TO: Advisory Board on Radiation and Worker Health Work Group on TBD-6000
FROM: Robert Anigstein and John Mauro, SC&A
SUBJECT: Response to NIOSH Report: "GSI Dose Estimation Comparison"
DATE: February 12, 2013

SC&A Response to NIOSH Report: "GSI Dose Estimation Comparison"

On February 4, 2013, Dave Allen (2013) transmitted a report comparing NIOSH and SC&A dose estimates for General Steel Industries (GSI). The same day, Paul Ziemer (2013), Chairman of the ABRWH Work Group on TBD-6000, sent an e-mail message asking if SC&A will be able to provide responses to this and another document in time for the February 21 meeting. This memo is our response to Allen's report. The following discussion is keyed to Allen (2013) and follows the same sequence as Allen. Allen's intent was to present a historical account of the development of the dose estimates—we will bring the SC&A dose estimates up to date while reviewing Allen's presentation, thus deviating somewhat from Allen's framework.

1 Exposures During "Radium Era": 1953–May 21, 1962

In a table on p. 1, Allen (2013) lists estimated exposures of radiographers during the "Radium Era" (i.e., 1953–May 21, 1962 [date when GSI procured ^{60}Co radiography sources to replace ^{226}Ra]). The table compares the NIOSH results to the SC&A ^{226}Ra exposure estimate that we derived from first principles. However, this was but one of three exposure estimates that we developed for radiographers during the Radium Era, which are listed below:

1. Time and motion study of a radiographer handling the ^{226}Ra sources and staying in the radiographer's office inside the concrete block radiographic facility in the No. 6 Building during radiographic exposures, which yielded an exposure rate of 9.69/y (listed in Allen's table);

2. Extrapolation of radiation exposure records for [redacted]—who performed radiography part-time on weekends—to a full-time radiographer. Mr. [redacted] received a dose of 9.1 rem during 18 calendar quarters. An estimated range of work shifts that he spent performing radiography over the course of a year yielded a range of 9.1–20.5 rem/y to a full-time radiographer (a rounded range is cited in a footnote to Allen's table).

3. The statement on the AEC license application that the *applicable* AEC dose limits for each time period were never exceeded (NRC 2009a, p. 26), which implies that the dose rates could have been as high as 15 rem/y in 1953–1954, and 12 rem/y in 1955–1962 (only the latter value is cited in Allen's footnote).

Allen (2013) next compared SC&A and NIOSH estimates of exposures to sources used by St. Louis Testing Laboratories (SLTL) on the GSI site. The SC&A value was presented by Anigstein (2011a), who assigned an annual exposure of 2.669 R to a GSI worker remaining at

the boundary of the exclusion zone set up by SLTL. An additional exposure of 133 mR was assigned, based on an excursion into the exclusion zone while the radiographer was assumed to take breaks. However, we later learned from [redacted] a former administrator of SLTL, that the source was retracted into its shield whenever the radiographer left the area (Anigstein 2011b). Therefore, the limiting exposure should be 2.669 R/y.[1] At the same time, we learned that the SLTL activities at GSI did not begin until 1963, past the end of the Radium Era. Consequently, these exposures, although presented during an earlier phase of our studies, should not be included in exposure assessments during this period. Later in his report, Allen took note of this last observation.

By the same token, the exposures of the layout man resulted from the operation of the New Betatron, which was not installed until late 1963, and should likewise not be included in the Radium Era assessments. This is also noted in a later part of Allen's report.

Allen (2013) next presented a table entitled "Others – Radium Era." The table correctly cites the SC&A assessment of exposures outside the radiographic facility in No. 6 Building; however, we disagree with Allen's derivation of an annual exposure from ^{226}Ra radiography outside the facility that he ascribed to SC&A. That value is based on all of the ^{226}Ra radiography being performed in an open area, which we do not believe was the case. The same comment on the previous table with respect to the SLTL sources applies here. Finally, we note that the table includes the betatron operator and the layout man, who are also listed in the previous table.

2 Exposures Following the Radium Era

Allen (2013) designated the period from the end of the Radium Era until the end of AEC operations as the "Cobalt Era." This era needs to be subdivided, since it comprises three distinct periods—pre-SLTL operations, SLTL operations prior to the New Betatron, and New Betatron operations—each of which experienced significantly different limiting exposures. Allen lists exposures from the GSI-owned ^{60}Co sources—we agreed with the exposures calculated on the basis of the survey of the radiographic facility performed by the Nuclear Consultants Corp., but disagreed with the exposures from performing ^{60}Co radiography in open areas, since this was an infrequent scenario that should not be used to calculate annual exposures.

2.1 Period Preceding SLTL Operations: May 22—December 31, 1962

During the period after the Radium Era but prior to SLTL operations—May 22 to December 31, 1962—SC&A recommended that the limiting exposure be that of the betatron operator—1.35 R/y—as listed by Allen in each of his four tables.

[1] Allen (2013) erroneously ascribed a rate of 2.771 R/y to SC&A—in fact, Anigstein (2011a) cited this value (in units of "mrem") but ascribed it to Allen (2011). In the subsequent discussion, whenever a time period encompasses a fraction of a calendar year, the recommended annual exposures should be prorated to the actual period of exposure.

2.2 Exposures from SLTL Sources: January 1–September 30, 1963

The highest exposures during the period January 1–September 30, 1963, were from the high-activity ^{60}Co and ^{192}Ir sources by SLTL to perform radiography at GSI. As discussed in section 1, above, the limiting exposure in this scenario should be 2.669 R/y. As stated earlier, the SLTL work did not begin until 1963. Since we do not know the exact date, the claimant-favorable assumption is that it began on January 1, this limiting exposure rate should be assigned to all GSI workers during the period January 1–September 30, 1963.

2.3 Exposures from New Betatron: October 1, 1963–June 30, 1966

The next period for which doses or exposures need to be assigned is from the installation of the New Betatron in late 1963 until the end of the covered period. The September 1963 edition of *GSI General Steel Industries Magazine* shows a photograph of the New Betatron Building under construction (SC&A 2008). Presumably, this issue was prepared in August or later. It is unlikely that the New Betatron was put in service before October 1, 1963, which would be a claimant-favorable date for the start of operations. Further indirect evidence for this starting date is the summary record of external exposure of [redacted] for 1963 (Attachment 1). During the first 3 calendar quarters, his quarterly doses ranged from 0–15 mrem. Since he performed radiography only on a part-time, weekend basis, it was likely that he did little radiography during this period. However, in the 4th quarter, which began on October 1, the dose jumped to 100 mrem, which suggests a marked increase in his radiographic activities.

Further information on radiographic activities in the 4th quarter can be inferred from the film badge dosimetry data that NIOSH obtained from Landauer, the vendor who supplied and processed the film badges. The first weekly report included in these records, which is for the week starting Monday, January 6, 1964, lists doses to Mr. [redacted] and to 17 other GSI workers. The report states that there were seven reports to date for each of these workers, implying that they had been issued six film badges prior to the ones listed in that report. We thus infer that the Landauer dosimetry program began during the week of November 25, 1963. Since Mr. [redacted]' cumulative dose is left blank in the report, we can infer that each of these six previous badge reports had readings below the MDL, which was 10 mrem for the Landauer badges. Thus, to accumulate 100 mrem during the 4th quarter, [redacted] would have to have had at least one film badge prior to the Landauer dosimetry program. This increase in his work schedule would indicate an increase in radiographic operations at GSI, which, according to the accounts of former workers, occurred when the New Betatron was put into service.

From the assumed date of installation of the New Betatron until the end of the covered period—October 1, 1963–June 30, 1966—the limiting exposure rate should be 9.20 R/y. We calculated this rate for the layout man working in No. 10 Building, just outside the New Betatron Building (Anigstein and Olsher 2012). This value was cited by Allen (2013), first under "Radiographers – Cobalt Era," then again under "Others – Cobalt Era." The following tables summarize the differences between the NIOSH and SC&A estimates of limiting exposures connected with betatron operations.

Table 1. Annual Doses to Betatron Operators

Year	Exposure (R)		Neutron dose (rem)		Beta dose to skin (rads)			
					Hands and forearms		Other skin	
	SC&A[a]	DCAS	SC&A	DCAS	SC&A	DCAS	SC&A	DCAS
1953-1957	1.35	0.734	0.48	0.050	33.4	25.9	6.27	2.27
1958	1.35	0.734	0.48	0.050	32.1	25.9	6.22	2.27
1959-1960	1.35	0.734	0.48	0.050	30.9	25.9	6.18	2.27
1961	1.35	0.763	0.48	0.056	34.2	29.5	6.30	2.47
1962	1.35	0.702	0.48	0.043	27.2	21.8	6.04	2.04
1963	1.35	0.586	0.47	0.019	13.9	7.0	5.56	1.23
1964	1.35	0.558	0.46	0.013	10.7	3.5	5.45	1.03
1965	1.35	0.554	0.46	0.012	10.2	3.0	5.43	1.00
1966[b]	0.68	0.275	0.23	0.006	4.8	2.4[c]	2.71	0.97[c]

Source: Anigstein and Mauro (2012)

Note: SC&A values from Anigstein and Olsher (2012)

[a] Maximum exposure, assuming hypothetical 30-keV residual radiation from betatron behind operator's back

[b] During contract period: January 1–June 30

[c] As listed by Allen (2012)—should be prorated for 6-months of exposure in 1966 for consistency with exposure to photons and doses from neutrons

Table 2. Annual Doses to Layout Men

Exposure (R)		Neutron dose (rem)		Beta dose to skin (rads)			
				Hands and forearms		Other skin	
SC&A	DCAS	SC&A	DCAS	SC&A	DCAS	SC&A	DCAS
9.20	4.483	0.46	0.148	4.20	1.02	2.45	0.54

Source: Anigstein and Mauro (2012)

Note: SC&A values from Anigstein and Olsher (2012). See text for applicable periods.

We note that Allen (2013) agreed to accept the SC&A estimates of doses to the skin. However, there is disagreement on photon and neutron doses.

3 Areas of Agreement

NIOSH and SC&A agree that the layout man represents the bounding scenario during the operation of the New Betatron (not during the entire "Cobalt Era," as stated by Allen, 2013). As Allen points out, both groups agree that radium radiography constitutes the bounding scenario to radiographers during the Radium Era.

4 Unresolved Issues

4.1 Layout Man

As shown in Table 2, the SC&A estimate of the exposure of the layout man is more than twice the NIOSH estimate, while our estimate of the neutron dose is more than three times that of NIOSH. Allen (2013) disagrees with our calculations, claiming that our betatron shot scenario would have led to exposures in the control room that would exceed the film badge dosimetry records of the betatron operators. That conclusion is inconsistent with our analysis and with observations regarding film badge dosimetry for the reasons discussed below.

> [Allen (2013) fails] 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 integral part of any personal dosimetry program, the control badge is stored in the same location as the film 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.' . . . 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." (Anigstein and Olsher 2012)

Therefore, Allen's (2013) assumption that the film badge dosimetry reports include the exposure of the film badge while it was stored in the rack is incorrect. To the extent that the control badge might have been exposed to stray betatron radiation while the operator was wearing his badge, the dosimetry records might actually understate the doses to the workers.

Our calculation of the exposure of the layout man comprises 22.11 mR per 8-h shift from betatron radiation and 0.53 mR from the activated steel. This yields an annual exposure of 8.98 R from stray radiation from the betatron and an additional 0.22 R from activated steel. With the same shot geometry, we calculated an exposure rate of 0.339 mR/h at the operator's desk in the control room. This results in an annual exposure of the betatron operator of 0.46 R, assuming he sat at the desk in the control room during the entire part of his shift that the betatron was in operation. Thus, his weekly exposure, averaged over 50 weeks, would be 9.2 mR, less than the MDL of the film badge. In reality, especially during the "long shots," he may have left the control room through a back door. Such a scenario is plausible if we note that the operator was a member of the betatron team that was also responsible for processing the exposed films, and that the room directly behind the control room is marked "Processing Area" on the floor plan in Figure 1. This is consistent with the account of the late [redacted] a GSI betatron operator, who said the exposed films were processed in the betatron building. Thus, the operator may have spent part of the time during betatron exposures away from the control room.

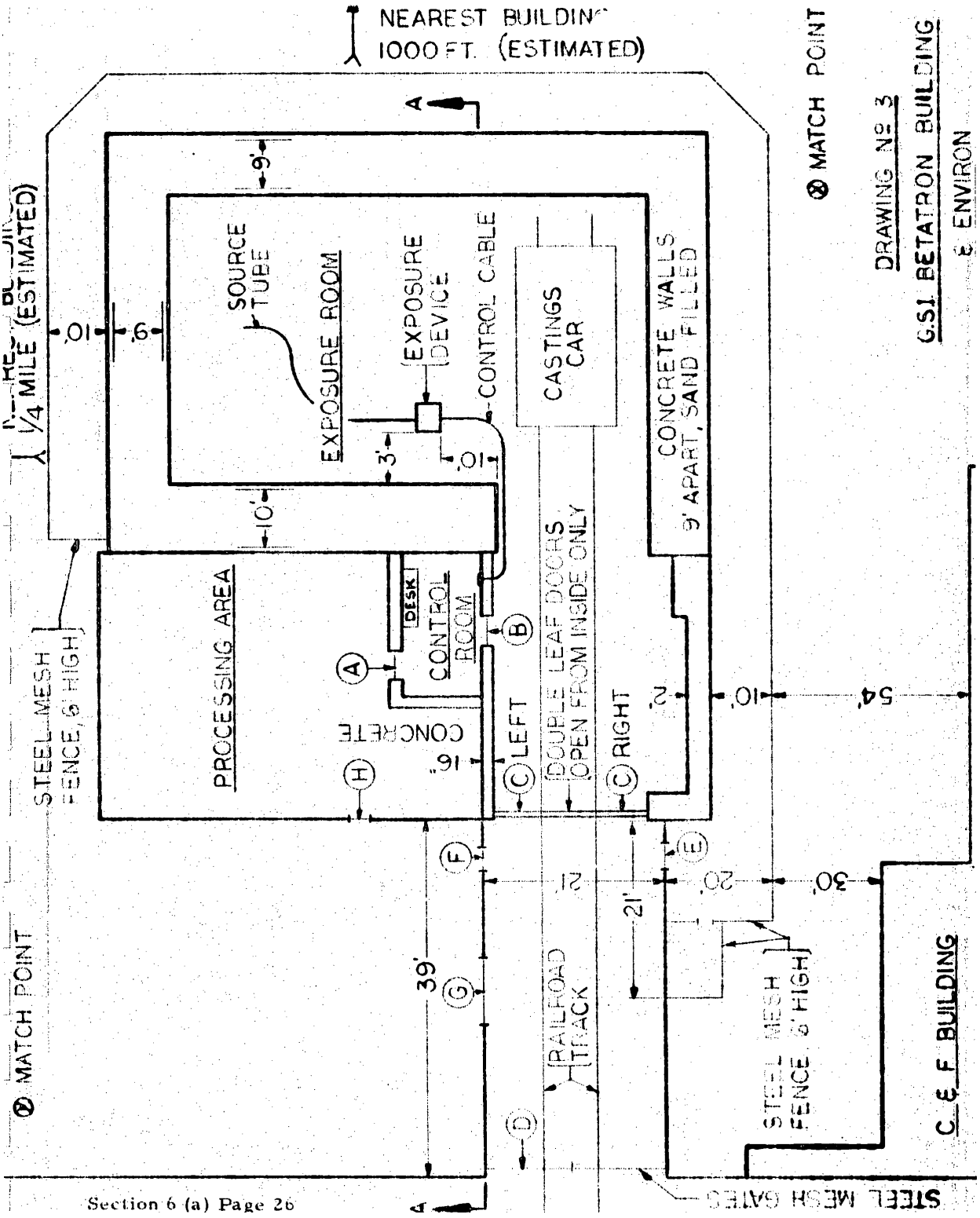

Figure 1. Drawing of New Betatron Building Showing Desk in Control Room (NRC 2009b)

We therefore believe that our estimated exposure of the layout man of 9.2 R/y is a realistic and claimant-favorable bounding value. This value was presented to the Advisory Board at the June 20, 2012, meeting in Santa Fe, New Mexico.

4.2 Radium Radiography

Allen (2013) correctly summarizes the SC&A exposure analysis of the radiographer using ^{226}Ra sources described in paragraph 1 of section 1 of this memo. We would rephrase his reference to our use of "worst case" parameters: we would characterize the parameters as being claimant favorable yet realistic, the regulatory requirement for assumptions used in dose reconstructions. However, our exposure analysis based on time and distance, as well as the one based on extrapolating the doses of a part-time radiographer to one occupied full time with such work, serve only to buttress our recommendation that the bounding exposures should be equal to the AEC limits. These limits were 15 rem/y prior to 1955 (which Allen failed to mention) and 12 rem/y in 1955 and subsequent years—up to the end of the Radium Era. We disagree with Allen's assertion that "Based on a statement GSI made to the AEC that no one had exceeded the annual limit and the average was below 25% of that limit, the maximum dose can be established as falling between 3 R/yr and 12 R/yr." We interpret GSI's statement that no one exceeded the annual limit to imply that someone's dose might have been at the limit. Since there is no way of knowing who that person was, the AEC limit represents the bounding value. The average dose is immaterial—the decision to compensate a claimant must be based on the real individual, not an imaginary statistical average individual.

We further disagree with NIOSH's adopting our calculated exposures of workers outside the radiography room as a basis for dose reconstructions. Anigstein (2011b) calculated doses outside the steel door to the radiography room to check limiting doses to nonradiographers calculated by Allen (2011). It was not our intention to endorse the assignment of different doses to different classes of GSI workers, although we admit that citing that calculation in that report may have implied as much. From the time of our earliest review of the GSI site profile (SC&A 2008), we have questioned the division of GSI workers into two categories by NIOSH. We believe that the limiting exposures of 15 rem/y in 1953–1954, and 12 rem/y in 1955–1962 should be assigned to all GSI workers. This is the SC&A position that was presented to the Advisory Board on June 20, 2012 and reiterated in response to questions from board members at its meeting in Knoxville, Tennessee, on December 11, 2012. This position is confirmed in the following excerpt from Issue 11 of the Appendix BB issues matrix:

> [NIOSH] 1/13/12: Allen [(2012)] stated that, in assessing doses from betatron operations, dose reconstructors will choose the most favorable exposure scenario (i.e., betatron operator or layout man) in each case.
>
> SC&A Response (7/28/12): We agree that the most favorable exposure scenario should be applied in all dose reconstructions. *The same procedure should be extended to reconstructing the doses from external exposure to sealed sources.* If

> such instructions are included in the revised Appendix BB, we will recommend that this issue be closed. [Italics added]

Since these are the only exposures for which there is a factual basis, it is SC&A's position that doses derived from these exposures should be assigned to all workers, not just known or presumed radiographers. This was the basis on which we supported NIOSH's assertion that they can reconstruct doses to all workers during this period.

Otherwise, NIOSH would need to track each worker's job assignment and activities. For instance, was he the one who was taking measurements inside a tank hull while it was being radiographed with a betatron, as recounted by the late [redacted]? Was he the draftsman (not likely to be considered a radiographer by dose reconstructors) who was in the betatron shooting room during a radiographic exposure? Such incidents would most likely be bounded by the 12–15 R/y limiting exposures, but not necessarily by exposures from other scenarios. Likewise, how can NIOSH assign any doses to workers whose job assignments placed them in locations that were not in the proximity of the radium sources? Since the New Betatron Building was not erected until after the Radium Era, the scenario in which workers in No. 10 Building were exposed to stray betatron radiation is not applicable. Since not many workers would have reason to be in or in the proximity of the Old Betatron Building, which was about 250 ft from the nearest other building, stray betatron radiation from the old betatron is likewise not a basis for assigning doses to such workers.

Discussions among Advisory Board members during the Knoxville meeting indicated that at least some believed that the limiting doses would be assigned to all workers during the Radium Era, not just to the small number of known radiographers. Furthermore, using different exposure scenarios in dose reconstructions of different workers is inconsistent with the policy enunciated by Allen (2012), who stated,

> Betatron operator dose is intended to apply to anyone working in the betatron building. Because little information is available for the location of most workers, these doses will apply to *all* workers at GSI. For the same reason, the layout worker dose is intended to apply to *all* workers. . . . Dose reconstructors will choose the most favorable set of doses for the given case. [Italics added]

There is no reason why workers employed during the Radium Era should be treated differently from those employed during the period when the New Betatron was in operation.

4.3 Exposure to SLTL Sources

It is our position that an exposure of 2.67 R/y from SLTL radiography should be assigned to all GSI workers from January 1 to September 30, 1963, whereas NIOSH would assign this exposure only to GSI radiographers, assigning approximately one-half this value to other workers. Since there was no need for GSI radiographers to be involved in this operation, there is no reason they would have a higher exposure than other workers. GSI employees that were most likely to remain in the vicinity of these operations would have been those involved in the production and

testing of the castings—supervisors, metallurgists, layout men, etc.—and perhaps chippers, grinders, and welders who repaired any defects uncovered by the radiographs. Since the identities and even the categories of these workers are unknown, all workers should be assigned this exposure.

5 Summary and Conclusions

NIOSH and SC&A agree on who are the maximally exposed individuals during each era. There is, however, substantial disagreement on the doses to be assigned to GSI workers. SC&A believes that all workers should be assigned the same doses in a given era. NIOSH is inconsistent in this respect, assigning lower doses to nonradiographers prior to New Betatron operations, but the maximum doses—either those modeled for the layout man or the betatron operator, whichever is the most claimant-favorable—during New Betatron operations.

References

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Ziemer, P. 2013. <[redacted]@comcast.net> "FW: Products for TBD-6000 WG" February 4, 2013, personal e-mail to Robert Anigstein, SC&A, Inc., CC: John Mauro, John Stiver, Ted Katz.

Attachment 1

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U.S. Atomic Energy Commission

CURRENT OCCUPATIONAL EXTERNAL RADIATION EXPOSURE

Identification

Name (Print--Last, first, and middle)	2. Social Security No.
[redacted]	[redacted]
Date of Birth (Month, day, year)	4. Age in Full Years (N)
[redacted]	32

Occupational Exposure

Dose Recorded For (Specify: Whole body; skin of whole body; or hands and forearms, feet and ankles.)	6. Permissible Dose at Beginning of Period Covered by This Sheet	7. Method of Monitoring (e.g., Film Badge--FB; Pocket Chamber--PC; Calculation--Calc.)
Whole Body	48.26 REM	Gamma FB Beta Neutrons

Period of Exposure (From--to)	Dose for the Period (rem) MREM				13. Running Total for Calendar Quarter (rem)
	9. Gamma	10. Beta	11. Neutron	12. Total	
1963					
1-1 To 3-31 Total	15				.015
4-1 To 6-30 Total	0				.015
7-1 To 9-30 Total	5				.020
10-1 To 12-31 Total	100				.120
Grand Total	120				.120

Lifetime Accumulated Dose

14. Previous Total	15. Total Dose Recorded on This Sheet	16. Total Accumulated Dose	17. Perm. Acc. Dose	18. Permissible Dose
16.74 rem	.12 rem	16.86 rem	5(N--18)= 70.0 rem	53.14 rem

). Name of Licensee

GENERAL STEEL INDUSTRIES, INC.
COMMONWEALTH DIVISION