Draft White Paper

RESPONSE TO "BATTELLE-TBD-6000 APPENDIX BB GENERAL STEEL INDUSTRIES: DOSE ESTIMATES FOR BETATRON OPERATIONS"

Contract Number 200-2009-28555

Prepared by

Robert Anigstein and Richard H. Olsher
S. Cohen & Associates
1608 Spring Hill Road, Suite 400
Vienna, Virginia 22182

March 2012

Disclaimer

S. Cohen & Associates: *Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program*	Document Description: Response to "Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations"
	Effective Date: Draft –March 12, 2012
	Revision No. 0 (Draft)
RESPONSE TO "BATTELLE-TBD-6000 APPENDIX BB GENERAL STEEL INDUSTRIES: DOSE ESTIMATES FOR BETATRON OPERATIONS"	Page 2 of 22
Task Manager: ____________________ Date: Robert Anigstein, PhD	Supersedes: N/A
Project Manager: __________________ Date: John Stiver, CHP	Reviewer: John Mauro, PhD

Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	3/12/2012	Initial issue

Response to "Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations"

During its meeting on November 2, 2011, the ABRWH Work Group on TBD-6000 assigned several action items to SC&A, including responding to the NIOSH white paper on betatron operations at GSI, which was scheduled to be released on December 30, 2011. We begin with a review of "Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations" (Allen 2012). Our comments are keyed to the relevant sections of Allen's report. Following the review we will present our recommended approach to resolving some of the issues raised in the review.

1 Review of NIOSH Betatron Report

1.1 New Betatron Building

1.1.1 Door Between New Betatron Building and No. 10 Finishing Building

Our first observation addresses Allen's (2012) assumption about a lead-shielded double-leaf door separating the New Betatron Building from No. 10 Finishing Building. The earliest reference to such a door is in a hand-drawn sketch of the New Betatron Building, shown here in Figure 1, that is dated January 10, 1968 (NRC 2009a), and is apparently part of the AEC license application for the 80-Ci ^{60}Co source, transmitted with a cover letter dated January 15, 1968 (NRC 2009b).

Further information regarding the door during the period of AEC operations was provided by [[redacted]] a former GSI betatron operator: "[T]he railroad tracks ran from the 10 Building into the new Betatron facility through an unshielded ribbon door." ("Dr. Robert Anigstein . . ." 2007) However, Mr. [[redacted]] went on to say: [T]hey put sandbags down over the railroad tracks at the base of the ribbon door to the 10 Building when they inverted the Betatron for a shot because the tracks left gaps when the door was down (*ibid*.) The second comment calls into question the statement that the door was unshielded: there would be little reason to cover the gap with sandbags except to prevent radiation from leaking under the shield. The ribbon door was also mentioned by [[redacted]], another GSI betatron operator, at the August 21, 2006, worker outreach meeting; however, Mr. [[redacted]] spoke immediately after Mr. [[redacted]] mentioned the ribbon door, so he might just have been echoing [[redacted]]'s words (SimmonsCooper 2006).

The New Betatron Building was erected by GSI; however, the building plan is quite similar to the drawings of a betatron facility in the Allis-Chalmers betatron manual (Allis-Chalmers 1951). Since the manual does not describe the door leading into the betatron shooting room, we contacted Jack Schuetz, a former Allis-Chalmers maintenance engineer, to inquire if the company had any standard specifications or recommendations regarding the shielding on such a door. Mr. Schuetz began by saying that he was not personally acquainted with the New Betatron Building, his involvement with GSI having ended before the building was erected at the end of 1963. However, he said that the standard configuration for an industrial betatron facility relied on the L-shaped shooting room's providing radiation protection. The crane on which the betatron was mounted was limited in its motion toward the railroad track by the crane used to transport the castings into the building. Further protection was rendered by the limit switches which, in normal operation, prevented the betatron from pointing toward the door. The door was

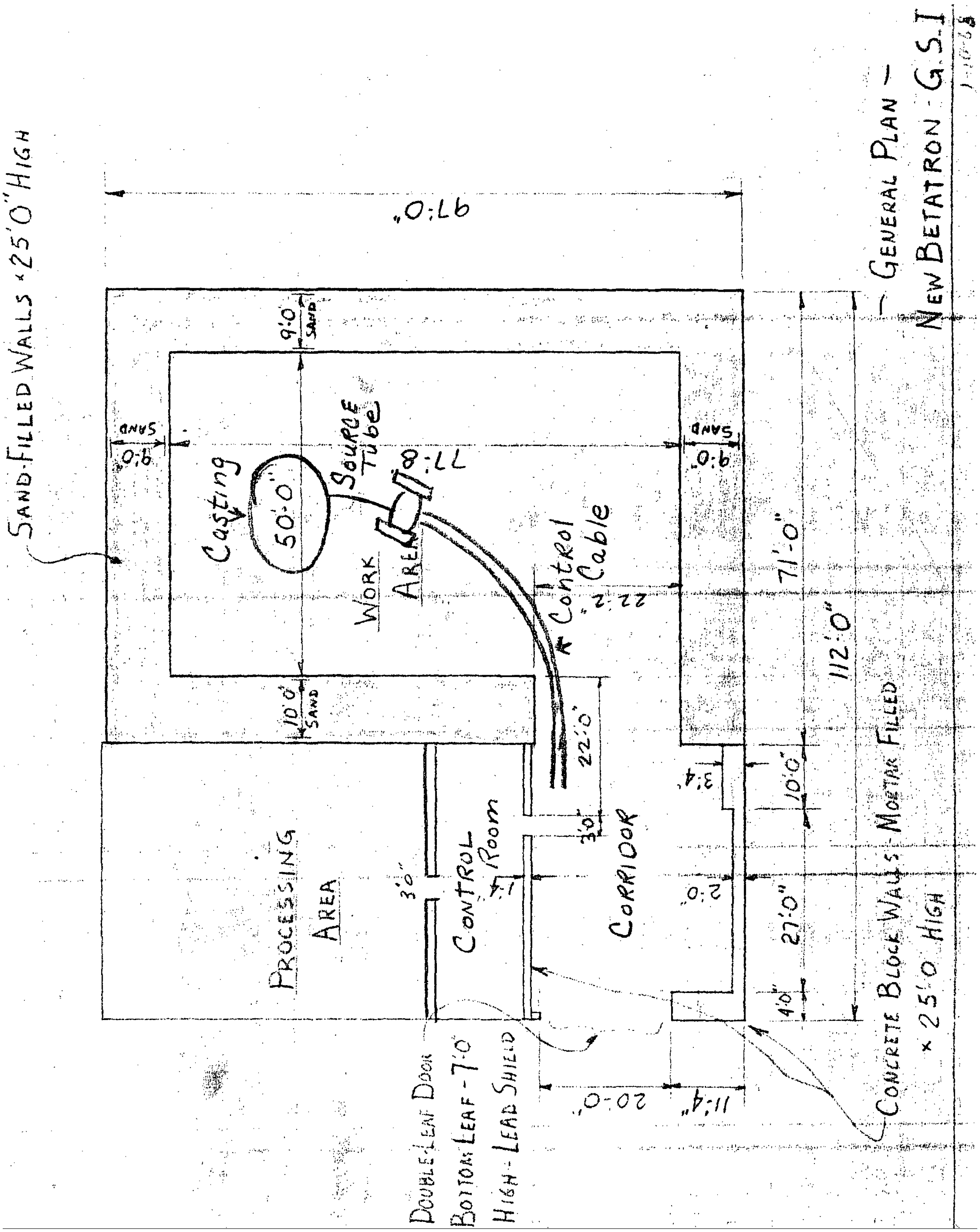


Figure 1. Sketch of New Betatron Building, Showing ^{60}Co Source and Lead-Lined Double-Leaf Door (NRC 2009a)

typically made of aluminum, so its function appears to have been the prevention of unauthorized access to the shooting room.[1]

It is therefore plausible that the lead-lined door was installed in the New Betatron Building some time after the building was erected. It could have been installed ca. 1968 to facilitate AEC approval of the license for the 80-Ci ^{60}Co source. Since there is no direct evidence that the lead shield was present during the operational period and there is worker testimony that it wasn't, the analysis of radiation exposure levels outside the New Betatron Building should be based on the claimant-favorable assumption that the door was made of thin sheet metal.

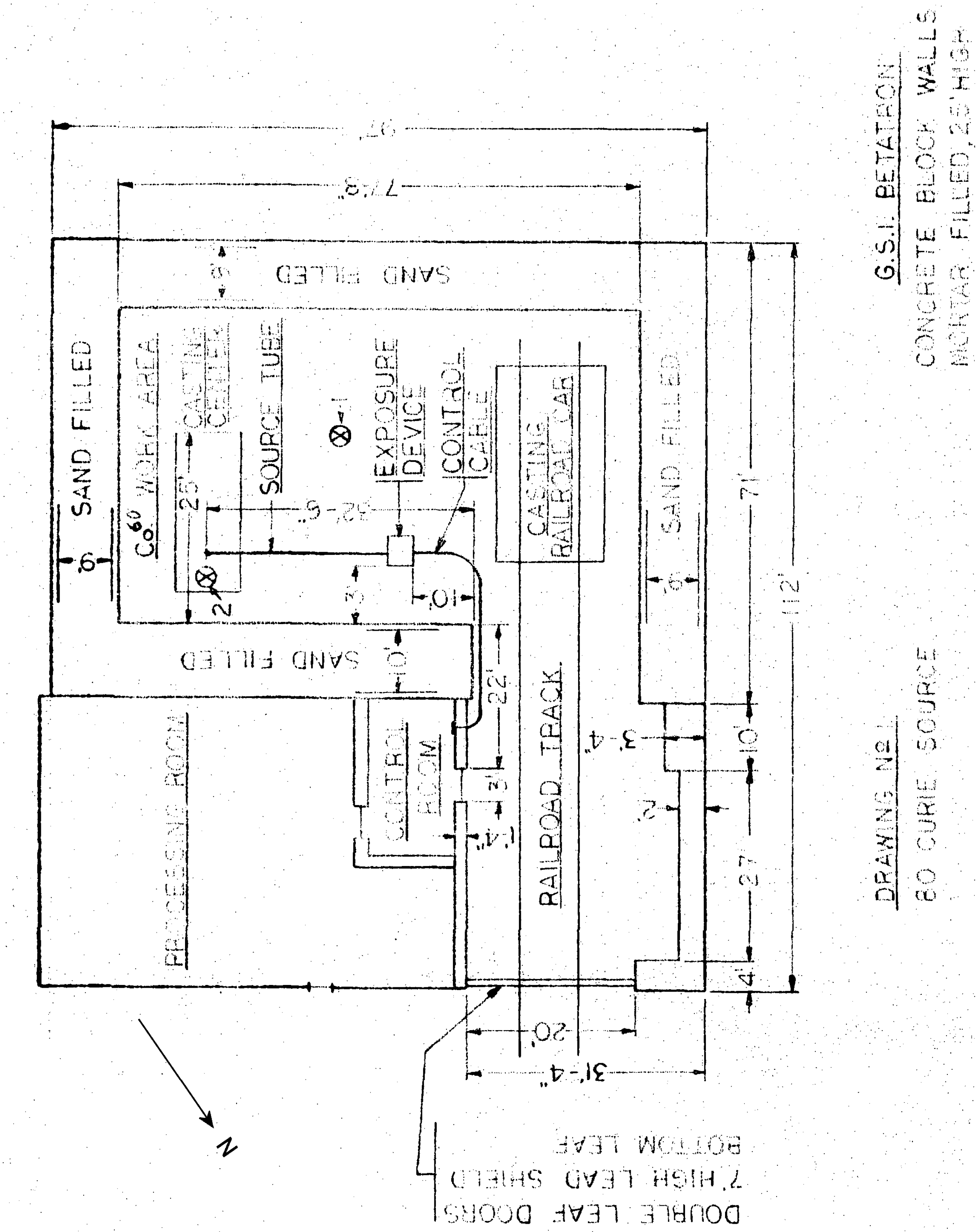
1.1.2 NIOSH MCNPX Simulation of GSI Radiation Survey of ^{60}Co Source

Allen (2012) utilized the drawings and description of the New Betatron Building in the radiation survey report (NRC 2009c), shown here in Figure 2, to update the original SC&A (2008) model of the building, which was based on the less detailed description by Murray and Uziel (1992). Since the latter authors were primarily concerned with describing a survey of uranium contamination, they had little reason to present a detailed description of the shield walls. Allen then used MCNPX to model the exposure rates in various locations and compared them to exposure rates measured during the 1971 survey.

One significant difference between Allen's (2012) MCNPX simulation and information in the GSI AEC files, is that Allen assumed a source strength of 80 Ci. Although it was referred to as an "80-Ci" source, the source had been procured 3 years prior to the survey. Assuming it had a nominal activity of 80 Ci at that time (there is no record of the actual assay of the source), the decayed activity at the time of the survey would have been approximately 54 Ci. Another significant difference is that Allen adopted the density of the control room wall, 0.92 g/cm^3, from our original model (SC&A 2008). In the absence of other information, we had assigned the lowest density of commercially available hollow concrete blocks in the interest of a claimant-favorable analysis. Since film badge reports were not available at that time, a lighter shield wall would have produced results that were more claimant favorable. However, as shown in Figure 1, the wall is described as mortar-filled, which would result in a higher density. Furthermore, Allis-Chalmers (1951, p. 54) recommends that concrete block used for radiation shielding have a minimum density of 125 lb/ft^3 (2.0 g/cm^3).

There are some minor discrepancies in the room geometry as well as in the location of the source and some of the tally locations (dose points). Some of these may have resulted from inconsistent dimensions in the GSI drawings, and the fact that the drawings do not have a consistent scale. Nevertheless, the results of Allen's (2012) MCNPX simulation, after adjustment for the lower source strength, are in reasonable agreement with the 1971 survey data.

[1] Jack Schuetz, private communication with Robert Anigstein, SC&A, Inc., February 1, 2012.



Section 6 (a) Page 23

Figure 2. Architectural Drawing of New Betatron Building, Showing Lead-Lined Double-Leaf Door (NRC 2009c). Arrow indicating north added by present authors.

1.2 Shot Scenarios

1.2.1 NIOSH Assessments of Exposure to Direct and Scattered Radiation from Betatron

Allen (2012) next used the revised model of the New Betatron Building to update the MCNPX analyses of the betatron described by SC&A (2008).[2] In our original analysis, the casting being radiographed—a hollow, cylindrical axle—was positioned on the railroad tracks, as far into the radiography bay as space permitted. (An illustration from our original report is shown here as Figure 3.) Since the purpose of our analysis was to demonstrate the impact of this process on workers in various accessible locations, both in the control room and in adjacent structures, we confined it to a single exposure geometry that represented the maximum reasonable scenario.

Allen constructed a series of 15 scenarios. His first scenario reproduced our original geometry: the betatron beam was pointed in the horizontal direction perpendicular to the axis of the cylinder. In his next two scenarios, the betatron was pointed in the horizontal direction, but at a 45º angle to the right and left of the axis of the cylinder. He then created two additional scenarios in which the betatron pointed 45º above and below the horizontal plane, perpendicular to the axis of the cylinder. In two more scenarios, the betatron was pointed at a 45º angle to the axis and 45º above and below the horizontal plane.

Allen (2012) next placed the casting and the betatron in two other locations in the shooting room. First, he located the casting near the southwest wall, away from the control room (the wall is shown at the top of the page in Figure 2). Here, he utilized three betatron orientations: perpendicular and 45º to the right and left, all in the horizontal plane. Finally, he placed the casting along the southeast wall (left side of the page in Figure 2), where he aimed the betatron in the same three directions; in addition, for the 45º to the left position, he rotated the beam 45º above and below the horizontal.

For each scenario, Allen (2012) calculated the exposure rate at each of 10 locations inside and outside the betatron building. One of these locations was the desk in the control room, shown here in Figure 4. He then postulated that Film Badge No. 001, given the name "Betatron Ctl" in the weekly Landauer film badge dosimetry reports, was stored in this location. Since the report for this badge was always *M* (minimal), and since Landauer claimed the minimum detectable level (MDL) of 10 mrem for the film badges, Allen assumed that the badge received a limiting dose of 10 mrem during each weekly cycle. Since, according to Allen's calculations, the betatron operated 69.89 hours per week, the average hourly dose rate to the badge was 0.143 mrem. He then used the Excel Solver function to select two out of the 15 scenarios and divided the total exposure duration of the betatron between these two scenarios such that the weighted average exposure rate (which he equated to the dose rate) equaled 0.143 mR/h at the location of the desk. To determine the weekly exposure at each of the aforementioned locations, he multiplied the exposure rate from each of the two selected shot scenarios by the fraction assigned to that scenario by the Excel Solver function.

[2] Because NIOSH employed parts of the SC&A analyses in its dose assessment, we performed a formal QA review of our original study. The analyses were reviewed by an MCNPX expert who was not involved with its original development—his QA report is found in Attachment 1 of the present review.

Figure 3. Betatron Radiography of the Axle of a Power Shovel Cast at GSI
(Courtesy of [redacted])

1.2.2 SC&A Observations and Findings on NIOSH Assessments of Betatron Exposures

Our first finding concerns a lack of realism in depicting the use of the betatron in industrial radiography. Of the 15 scenarios described by Allen (2012), only five represent actual radiographic practices. Shooting perpendicular to the axis of the cylinder, both in the horizontal plane and at various angles to the horizontal, allows different sectors of the axle to be radiographed. Shooting at an angle of 45º to the axis does not represent the practice used in radiographing such castings. To radiograph the length of the cylindrical casting, the betatron crane would move on a track parallel to the axle, placing the betatron in various locations along the axle, with its beam always perpendicular to the axis of the cylinder. Turning the beam to the right or left would serve no purpose.

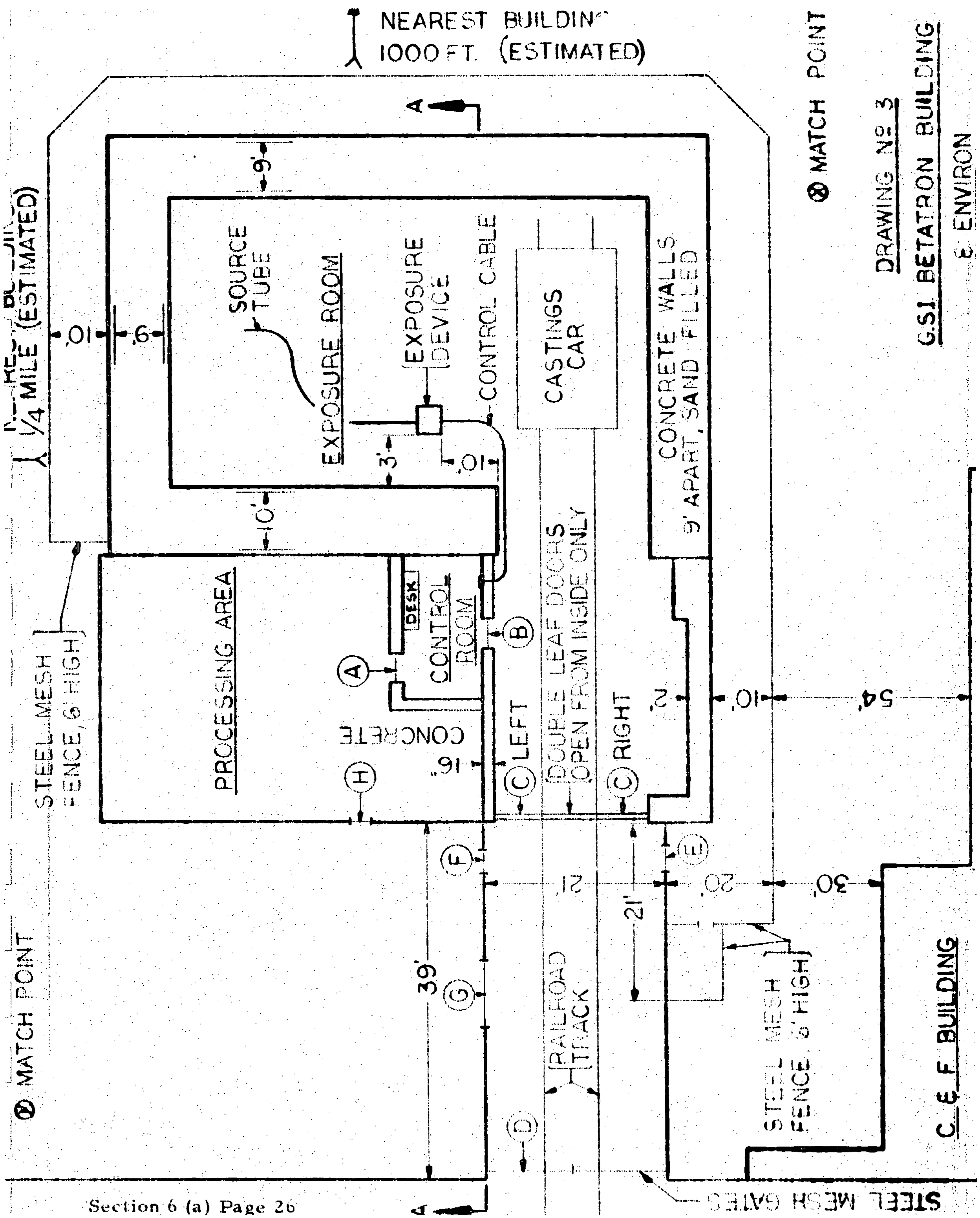


Figure 4. Drawing of New Betatron Building Showing Desk in Control Room (NRC 2009c)

Our second finding involves the assumption regarding the control room film badges. Except for the laconic title "Betatron Ctl," there is no information regarding where this badge was stored. No former employees who handled the film badges are known to be available. Consequently, there is no reliable information that would place Film Badge No. 001 in the control room desk or in any other identifiable location.

Our third finding is that the 15 scenarios were selected arbitrarily. Even in the case of the five plausible scenarios, there is no basis for assigning a unique frequency of occurrence. Even if one were to accept the hypotheses that the control room desk had an exposure rate of 0.143 mrem/h while the beam was on, there is no unique way of selecting two scenarios that contribute to this rate. Of the 15 exposure rates listed by Allen (2012, Table 3), seven are above 0.143 mR/h, while eight are below. Any one of the high rates could be paired with any one of the low rates such that, with the appropriate frequencies, the time-weighted-average rate would be 0.143 mR/h. As an arbitrary example, in which we confined ourselves to the five plausible scenarios, if the "straight" shot on the railroad track, which, according to Allen's analysis, produces a rate of 0.41 mR/h at the desk, occurred 43.19% of the time, and the "straight" shot in the center position, which has a listed exposure rate of 0.06 mR/h, occurred the other 56.81% of the time, the time-weighted-average at the control room desk would be 0.143 mR/h. This is quite different than Allen's Excel Solver result: 67.46 hrs per week oriented in the back shot, left, up position and 2.42 hours per week oriented in the railroad, right, level position (Allen 2012, p. 25). According to this result, the betatron was pointed toward the wall away from No. 10 Building 96.5% of the time and toward the wall facing No. 10 Building 3.5% of the time. There are 56 possible pair-wise combinations of Allen's 15 scenarios, as well as many more involving more than two scenarios. The Excel Solver function thus arbitrarily selected a solution to a problem that has no unique solution.

We thus find that dose calculations based on the 15 shot scenarios do not constitute a scientifically correct or claimant-favorable methodology to assign doses from direct betatron radiation to unmonitored workers.

1.3 External Exposure to Delayed Radiation From Uranium and Steel

Allen (2012) utilized our MCNPX input file for the analysis of delayed penetrating radiation from a slice of a uranium ingot to calculate the exposures to the irradiated metal, only changing the time steps following the instantaneous exposure modeled by MCNPX. However, our model was based on initial misinformation on the actual distance from the internal betatron target to the object being radiographed, as explained in SC&A 2008 (footnote 7, p. 20 of the PA-cleared version). We had initially been informed that the casting was 6 ft from the tip of the aluminum beam compensator rather than 6 ft from the target. Allen does not indicate that he made any corrections to account for the larger distance in the MCNPX model, as we did in utilizing the results of the MCNPX analyses. The beam is peaked at the center but is still larger than the area of the slice; consequently, the radiation would be somewhat less intense at the distance in Allen's analysis: 240.6 cm vs. 182.88 cm (6 ft).

A second problem is Allen's use of 1-minute time steps to evaluate the dose from delayed radiation. First, the dose rate changes rapidly with time after irradiation, so initial time steps on the order of 1 s are needed to correctly integrate over this rapidly decaying source. Second, we were advised to use the time steps in the MCNPX Cinder90.dat data file to perform a more reliable analysis. Our initial analysis involved a fine-grained integration over the time steps.

Allen (2012) used MCNPX version 26e for all his analyses. This is a beta version of the code that was released in November 2007. It has been replaced several times—the current version is 27e, which is the same as MCNPX 2.7.0 that was publicly released by the Radiation Shielding Information and Computation Center (RSICC) in April 2011. Although version 26e is adequate for most purposes, such as calculating the direct exposure to the betatron beam, the delayed-gamma/delayed-neutron capabilities are still in a developmental stage. The current version uses more advanced algorithms and cross-section libraries, the result of over 3 years' additional development.

1.4 Residual Radiation from the Betatron

Allen (2012) cites a report from a former Allis-Chalmers maintenance engineer regarding radiation measurements performed in the vicinity of a betatron immediately after power was shut off (Schuetz 2007). Both NIOSH and SC&A examined the possible origin of such radiation and have failed to find a physical explanation for this reported phenomenon. One hypothesis discussed by Allen, the activation of the aluminum compensator, is inconsistent with other information from Mr. Schuetz, who reported that the compensator was not in place when he made the measurements.[3]

Allen (2012) also discussed the possibility that air activation could be responsible for this phenomenon. We had performed a preliminary MCNPX analysis to explore this possibility, as reported at the October 12, 2010, meeting of ABRWH Work Group on TBD-6000, and found that the bounding exposure of a betatron operator to air activation was 6 μR/shift (Neal R. Gross 2010, p. 167). This analysis assumed that the worker stood in a location corresponding to the centerline of the betatron beam after the beam was turned off, and that the air did not circulate. Such an exposure would be far smaller than the exposure that would result from the initial exposure rate of 15 mR/h reported by Schuetz. We agree that the phenomenon reported by Schuetz cannot be attributed to air activation.

Despite these findings, there is some anecdotal evidence for residual radiation from the betatron in addition to the Schuetz report. First, the betatron instruction manual (Allis-Chalmers 1951) warns users not to touch the betatron doughnut for at least 15 min after the machine is turned off, stating that the tube becomes "intensely radioactive" while generating x rays. However, the manual has no warnings about approaching the apparatus, from which one might conclude that the hazard is confined to skin dose from beta radiation. In addition, one of the present authors (RHO) has the following recollection:

> During the period of 1980 to 1986, I was the responsible staff member for x-ray safety at the Los Alamos Scientific Laboratory. During that time frame I was involved in several x-ray safety surveys of the Los Alamos Betatron facility, nominally a 22-MeV installation [utilizing an Allis-Chalmers betatron]. During

[3] Jack Schuetz, former Allis-Chalmers engineer and a NIOSH/DCAS contractor, private communications with Robert Anigstein, SC&A, Inc., various dates.

> one of those surveys I discussed the subject of residual activation with the operator, Mr. [redacted] (now deceased), a former Allis-Chalmers engineer who took part in the initial accelerator installation. He told me that, as a minimum, a 24-hour cool off period would be used prior to working with accelerator head components.
>
> When I asked to enter the radiation bay immediately after the conclusion of an exposure (I do not recall the length of the run), he asked that I wait a couple of minutes, as that was part of the standing operating procedure. Approximately five minutes after the conclusion of the Betatron run, I performed exposure rate measurements at the front and back of the accelerator. The instrument used was an Eberline model RO-3 ionization chamber, which was in calibration. I did not detect any photon radiation above background levels at a distance of about 1 meter from either the front or back of the accelerator.

Thus, the late Mr. [redacted] confirmed the warnings that Mr. Schuetz had also heard about not approaching the betatron until a few minutes after shutdown.

No definitive conclusions can be drawn about the presence of residual radiation immediately following shutdown, since we cannot verify Shuetz’s observations with theoretical calculations. Mr. Schuetz reported a reading of 15 mR/h immediately after shutdown, which went to zero in 15 minutes. Based on this statement, one could conclude that there was measurable radiation 5 minutes after shutdown, which is contrary to RHO’s observation. The overwhelming majority of the weekly film badge dosimetry reports for GSI betatron operators showed readings below the MDL. It is nonetheless possible that there could have been some residual radiation of such low energy that most of it was absorbed by the worker’s body, which shielded the film badge while his back was to the machine, as illustrated in Figure 3. Were that the case, the film badge dosimeters would underreport the actual dose. An estimate of the underreported dose from such a scenario is presented later in this report.

1.5 Betatron Operator Dose Estimate

Allen (2012) assumed that the film badges of the betatron operators were stored in the control room and were thus exposed to stray radiation from the betatron, whether or not they were being worn by the workers. He concludes that the maximum dose to a worker was less than the MDL of 10 mrem because part of this dose was accumulated while the worker was off duty. This assumption is based on two errors. The first is that, while former GSI workers reported that the badges were stored in the New Betatron Building, they were not kept in the control room. According to [redacted], a former betatron operator, they were stored in a rack that was mounted on the wall of a hallway just past the main entrance to the building, as shown in Figure 5. The location of the rack is based on a detailed description by Mr. [redacted].[4] The second error is failing to account for the unnumbered control badge (not Badge No. 001: Betatron Ctl) that was included with each batch of film badges sent to GSI by Landauer. As an

[4] [Redacted], former GSI worker, private communication with Robert Anigstein, SC&A, Inc., March 8, 2012.

integral part of any personal dosimetry program, the control badge is stored in the same location as the film

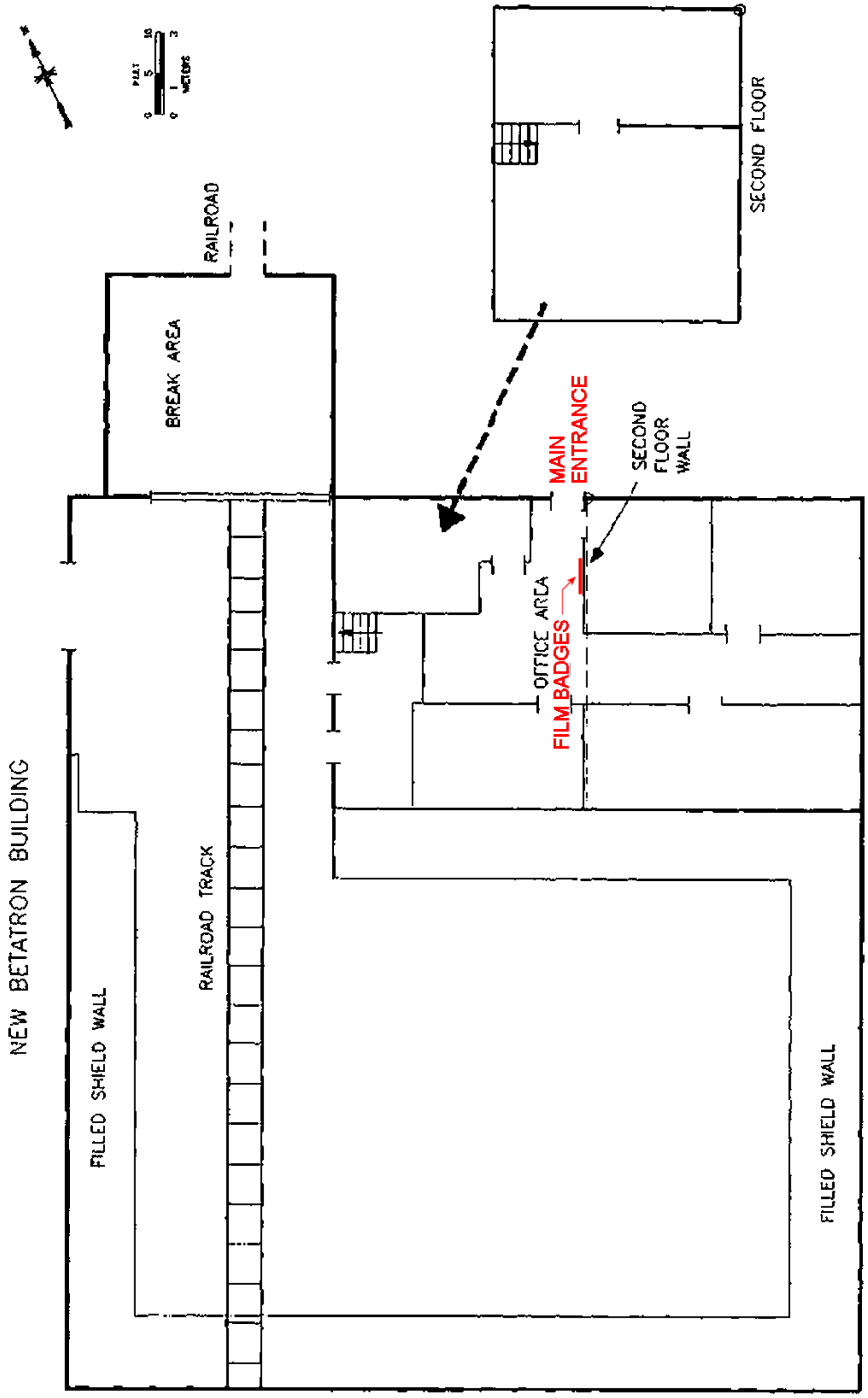


Figure 5. Floor Plan of New Betatron Building, Showing Location of Rack for Storing Film Badges. (Original drawing from Murray and Uziel 1992—entries in red by present authors)

badges of off-duty workers. It is returned to Landauer along with each batch of film badge dosimeters, where all the films are developed in a single batch and read with an optical densitometer. The control badge determines the background—in the terminology of an analytical laboratory, it constitutes a blank. According to Joseph Zlotnicki, CHP (former Landauer official, currently a member of the SC&A staff): The assigned dose is determined by subtracting two numbers that are derived from the density on the user film and the density on the background or “blank.” (SC&A 2011) Thus, any doses in the film badge dosimetry report represent the doses received by the worker while wearing the badge, not while it was stored in the rack. Allen’s estimate of the dose to the betatron operators, derived by subtracting the assumed exposure of the badge while the operators were off duty, is thus incorrect.

1.6 Workers Outside the Betatron Building

Allen (2012) estimated the dose to a maintenance worker who serviced the ventilating fans on top of the New Betatron Building. Given the short duration and low frequency of these exposures, we agree that the exposures of such a worker would not constitute the bounding exposure scenario for workers outside the betatron building. We therefore did not examine the doses from this scenario any further.

1.6.1 Layout Worker

According to Allen (2012), the layout man received the highest doses from external exposure to penetrating radiation of any GSI workers. There were two sources of such exposures: (1) direct and scattered radiation from the betatron during radiographic exposures, and (2) delayed radiation from photoactivation products in irradiated steel castings. In both cases, Allen’s estimates of the doses were substantially lower than those resulting from our current analyses, which are described later in this report. As discussed in section 1.2.2, the selection of betatron exposure scenarios is not scientifically correct nor claimant favorable. Furthermore, Allen’s assumption of a lead-lined door between the betatron building and No. 10 Building, where the layout man is presumed to work, is questionable and thus not claimant favorable.

2 SC&A Estimates of Bounding Doses to GSI Workers

2.1 Doses from External Exposure to Penetrating Radiation: Exposure to Photons

2.1.1 Betatron Operator

Photon Exposure

The nominal weekly dose to a radiographer (i.e., betatron operator or “isotope operator” [radiographer using ^{60}Co]) should be 10 mrem, the MDL of the film badges, since almost all the readings were *M*. However, this value does not account for the possibility that the badges were partially shielded by the betatron operator’s body when exposed to residual radiation from the betatron following shutdown. We have performed a simple scoping analysis to place an upper limit to such underreported radiation exposure, based on the ICRP (1996) external exposure conversion coefficients for doses to various organs of the human body in various exposure geometries. These coefficients were calculated using an androgynous anthropomorphic mathematical phantom based on the specifications for Reference Man. Such a phantom contains both male and female organs, including the female breast. The location of the breast makes it a reasonable surrogate for a film badge worn on the breast pocket of a worker’s shirt, as shown in some photographs of GSI workers. We can thus estimate the maximum effective dose to the whole body from photon radiation in the PA orientation such that the breast would not receive more than 10 mrem in the same orientation.

Table 1 shows the estimated maximum effective dose, based on this assumption, for various photon energies. As shown in the table, the highest dose would be from 30 keV photons, the lowest energy considered in NIOSH dose assessments. Assuming that the only exposure of the film badge was to 30 keV photons incident on the body in the PA exposure geometry, the actual effective dose could be as high as 26 mrem per week. Since not all the dose registered on the film badge would have been from this scenario, the maximum dose to the betatron operator would be closer to the nominal 10 mrem MDL of the film badge. A limitation of this simplified approach is that it assumes that the response of the film badge is symmetric front to back, which is not the case due to beam flattening metal filters that were used in the Landauer dosimeter. The aim of this estimate is to maximize the dose to the operator from external exposure to penetrating radiation in order to determine whether the betatron operator could receive the bounding dose of all GSI workers.

There was no need to re-evaluate other sources of external exposure of betatron operators to direct photon radiation, since the radiation would primarily be in the antero-posterior (AP) orientation and would thus be registered by the film badge.

Exposure to Neutrons

There were two sources of potential neutron exposure of the betatron operator: external exposure to direct neutron radiation from the betatron while the operator was in the control room during a radiographic exposure, and exposure to uranium metal. We evaluated the neutron doses from the betatron by repeating our original MCNPX analyses, using the revised model of the New Betatron Building discussed in section 1.1.

Our MCNPX analysis estimated the neutron dose rates in the control room at two of the locations evaluated in the 1971 GSI survey of the ^{60}Co source: in front of the desk and 2 ft inside the door. The highest dose rate, 0.36 mrem/h, was near the door. As discussed in SC&A 2008, the betatron exposure assessments assumed that 90% of the radiographic exposures were short shots and the remaining 10% were long shots. The short shots lasted 3 min, with 12 min between shots, while the long shots lasted 60 min, with 15 min between shots, resulting in a betatron duty cycle of 41.43%. During a typical 8-h shift radiographing steel, the operators were exposed to stray radiation from the betatron for approximately 3.3 h, resulting in a neutron dose of 1.19 mrem/shift.

The estimated exposure of the betatron operator to delayed neutron radiation from irradiated uranium is 0.40 mrem/shift, based on the results reported by SC&A (2008). This assumes an entire shift spent radiographing uranium. These results were also utilized by Allen (2012).

Table 1. Estimated Maximum Weekly Photon Dose to Betatron Operators

Photon Energy (keV)	Dose Coefficients for PA geometry		Maximum weekly dose (mrem)
	Breast (Gy/Gy)	Effective dose (Sv/Gy)	
30	0.0489	0.128	26
40	0.181	0.37	20
50	0.328	0.64	20
60	0.439	0.846	19
70	0.511	0.966	19
80	0.545	1.019	19
100	0.574	1.03	18
150	0.6	0.959	16
200	0.625	0.915	15
300	0.663	0.88	13
400	0.693	0.871	13
500	0.717	0.869	12
600	0.737	0.87	12
800	0.767	0.875	11
1,000	0.791	0.88	11
2,000	0.863	0.901	10
4,000	0.905	0.918	10
6,000	0.911	0.924	10
8,000	0.911	0.927	10
10,000	0.911	0.929	10

Note: Based on an assumed dose to female breast (surrogate for film badge) of 10 mrem

2.1.2 Layout Man

SC&A has reassessed the exposures of unbadged workers to radiation from the betatron, using the updated room geometry and new information on the operation of the betatron. Given the numerous types of castings and exposure geometry, we still consider our original exposure geometry (what Allen, 2012, calls a "straight" shot) to lead to a reasonable upper-bound exposure. One result of the new assessment, based on the updated model of the New Betatron Building, is that the restroom that abuts the No. 10 Building was no longer a location with a high exposure potential. This is because of the walls opposite the control room shown in the lower right-hand corner of the page in Figures 1, 2, and 4 that do not appear in Figure 5, which was the basis of our earlier model.

The layout man (to use the term employed by the GSI workers) received the highest dose from external exposure to penetrating radiation of any worker outside the control room. He was assumed to spend his entire shift marking the areas of the castings to be radiographed by the betatron in a location in No. 10 Building adjacent to the New Betatron Building. He could not work opposite the center of the entrance to the New Betatron Building since the casting would block the railroad track leading into the building. To allow clearance for the passage of rail cars in and out of the building, he was assumed to be located 10 ft from either the left or the right side of the tracks—we calculated the exposure rates from stray radiation from the betatron in both locations and selected the one with the higher exposure. Given the much lower exposure rate in the restroom, we made the claimant-favorable assumption that the layout man spent his entire shift in the location where he would have received the highest exposure. The exposure of the layout man from stray radiation from the betatron is listed in Table 2.

Table 2. External Exposure of Layout Men to Direct Penetrating Radiation

Source of radiation		Betatron duty cycle	Duration (h/shift)	Exposure (mR/shift)	Neutron dose (mrem/shift)
Steel	Short shots–90%	—	7.20	0.3	
	Long shots–10%	—	0.80	0.2	
Betatron		41%	8	22.1	1.1
Total				22.6	1.1

The second source of external exposure of the layout man was the irradiated steel casting on which he was working. We reassessed the exposure from this source, using the latest version of MCNPX. As it happened, the calculated doses were lower than in the original assessment. Since the doses from photon radiation from the castings were a small fraction of the dose from the operating betatron, we retained the original values, which are claimant-favorable. The results are listed in Table 2.

2.2 External Exposure to Beta Radiation

2.2.1 Uranium Slices

Allen (2012) utilized the SC&A (2008) analysis to assign dose rates from beta radiation from the uranium "betatron slices," as they were referred to in the Mallinckrodt site profile (Westbrook and Bloom 2007). He erroneously referred to these as dose rates from natural uranium; in fact, we had calculated the beta dose from irradiated uranium by adding the time-integrated specific activities of the ^{237}U and ^{239}U, beta-emitting isotopes that are products of photoactivation.

We recalculated the production of these isotopes, using the current version of MCNPX. Unlike the results for steel, which are discussed in the next section of this report, we found that the production rate of ^{237}U was two orders of magnitude smaller than in the previous analysis, while that of ^{239}U was 10% smaller. Since these isotopes make a minor contribution to the spectra of beta rays from the irradiated uranium—the naturally occurring nuclides predominate—and since the earlier analysis in this case was claimant favorable, we did not reassess the beta dose from the handling of uranium.

2.2.2 HY-80 Steel Alloy

Beta radiation from irradiated steel casting composed of HY-80 steel, a commonly cast alloy at GSI, was due to beta-emitting photoactivation products. We repeated our earlier analysis of the production of these residual nuclides, using MCNPX version 27e. The results showed a significantly higher rate of production of these nuclides, due to additional data on nuclear crosssections being included with the code, as well as improved modeling of the physics involved in these reactions. The results of the dose calculations are shown in Table 3.

Table 3
Dose Rates to Skin from External Exposure to Beta Radiation from HY-80 Steel (mrad/shift)

Distance	Shield	Betatron operator	Layout man
Contact	None	21.8	10.3
Contact	Cloth	18.5	8.6
1 ft	Cloth	13.2	6.0

2.3 Summary of Annual Doses

The estimated annual doses to the betatron operators are listed in Table 4 while the annual doses to the layout men are shown in Table 5.

Table 4. Annual Doses to Betatron Operators

Year	Exposure (R)	Neutron dose (rem)	Beta dose to skin (rads)	
			Hands and forearms	Other skin
1953-1957	1.35	0.48	33.4	6.3
1958	1.35	0.48	32.1	6.2
1959-1960	1.35	0.48	30.9	6.2
1961	1.35	0.48	34.2	6.3
1962	1.35	0.48	27.2	6.0
1963	1.35	0.47	13.9	5.6
1964	1.35	0.46	10.7	5.4
1965	1.35	0.46	10.2	5.4
1966[a]	1.35	0.46	4.8	2.7

[a] Annual rate during contract period January 1–June 30

Table 5. Annual Doses to Layout Men

Exposure (R)	Neutron dose (rem)	Beta dose to skin (rads)	
		Hands and forearms	Other skin
9.20	0.46	4.20	2.45

We found that the layout men received the bounding external exposures to direct photon radiation, while the betatron operators receivedequal or slightly higher neutron doses, depending on the year. In all years, the betatron operators received higher doses to the skin. All of our calculated doses are significantly higher than those reported by Allen (2012).

References

Allen, D., (NIOSH/DCAS). 2012. "Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations."

Allen, D., and S. Glover. 2007. "Site Profiles for Atomic Weapons Employers That Worked Uranium and Thorium Metals - Appendix BB: General Steel Industries," Battelle-TBD-6000,Appendix BB, Rev. 0. http://www.cdc.gov/niosh/ocas/pdfs/tbd/b-6000-apbb-r0.pdf

Allis-Chalmers Manufacturing Company (Allis-Chalmers). 1951. "Betatron Instruction Manual." Milwaukee, WI: Author.

Anigstein, R., J. Zlotnicki, R. H. Olsher, and J. J. Mauro. 2011. "Review of 'Evaluation of the Response of Film Badges to High Energy Photons'," Memo to Advisory Board on Radiation and Worker Health Work Group on TBD-6000 (October 28, 2011).

"Dr. Robert Anigstein of Sanford Cohen & Associates (SC&A) Interviewing Former Employees of General Steel Industries (GSI)." 2007.

International Commission on Radiological Protection (ICRP). 1996. "Conversion Coefficients for use in Radiological Protection against External Radiation," ICRP Publication 74. *Annals of the ICRP*, *26* (3/4). Tarrytown, NY: Elsevier Science, Inc.

Murray, M. E., and M. S. Uziel. 1992. "Results of the Radiological Survey at the New Betatron Building, Granite City Steel Facility, Granite City, Illinois (GSG002)," ORNL/RASA-91/8. Oak Ridge, TN: Oak Ridge National Laboratory.

Neal R. Gross, Court Reporters and Transcribers. 2010. "Advisory Board on Radiation and Worker Health Work Group on TBD-6000, Tuesday, October 12, 2010."

Nuclear Regulatory Commission (U.S.) (NRC). 2009a. "Application for amendment from General Steel Industries for AEC License 12-8271-1," ADAMS acquisition number ML093451445.

Nuclear Regulatory Commission (U.S.) (NRC). 2009b. "General Steel Industries Byproduct Materials License for License Number 12-08271-01 to amend Item 4," ADAMS acquisition number ML093451491.

Nuclear Regulatory Commission (U.S.) (NRC). 2009c. "General Steel Industries Byproduct Materials License for Cobalt-60, Budd Company Model 41706 Sealed Source not to exceed 1 curie in a single source," ADAMS acquisition number ML093480290.

S. Cohen & Associates (SC&A). 2008. "Review of 'Site Profiles for Atomic Weapons Employers That Worked Uranium and Thorium Metals - Appendix BB: General Steel Industries,' Battelle-TBD-6000, Appendix BB, Rev. 0." http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/scagsireview.pdf

S. Cohen & Associates (SC&A). 2011. "Issue Resolution Matrix for SC&A Findings on Appendix BB to TBD-6000." (Updated: July 25, 2011)

SimmonsCooper, LLC. 2006. "GSI Affidavit Testimony," August 11, 2006. http://www.cdc.gov/niosh/ocas/pdfs/tbd/outreach/gsi081106.pdf.

Westbrook, J. L., and C. W. Bloom. 2007. "Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site and the St. Louis Airport Site, St. Louis, Missouri," ORAUT-TKBS-0005, Rev. 02. http://www.cdc.gov/niosh/ocas/pdfs/tbd/mallink-r2.pdf

Attachment 1

QA REVIEW OF MONTE CARLO MODELING OF DOSE ESTIMATES FOR GSI BETATRON OPERATIONS

prepared by
Michael W. Mallett, PhD, CHP
S. Cohen & Associates
March 11, 2012

I have completed a thorough QA review of the Monte Carlo modeling included as part of the dose estimates for General Steel Industries betatron operations performed by NIOSH. I have verified that the calculations were performed and reported in a technically qualified manner.

The Monte Carlo model of the betatron, as constructed in the file BAXSP7 for MCNPX (Olsher 2007), is an excellent technical representation consistent with numerous references, most notably the information provided by Jack Schuetz, formerly of Allis-Chalmers (Schuetz 2007). This includes the components defined for the unit (platinum target, aluminum compensator, ceramic doughnut, and ion chamber), relative dimensions, material specifications, and transport physics models employed. Two minor transcription errors in the definition of the aluminum compensator were noted. However, both differed by less than 0.003” and did not affect the overall dimensions of the compensator. The effect of the minor discrepancies is considered to be negligible.

Integral to the Monte Carlo model of the betatron is the process for normalizing the transport results based on the source definition and tally sampling. This was accomplished by calculating the beam intensity given the nominal and reported output of the unit (SC&A 2008). Tally results computed as per source electron were then correctly adjusted via the calculated beam intensity. (Results referencing the “22-MeV betatron” were accepted as synonymous with the “24-MeV betatron”, i.e., “old betatron” unit upgraded to 24-MeV.)

Subsequent calculations performed by NIOSH using the betatron model were observed to be correctly implemented. Of particular note:

- Transformation cards relocating the betatron model for the various irradiation geometries were verified to be correct.
- The source definition, including particle type, energy, location of origin, and direction sampling was verified to be correct.
- The tally sampling, including type, location, and energy distribution was verified to be consistent with the reported dose results (Allen 2012).
- The employed dose conversion factors were verified as correct and consistent with the methodology used to produce the published results.
- The variance reduction methods employed were appropriate and did not incorrectly bias the results.
- The error reported for the Monte Carlo simulations was appropriate and yielded a high degree of confidence in the reported results.

A QA review was performed of the Monte Carlo computations of photon doses from unirradiated natural uranium. These calculations utilized highly detailed and accurate source terms, proper material specifications, and appropriate tally specifications, including correct dose conversion functions and tally multiplier factors. An error in the calculation of the mass of the uranium slice was observed. This resulted in an underestimation of the calculated photon dose rate by approximately a factor of 3 (Table 9, SC&A 2008). Whereas the dose to the worker from unirradiated natural uranium is relatively small contribution to the total occupational doses presented in the report, this discrepancy is considered to be negligible. No use is made of this result in either the NIOSH analyses (Allen 2012), nor in the present review of these studies.

A QA review was performed of the calculated exposure to beta radiation from residual nuclides in steel. These calculations accurately modeled the dose rate scenario, correctly computed the skin and relevant organ doses, given the photoactivation models employed in MCNPX, and properly prioritized the most pertinent nuclides contributing to the dose. Dose calculation methods performed external to the code were verified correct.

A QA review was performed of the calculated exposure to beta radiation from residual nuclides in uranium. These calculations accurately modeled the dose rate scenario and correctly computed the skin and relevant organ doses from the uranium radionuclides. Dose calculation methods performed external to the code were verified correct.

References

Allen, D. 2012, Battelle-TBD-6000 Appendix BB General Steel Industries, Dose Estimates for Betatron Operations, January 2012.

Olsher, R.H. 2007, 25 MeV Betatron: Shielding Analysis: Photon Transmission + Skyshine, MCNPX input file, December 31, 2007.

S. Cohen & Associates 2008, Review of “Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals – Appendix BB: General Steel Industries,” Battelle-TLD-6000, Appendix BB, Rev. 0, (Draft) April 2008.

Schuetz, J.G. 2007, Letter report to Samuel Glover, NIOSH/OCAS, May 1, 2007.