more than just radiographers. There is nothing in the Appendix to indicate these people worked exclusively in the Betatron buildings. There is nothing in the Appendix indicating a cooling-off period was accounted for, and there is nothing in the Appendix indicating the work only occurred during the day. Again, the Appendix presents a worst-case exposure scenario for all GSI workers, not just Betatron operators.

Comments on Section BB.2.1

The language about "late 1950s" was unfortunately taken from a FUSRAP report and will be modified for clarity when the Appendix is revised. The reasons for that language in the report appears to be that February 1958 through 1966 is the only period where it is clear the facility was x-raying uranium. The only indication uncovered of operations outside of that period was a correspondence cover page referring to x-raying uranium in 1953. There is no indication if this work was performed or just considered. There is no indication this continued until 1958. There is actually information indicating no purchase orders were in place in February of 1958. You quote this information later in your comments. This was a request for payment without purchase order for work performed 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.

You commented about the size of the uranium ingot as it pertains to external dose rate from that ingot and referenced page 13 of OTIB-0004. Page 14 of that document shows dose rates from those ingots. It can be seen there that the rectangular ingot emits a higher dose rate at various distances than that for a cylindrical ingot. This is due to the fact that uranium metal is dense enough to absorb much of the radiation produced within its volume. This causes the surface area to be the main factor in determining dose rate. The rectangular ingot has a surface area of 384 square inches (24 inches by 16 inches) while the cylindrical ingot you describe has a cross-sectional surface area of 360 square inches (20 inch diameter by 18 inches long). Also, dose rates from the cylindrical ingot would be reduced somewhat because some of the surface is further away. That is, a point that is one foot from the center line of the cylinder is about 22 inches away from the metal at the edges of the cylinder. The GSI Appendix as well as OTIB-0004 used the rectangular ingot to bound all the possible sizes and shapes that could have been present at GSI.

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.

Comments on Section BB.2.2

You again comment on the purchase orders from 1953 to 1958. 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. As you point out, the purchase orders we have account for about 62% of the covered period, and the amount of work was relatively consistent in the first few years that were covered.

You indicated SINEW believes 100% of the material from Mallinckrodt had to be tested. As discussed earlier, we have found no evidence or indications that this is true. Also, as discussed earlier, it does not appear feasible that GSI x-rayed all the uranium metal produced at Mallinckrodt.

You asked what "type" of uranium was x-rayed at GSI. You mention alloys and pitchblende. Pitchblende is a uranium ore. It is highly unlikely there would be any interest in performing x-ray inspections of ore. Nor has there been any indication of this in any documentation or from the operators at GSI. Alloys were discussed earlier primarily pertaining to steel. The same issue is even more true for uranium. The primary source of increased radiation dose in uranium metal after irradiation by a Betatron is photo-fission. Unless the uranium was alloyed with a fissionable material, alloys of uranium would produce a lower dose rate than pure uranium. Pure uranium metal was assumed in the Appendix as both a credible and bounding estimate.

You stated "The highly classified LAMS-2064 report helped us confirm beyond any doubt a procedural and scientific fact". It is difficult to ascertain exactly what the "fact" is to which you refer. You seem to be saying a Betatron can not penetrate 18 inches of uranium metal. We don't disagree with this; in fact, that was discussed earlier when we indicated a large piece of uranium metal can be used as a favorable assumption because it will absorb all the energy from the Betatron beam. Your discussion of 4 or 5 shots is confusing. It was discussed earlier that multiple shots on one object does not mean they shot the same spot over and over. There would be no reason for this. In fact, you indicate there were 4 or 5 films on each ingot. This indicates they were examining different areas of the ingot with each shot.

You commented that pure iron was used to model dose rates rather than actual alloys. This was discussed in detail earlier in our response. The replacing of iron with other materials or alloys will lower the dose rate from that produced by pure iron. This model is intended to encompass all the possibilities into one bounding estimate.

Comments on Section BB.4
In this section you ask several questions, all of which have been addressed earlier. You indicate NIOSH must be able to answer these questions. Your questions and the answers are:

**From where does the proposed dose rate information come?** The proposed dose rate information is actually a number of dose rates. The dose rate from skyshine while the Betatron is operating, the dose rate from uranium metal before it is irradiated, the dose rate from uranium metal after it is irradiated, the dose rate from iron after it is irradiated. The basis for each of these dose rates is described in the Appendix and discussed in this letter.

**What are the dimensions, and weight of a rectangular uranium ingot?** The dimensions of the rectangular ingot used to determine dose rates from non-irradiated uranium metal were described earlier as 24 inches by 16 inches by 4 inches. As described earlier, this produces a dose rate higher than any of the ingots mentioned by operators or found in any documentation pertaining to GSI. As indicated in the Appendix, more than one dimension was used to model the photo-fission. This was done to verify that the size and shape did not affect the result as long as it was large enough to absorb the entire x-ray beam.

**Are rectangular uranium ingots all the same size? What about the components?** As discussed previously, several sizes and shapes of uranium metal were sent to GSI. The Appendix used bounding estimates of these sizes to insure a claimant-favorable estimate.

**What is the chemical make-up of these types of ingots vs. direct ingots?** Most of the uranium metal manufactured at Mallinckrodt was not an alloy. As discussed earlier, the Appendix uses pure uranium metal as a bounding estimate since this produces larger dose rates than alloys, and uranium was more likely sent to GSI for testing than alloys of uranium.

**Is there any proof that Mallinckrodt even manufactured rectangular ingots?** As discussed earlier, the sizes and shapes of the uranium used in the Appendix was selected as a bounding estimate. It was not intended to be an exact match to the conditions at GSI but to encompass all possibilities.

Your last comment in this section indicates the Appendix should use the known and recognized cylindrical shape and size. We do not feel this comment requires a revision to the Appendix at this time because it would lower the dose estimate.

<u>Comments on Section BB.4.1</u>
In this section you again question the size, shape, and content of the uranium used in the Appendix. As discussed earlier, the size, shape, and content of the uranium was selected as a bounding estimate in order to encompass all possibilities. This prevents the necessity of determining the exact parameters, and it also presents a claimant-favorable and bounding dose reconstruction approach.

<u>Comments on Section BB.4.2</u>
In your first paragraph, you indicate the new Betatron building was left out of the Appendix. As discussed earlier, the Appendix addresses exposures at a Betatron whether it is the new or the old machine. The comments about the proximity of the new Betatron to the other buildings appears to imply the population was not shielded from the beam. As discussed earlier, 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 second paragraph indicates the skyshine dose rates should be doubled because there were two Betatron buildings. Such an approach would be technically incorrect. As you mentioned in other comments, distance is also an important factor to consider in determining radiation dose from a source. After the first several feet, the skyshine from each building decreases as the distance from the building increases. The skyshine value used in the Appendix is the highest occurring in occupied areas outside the shielded area. This is in the control room. The skyshine from the other Betatron is negligible at this point even without considering the shielding of the building materials. The combined skyshine in other areas does not exceed this value. This is again a bounding estimate used in the Appendix.

Next you comment that the walls were not 10 feet thick because they were two one-foot concrete walls with 8 feet of sand between. Sand has shielding characteristics similar to concrete making the shielding 10 feet thick. Also, as discussed earlier, for the shielding to be effective, it needs only to be in direct line of sight between the source and the area of interest. Radiation scattering down the labyrinth to occupied areas is commonly referred to as shine and was accounted for in the skyshine calculation.

Drawings of the buildings used for skyshine calculations were from FUSRAP documentation which is consistent with the scrapbook you supplied. There was nothing elaborate about the model. As described in the Appendix, the thick shield of the walls were included but the second story and the roof were not. This maximizes the amount of radiation that could have scattered out of the shielded area by eliminating the small amount of shielding supplied by the thin walls and roof.

You mentioned roof ventilators that would have removed radioactive material. The Appendix did not account for this dilution of the dust in the Betatron building. This again is a favorable assumption since operators were assumed to have been exposed to the more concentrated dust.

You mentioned other sources were also used in these buildings. This is true; however, the x-ray exposures would not be performed with the Betatron and the radioactive source simultaneously. When the sources were used, the Betatron was not. Since none of the sources are capable of producing photons of high enough energy to cause activation, and since the dose rate from these sources are lower than from the Betatron machine, the claimant-favorable assumption would be to assume the Betatron was always used. This is the assumption used in the Appendix.

In your last paragraph of this section, you asked several questions about skyshine. As mentioned earlier, the highest modeled skyshine dose rate was in the control room. As for the details of the calculation, the skyshine calculation was simplified by pointing the beam in various directions without attenuating it with castings or other material being x-rayed. Had material been placed in front of the beam, much of the beam would have been attenuated, and the skyshine would have been reduced. Since the size and shape of materials varied, the Appendix used the favorable assumption that no material was in the beam. You also ask how long the shot was. This is irrelevant since the dose rate was modeled, not the dose. The modeled dose rate was then used to determine the dose based on the shot scenarios in the Appendix.

<u>Comments on Section BB.4.3</u>

The fact that the Betatron was set to a desired total R is mentioned in these paragraphs of the Appendix. The fact that thick material required longer shots (more R) was mentioned in section BB.4.1 of the Appendix.

You indicate that the longer shot times result in more exposure to the operators. As discussed earlier, this is not the case. The dose rate from skyshine is lower than the dose rates operators receive while in close proximity to the irradiated material. Your own comments in other sections appear to support this understanding.

The Appendix used a Betatron output consistent with the operators' recollections. Since a number of years has past, the recollections were considered approximations. However, as you pointed out, the job they performed was to set the required number of R for a given shot, and speed was always an important consideration. Therefore, the memories of these two parameters (total R and time) would likely be reasonably accurate. Even so, the dose rate this represents was increased by about a factor of three to account for variations in the memories.

The operators did indicate the new Betatron had an additional capacitor bank. They also indicated there was a selector switch that allowed them to switch from one bank to the other. This was to allow the machine to continue operating when the capacitors became too hot. This implies the old Betatron would have been shut down from time to time to allow the capacitors to cool. The Appendix did not take this into account. It assumed the Betatron was operating 100% of the time that the operators were not in the shielded area setting up for or taking down a shot.

The Appendix indicated that the 100 R/min design maximum was only achievable with the compensator removed. You indicated this was not in accordance with your conversation with Jack Schuetz. It is, however, in accordance with conversations NIOSH had with Mr. Schuetz. It is also in accordance with the calibration curves supplied by Mr. Schuetz. The exposure rate depends on a number of parameters including whether or not the compensator is in place and the distance from the machine that the exposure rate is measured. The exposure rate can also decrease over time due to degradation in the tube and electrical components, drift in calibration settings as well as adjustments to some settings controlled by the operators. The operators at GSI even mentioned that they would call an electrician to work on the machine when the "clicker" appeared to have slowed down significantly. This "clicker" registers the integrated exposure or R accumulated during a shot. It was necessary for the manufacturer to install this device because total R actually measured during the shot is the only way to overcome all the variables that can affect the exposure rate. That device senses radiation via an ion chamber mounted on the device. It allows the machine to register total exposure and exposure rate based on the device's calibration. The device was calibrated to register the uncompensated exposure rate at three feet.

You again commented on the size, shape, and type of steel. As discussed earlier, the Appendix utilized pure iron of large enough size and thickness to completely absorb the x-ray beam. These are claimant-favorable assumptions intended to encompass all possible alloys and sizes of castings used at GSI.

Comments on Section BB.4.4
No specific comments were made in this section.

Comments on Section BB.4.5
You commented that the Betatron buildings were a very busy place with many people of different job classifications working in it. This does not appear to be inconsistent with the Appendix. The three paragraphs prior to your comment explain the exposure model is for all radiographers and anyone else working with the steel within 2 hours of it being irradiated. The exposure estimate for the remaining personnel is discussed in the paragraph just before your comment.

Comments on Section BB.5.3 and Section BB.6
We agree the conditions and contamination levels of the facility 30 years later are generally not indicative of the conditions during operations. That is why they were not used as the sole basis for the residual contamination model. The residual contamination was modeled based on the airborne contaminates settling to the floor with no removal mechanism, such as roof vents that would dilute the levels and reduce the doses. The modeling assumes an even level of contamination. This can be reasonable for airborne contamination estimates because airborne contaminates will diffuse throughout the area and are thus more proportional to the total contamination than to isolated spots. However, the external dose rates can be increased by concentrating the material such as in a vacuum cleaner.

The most likely events are that some uranium was collected in the vacuum cleaner over time while some was removed through building vents and by tracking contamination out of the building. While most of these removal mechanisms would dilute the uranium concentrations, the vacuum cleaner had the potential to concentrate it thereby increasing the external dose rate above what would occur if the uranium was spread throughout the area. Simultaneously the airborne concentrations would decrease as the uranium was collected. The Appendix assumes the vacuum cleaner dose rate of 90 uR/hr was always present. While we agree it could have been higher at times, the assumption that someone was in contact (not near but in contact) with the vacuum cleaner for 2400 hours per year is assumed to be a bounding estimate. Even inches of distance between the vacuum cleaner and the employee would reduce the dose rate as demonstrated by the survey which shows 90 uR/hr on contact with the vacuum cleaner and 40 uR/hr under it.

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

Sincerely,

Larry J. Elliott
Director
Office of Compensation Analysis and Support

cc:

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