PATH FORWARD FOR GSI APPENDIX AND ER REVIEW
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Background
After issuance of the GSI appendix (Appendix BB), and after the SC&A review of that appendix, NIOSH obtained film badge data from Landauer. Subsequent to this, NIOSH issued an Evaluation Report for the GSI SEC petition and SC&A reviewed that petition. Numerous pieces of information have been received by NIOSH since the approval of the appendix, including a number of NRC documents and various pieces of written and/or verbal information from former GSI employees. This report is an attempt to itemize some of that information and to present a path forward to revising the approach to dose estimation for GSI employees.

Information
Various critiques of the exposure scenarios, not addressed or considered inadequately addressed in the appendix, have been made. In these critiques, questions have been raised as to the type and exposure conditions of the radiography operations as well as the locations of employees. Some of the possible inadequately addressed scenarios include:

- Maintenance employees working on the roof of the betatron buildings during betatron operations;
- People being present in the restroom in #10 building during betatron operations;
- Betatron limit switches being overridden to allow shooting at an improper angle;
- Individuals walking through a delineated area while using sources in other buildings;
- Removal of film badges when leaving the new betatron building and working with recently irradiated castings;
- Performing radiography operations in the radiography room in #6 building;
- Operators estimate of hours worked in a typical week;
- Activation of the air by betatron operation; and,
- The frequency and duration of typical radiographic examinations in the betatron building.

Additional data received by NIOSH since the appendix was written include:

- Source type, strength and acquisition dates for GSI owned sources starting in 1962;
- Source type and strength of Ra-226 sources prior to 1962;
- Drawings and survey of radiography room in #6 building;
- Film badge results for radiographers starting in 1964;

- A survey of the new betatron building with a known source exposed (80 curie Co-60 source);
- A drawing indicating thick concrete walls on the new betatron building that did not show up on the FUSRAP drawings; and,
- Various dimensions of the new betatron building not previously recorded.

From the above information some fundamental concepts can be expressed, which can be applied to modeling exposure at GSI. This includes:

- Film badges were exchanged weekly and kept in the New Betatron building when the operator was not present. Also, control room badges were included for a number of periods. The last control room badge was issued for the week of January 31, 1966 through February 6, 1966. The film badge report indicted this badge had been issued starting in November 1963 and never exceeded 10 mrem in a week. Therefore, whatever combination of radiographic exposure scenarios used to model doses from betatron operations must result in no more than 10 mrem in the control room in 168 hours (1 week).
- A survey of the radiography room in the #6 building sets the typical (and maximum) dose rates from the two smaller (approximately 0.25 Ci) Co-60 sources when used in this building.
- The 80 Ci Co-60 source was purchased after the end of the contract period in 1966 and so exposure from this source is not covered under EEOICPA.
- In order to achieve a clear image on a radiograph, multiple sources of radiation cannot be present during an exposure.

Path Forward

With this information, a proposed path forward is as follows:

Develop a new exposure estimate for each source of radiation at GSI. Combine these estimates into individual exposure estimates for various job categories. Combine categories into appropriate groupings based on the results and the ability to categorize claims (one category containing all employees if necessary and appropriate).

The path forward for the various exposure estimates from individual sources of radiation follows:

New Betatron Building

- Develop exposure scenarios for betatron x-ray examination, “shooting scenarios” (shooting angle, duration of exposure, time between exposures, etc.);

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

Old Betatron Building

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

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.
- Add incident exposure based on frequency and amount of incidents

X-ray Machines

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

Uranium activation and fission products

- Assume four one hour shots per uranium ingot or slice

- Determine dose rates from activation and fission products and add to natural activity of uranium metal

Steel Casting activation

- Determine dose rate from multiple shots using a more realistic scenario
- Highest exposed area of steel is exposed 4 times in the beam due to overlapping x-ray films
- Assume an 11” film was used in a square pattern with no overlap (favorable to assume small)
- Four films make a 22” by 22” square area being exposed. Assume entire area is exposed for four continuous shots.
- Worst case is to include an additional 11” wide “ring” around the 22” by 22” area and assume it was exposed for a time equal 4 shots but that it had decayed for that amount of time also. Decay time accounts for the time necessary to expose the four shots in the center.
- Add additional “rings” to this estimate until the total dose rate increase reaches a point of diminishing returns.

Ra-226 sources

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

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

St. Louis Testing Sources

St. Louis Testing was contracted to perform some radiography at GSI. The individual that indicated he did this work discussed using a 10 curie Co-60 source outdoors to examine Westinghouse casings. He indicated the exposures took one week and a half a day (180 hours). He also indicated a boundary was delineated at the 2 mr/hr point and 2 radiographers kept the area under constant surveillance. Lastly, he indicated that 10 of these exposures were performed over a six month period.

For a typical work week of 65 hours, a GSI employee would be on site for approximately 69.6 hours of each exposure. If at the radiography boundary the entire time, it would equal 139 mrem of dose per shot. Multiplying that by 10 shots equals 1.39 rem of dose over that six month period.

The other radiography remembered by the St. Louis Testing employee was the use of a 50 curie Ir-192 source to perform some repair shots in the repair area. The individual indicated that the Ir-192 showed more detail than the betatron and implied this wasn't used a lot because it caused more castings to be rejected.

The 50 curie Ir-192 source would produce a dose rate approximately 1.8 times higher than a 10 curie Co-60 source reducing the duration of the exposure necessary to expose the film. Repair shots would concentrate on a particular area rather than the overall casting. This would allow the source to film distance to be reduced and further shorten the duration of the shot. Lastly, the St. Louis Testing employee implied few shots were performed with this source. Even though the source was stronger, the 2 mr/hr boundary would still be the standard used to delineate an area. Taken together, these pieces of information imply that number and duration of Ir-192 shots should be less than the Co-60 shots while the same 2 mr/hr boundary would be used. It should therefore be a bounding estimate to double the 1.39 rem estimate of the Co-60 source to account for dose from the Ir-192 source.

Air Activation from betatron

The high energy photons associated with a betatron can activate atoms in the air. The principle activation isotopes are O-15 and N-13. These isotopes represent primarily an external radiation hazard and emit a 511 keV annihilation photon. One paper measured a concentration of 3×10^{-11} Curies/cc and 1.5×10^{-12} Curies/cc for O-15 and N-13 respectively. According to Federal Guidance Report 12, an infinite cloud with these concentrations would produce a dose rates approaching 20 mrem/hr for most organs and 40 mrem/hr for skin.

The investigation method used in the paper was to irradiate a sealed container of air placed directly in the beam of the betatron. At GSI, the air obviously is not contained which allows air currents to move and prevent continuous exposure to the same volume of air. Also the betatron beam is highly directional irradiating a relatively small volume of air. Both of these effects prevent any activated air in the GSI betatron shooting area from becoming activated to the level presented in the paper.

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

Air activation would cause an external dose from the air, not the machine. Operators exposed to this would be exposed in an isotropic geometry. The 511 keV photon would be easily detectable by the film badges worn by the operators. Therefore, residual radiation coming from the machine will not be considered a source of radiation exposure for the radiographers. Instead, air activation will be considered in the scenarios. Since the photon dose from this phenomenon is measurable by the film badges, it may not appear important but this will affect the beta to photon ratio experienced by the operators and thus affect the estimated skin dose.

ISSUES RAISED FOR APPENDIX AND EVALUATION REPORT REVIEW

This path forward addresses most of the outstanding issues itemized in the two reviews as summarized below.

Appendix Review

The chairman of the working group asked NIOSH to review and update issues 3 through 11 of the appendix review. Issues 4 through 11 are addressed by the path forward as summarized later in this section. Issue 3 is not. Issue 3 pertained to the output of the betatron machines. The appendix assumed an output of 100 R/min per the transcripts of the worker meetings. The SC&A review points out that a value of 250 R/min would be more consistent with written statements from a former Allis-Chalmers employee. The written statement from the former Allis-Chalmers employee is:

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

The employee also included a table listing the output and date of several tubes sold to GSI.

Tube Output in R/min

Date Shipped	22 MeV	25 MeV
12/29/1969	205	265
3/2/1971	180	260
3/18/1971	240	280
3/22/1972	196	275
4/9/1973	200	282
5/9/1973	200	280
5/31/1973	195	262

Information in the table starts in the late 1960s which matches well with the statement that the output was 200 to 275 R/min in the 1960s. The statement also indicates lower values in the 1950s. Operators remembered a value of 100 R/min on the old betatron and higher on the new betatron. The new betatron was moved to GSI in 1963. It is apparent that the output of this equipment increased over time. NIOSH proposes using a value of 100 R/min for the old betatron machine and 250 R/min for the new betatron machine. This is in keeping with recollections of former GSI radiographers that indicate the old betatron had a lower output.

The remaining issues (issue 4 through 11) are addressed by the path forward outlined here.

Issue 4 – SC&A disagreed with the modeled results and NIOSH not including neutrons in the estmiate. The path forward addresses revising the model taking all new information into account and including neutron exposure.

Issue 5 – SC&A indicated radiography with sources other than the betatron should be explored further. The path forward indicates other sources will be addressed.
Issue 6 – SC&A indicated the appendix ignored beta dose from activated steel. The path forward addresses revising the model taking all new information into account and including beta exposure.
Issue 7 – SC&A disagreed with the exposure scenario associated with residual radiation from the betatron. The residual radiation issue is addressed in the path forward under the air activation topic.
Issue 8 – Operators provided an estimate of typical work hours different than that utilized by the appendix (3250 hrs per year). The path forward addresses revising the model taking all new information into account and including the operator's estimate of work hours.
Issue 9 – SC&A disagreed with appendix scenario describing the work flow at the betatron. The path forward addresses revising the model using new exposure scenarios.
Issue 10 – SC&A disagrees with the irradiated uranium dose rate calculated by NIOSH. The path forward addresses revising the model which involves recalculating this value.
Issue 11 – SC&A believes there is a number of worker exposure scenarios not considered 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.

Evaluation Report Issues

The chairman of the working group also asked that issues 1, 2, 3, 5 and 6 from the Evaluation Report review be addressed.

Issue 1 – 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. A preliminary review indicates a consistent frequency through the years that monitoring data is available.

Issue 2 – 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.

Issue 3 – 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.

Issue 5 – 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.

Issue 6 – 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.