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 White Paper: "Summary Dose Estimates for GSI"
DATE: October 6, 2013

SC&A Response to NIOSH White Paper: "Summary Dose Estimates for GSI"

On August 21, 2013, NIOSH prepared a white paper entitled "Summary Dose Estimates for GSI" (Allen 2013b). The present memo is the SC&A response to the NIOSH white paper. Our comments are keyed to the topical headings in the white paper. We will limit our comments to areas of disagreement.

1 Uranium Intake Estimates

The uranium intake estimate postulates two source terms of uranium dust:

1. Uranium dust that becomes airborne during uranium handling operations
2. Uranium that has settled to the floor and is resuspended

During the June 20, 2013 teleconference meeting of the Advisory Board's Work Group on TBD 6000, the work group, NIOSH, and SC&A agreed to use a fixed value of 68.7 dpm/m^3 as the airborne uranium activity concentration during uranium handling operations. The three parties also agreed that the annual duration of exposure to this concentration shall be equal to the duration of the uranium handling operations during each time period, based on the purchase orders from the Mallinckrodt Chemical Works (MCW). The earliest purchase order is for the period 3/1/1958 to 6/30/1958; there are no POs covering the period October 1, 1952 (the beginning of the covered period) until March 1, 1958. During the discussion, Jim Neton (Associate Director for Science) agreed that the maximum uranium handling hours during any one year, based on the POs, should be assigned to this period. This value, 437.5 h/y, for the period 7/1/1961–6/30/1962, should therefore be assigned for each year or fraction of a year, from November 1, 1952 (the beginning of the covered period) until February 28, 1958.[1] Furthermore, since there is an MCW PO for the period 3/1/58–6/30/58, the annual hours for that period should be derived from that PO. However, Allen (2013b) used a value of 337.5 h/y for the entire period 11/1/1952–6/30/1958, resulting in substantially lower intakes during this period.
The NIOSH estimate of airborne uranium activity due to resuspension is based on the aforementioned airborne activity of 68.7 dpm/m^3, a settling velocity of 0.00075 m/s, a settling time of 30 d, and a resuspension factor (RF) of 10^{-5} m^{-1}. The settling velocity and settling time are based on TBD-6000 (Allen 2011). We agree that these are reasonable parameter values to apply to the betatron shooting room and, by extension, to the rest of the GSI facility.

Table 1 shows a comparison of the SC&A and NIOSH annual hours of uranium handling and the calculated inhaled activities from both uranium handling operations and resuspension during the entire period of AEC operation. As shown in the table, the SC&A estimate is 24% higher than

[1] Dr. Neton referred to a rounded value of 400 h/y.

the NIOSH calculation during the first 5½ years of the operational period and by a smaller amount during the next 4 months. The slightly lower value calculated by SC&A during the remainder of the operational period is most likely due to round-off error, since both analyses utilized the same values of input parameters.

Table 1. Intakes of Airborne Uranium by Inhalation During GSI Operational Period

Start Date	End Date	Hours/year		Inhalation dpm/cal. day		Δ
		SC&A	NIOSH	SC&A	NIOSH	
10/1/52	2/28/58	437.5	337.5	113.09	91.4	24%
3/1/58	6/30/58	375.0	337.5	98.97	91.4	8%
7/1/58	10/31/58	337.5	337.5	90.50	91.4	-1%
11/1/58	6/30/59	337.5	337.5	90.50	91.4	-1%
7/1/59	6/30/61	337.5	337.5	90.50	91.4	-1%
7/1/61	6/30/62	437.5	437.5	113.09	114.22	-1%
7/1/62	6/30/63	125.0	125.0	42.50	42.93	-1%
7/1/63	6/30/65	28.1	28.0	20.62	20.8	-1%
7/1/65	6/30/66	12.9	13.0	17.17	17.38	-1%

During the residual period, the resuspended dust is the only source of inhalation exposure. Allen (2013b) abruptly lowered the RF from 10^{-5} to 10^{-6} m^{-1} on the day that uranium operations ceased. As we stated in an earlier memo:

> We do not agree that an RF of 10^{-6} m^{-1} is applicable to the residual period. As Allen (2013a) correctly pointed out, this RF value is applicable to *aged* activity in a *quiescent* setting. Although the contamination gradually aged, the setting—the betatron shooting room and other areas of GSI—was hardly quiescent. (Anigstein and Mauro 2013b)

We believe that, during the residual period, an RF of 10^{-5} m^{-1} should be used to calculate the resuspended dust. This would result in a 10-fold increase in the inhaled activities during this period. We agree that the surficial contamination should be gradually decreased during the residual period, according to OTIB-0070 (Sharfi 2012, Table 4-2).

2 Summary of External Dose Estimates

2.1 Doses to Plant Personnel During the Radium Era

Allen (2013b) assigned doses from external photon radiation to nonadministrative plant personnel during the Radium Era. These annual doses were represented by a triangular distribution, with a lower limit of 6.279 rem, a mode of 9.69 rem, and a maximum of 12 or 15 rem, depending on the year. The maximum was set to equal the AEC dose limit in effect at the time. However, we disagree with the assumption that the upper bound of the distribution should be reduced from 15 rem/y (not 15 R/y) to 12 rem/y on Jan. 1, 1959. The basis of the maximum dose is the statement on GSI's AEC license application that the *applicable* AEC dose limits for each time period were never exceeded. As stated in our earlier memo (Anigstein and Mauro 2013a),

> Ten CFR 20 was first put into effect on February 28, 1957. At that time, the regulation limited doses to blood-forming organs, gonads, and the lens of the eye to 300 mrem/week. This limit had been presented in NBS Handbook 41, dated March 30, 1949 (NBS 1949). The handbook embodied the recommendations of the NCRP, which AEC had agreed to follow, first in regulating its own operations, and later in promulgating rules for AEC licensees. Since the AEC observed the limit of 300 mrem/week (15 rem/y) since about 1949, this limit can assumed to have been followed by GSI during the early years of the operational period.
>
> On January 1, 1961, a revised 10 CFR 20 went into effect. This rule limited doses to a maximum of 3 rem per calendar quarter to a worker if his prior exposure history was known and if his lifetime dose did not exceed 5 (N-18), where N is his age in years. Thus, a worker well past the age of 18 with a sufficiently low cumulative exposure could receive doses as high as 12 rem in any one year. Thus, the upper bound of the triangular distribution should be set at 15 rem per year during the period 1953–1960, and reduced to 12 rem/year during 1961–62.

The net effect of our recommended change would be to increase the maximum dose by 25% during the years 1959–1960.

We also disagree with the NIOSH assumption that this distribution, based in part on the estimate of doses to a radiographer utilizing ^{226}Ra sources, should be used to assign doses during 1963. GSI was granted an AEC license to use ^{60}Co sources for radiography, and procured two such sources in May 1962, at which time the use of ^{226}Ra was discontinued. The New Betatron Building was constructed in 1963 and began operations sometime during that year. We believe that scenarios based on exposures of plant personnel to stray radiation from this betatron should be the basis of external doses, beginning in 1963 through the end of the covered period.

2.2 Doses to Plant Personnel After the Radium Era

Allen (2013b) assigned doses from external photon and neutron radiation to nonadministrative plant personnel following the Radium Era. The doses are based on the bounding exposure scenario, that of a layout man working just outside the New Betatron Building, which yields a photon dose of 4.483 rem/y and a neutron dose of 148 mrem/y. We have a number of objections to Allen's exposure analysis, which we discussed in detail in our previous memos (Anigstein and Mauro 2012, 2013a). In summary, "we . . . disagree with [Allen's] arbitrarily selected set of 15 betatron shooting scenarios, 10 of which do not represent realistic practices employed in betatron radiography." Next, "we disagree with Allen's . . . methodology of apportioning the shots among these 15 scenarios on the basis of the MCNPX analyses of exposure rates at the location of the film-badge storage rack." As we stated earlier,

> A question arose during the February 21, 2013, work group meeting regarding the betatron shooting scenarios. David Allen maintained that the betatron scenario

> proposed by SC&A was implausible because it would have led to exposures of control film badges in excess of 10 mR per week. We disagree with this assumption for two reasons. First, there is no information on where film badge No. 1, called "Betatron CTL," was stored. Since there was only one such badge, it could have been kept in the Old Betatron Building, which is where Gillium Burgess, one of the earlier betatron supervisors, had his office. The 000 control badge should have been stored on the film badge rack, along with all the workers' film badges. Allen correctly pointed out that the reports of this badge always had readings of *M*. The manner in which the dose to this badge was evaluated is explained in the memo from Joseph Zlotnicki, CHP (former Landauer official, currently a member of the SC&A staff) (see Attachment 1). The evaluation of the badges was a multi-step process. Landauer retained a control film that was matched to each batch of films sent to a customer—this film never left its premises. When the films were returned from the customer, the in-house control film was developed alongside the other films. The base fog on this film was subtracted from the densitometer readings of all the other films. The remaining "dose" on the 000 customer control badge was evaluated. If this film read less than 50 mrem, and if the reading was lower than that of one-half of the badges issued to workers, the reading was subtracted from that of the other badges, as well as from itself. In these cases, which constituted the vast majority, the control badge would be reported as *M*. Thus, the *M* readings cannot be used to place an upper limit on the cumulative weekly exposure at the film badge location.
>
> Furthermore, as we pointed out earlier (Anigstein and Mauro 2012), we disagree with the NIOSH MCNP model of the New Betatron Building, which used incorrect assumptions about the thickness and density of the control room wall and the absence of equipment, furniture, and internal walls that would have reduced the exposure rate at the film badge rack. We therefore restate our opinion that the betatron shooting scenario described in our earlier report (Anigstein and Olsher 2012) is more realistic and more claimant favorable than the one proposed by NIOSH. (Anigstein and Mauro 2013a)

Table 2 lists the exposures to penetrating external radiation to the layout man, which are applicable to all nonadministrative plant personnel from 1963 to June 30, 1966. In both the SC&A and NIOSH analyses, the radiation exposure of the layout man constitutes the bounding scenario for photon exposure. In the NIOSH analysis, this is also the bounding scenario for neutron exposure.

As shown in Table 2, our estimated photon exposure is more than twice as high as the NIOSH estimate. We note that the results of the SC&A analysis are presented in units of roentgens, while the NIOSH results are listed as rem. However, we note that in an earlier report, Allen (2012) listed a value of 4,483 mr for this quantity, which is equal to 4.483 R. He apparently uses the two sets of units interchangeably. Our estimated neutron dose is more than three times higher than the NIOSH estimate. We note that, according to our analysis, the limiting scenario for neutron exposures during the period 1952–1963 is the radiation exposure of the betatron operator, whereas it is that of the layout man in the NIOSH analysis. However, the differences in neutron doses in the two SC&A scenarios are slight.

Table 2. Annual Doses to Layout Men

Photon exposure		Neutron dose (rem)		Beta dose to skin (rads)			
				Hands and forearms		Other skin	
SC&A (R)	NIOSH (rem)	SC&A	NIOSH	SC&A	NIOSH	SC&A	NIOSH
9.20	4.483	0.46	0.148	4.20	2.658	2.45	1.462

Note: SC&A values from Anigstein and Olsher (2012), NIOSH values from Allen (2013b)

In both the SC&A and NIOSH analyses, the radiation exposure of betatron operator constitutes the bounding scenario for dose to the skin from beta rays. According to Allen (2013b), the beta skin dose analyses were performed using MCNPX Version 2.7. We used the same version of the code in our analyses; as shown in Table 3, the two analyses produced significantly different results. Since we have not seen the NIOSH MCNP files, we cannot explain the discrepancies. We do observe that the differences increase steadily during the years 1961–1966. We further observe that, since the annual exposure duration from uranium handling decreases steadily during these years, the handling of irradiated steel accounts for a steadily increasing fraction of the skin dose. It seems likely that differences in modeling the exposure to irradiated steel might account for at least some of the differences in the results.

Table 3. Annual Doses to Betatron Operators

Year	Neutron dose (rem)		Beta dose to skin (rads)					
			Hands and forearms			Other skin		
	SC&A	NIOSH	SC&A	NIOSH	Δ (%)	SC&A	NIOSH	Δ (%)
10/1/1952-1957	0.48	0.050	33.4	26.904	24%	6.27	2.755	127%
1958	0.48	0.050	32.1	26.904	19%	6.22	2.755	126%
1959-1960	0.48	0.050	30.9	26.904	15%	6.18	2.755	124%
1961	0.48	0.056	34.2	30.496	12%	6.30	2.946	114%
1962	0.48	0.043	27.2	22.863	19%	6.04	2.539	138%
1963	0.47	0.019	13.9	8.154	70%	5.56	1.755	217%
1964	0.46	0.013	10.7	4.669	129%	5.45	1.569	247%
1965	0.46	0.012	10.2	4.130	147%	5.43	1.541	252%
1966[a]	0.23	0.006	4.8	1.796	170%	2.71	0.756	258%

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

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

3 Conclusions

The work group, SC&A, and NIOSH have reached consensus on several issues related to the assessment of radiation exposures of GSI workers. However, there are significant areas of disagreement between NIOSH and SC&A that remain to be resolved.

3.1 Uranium Intake Estimates

We are in complete agreement with the methodology to estimate uranium intakes during the operational period. We disagree about the duration of uranium handling operations during the period 10/1/52–6/30/58. The higher annual duration recommended by SC&A, especially during 10/1/52–2/28/58, would result in a 24% increase in inhaled activities during this period.

We do not agree with the NIOSH estimate of inhaled activities during the residual period, which is based on an RF of 10^{-6} m^{-1}. Such an RF applies to a quiescent environment after decontamination, neither of which conditions necessarily apply to the betatron buildings nor the rest of the GSI facilities, especially during the period 7/1/1966–12/31/1973, since steelmaking activities continued until near the end of this period and the betatron buildings were still being used to radiograph steel castings. A higher RF would lead to proportionately higher inhaled activities.

3.2 Doses to Administrative Personnel from External Exposures

We are in complete agreement with NIOSH about the assignment of photon exposures of administrative personnel, with the understanding that the resulting doses shall be assigned only if it can be conclusively established that the employee performed administrative functions, that the employee's work station was remote from the production areas of the plant, and that the employee did not frequently enter the production areas.

3.3 External Exposures of Plant Personnel During the Radium Era

We are in agreement on estimating annual doses from external exposure of nonadministrative personnel based a triangular distribution, with a lower limit of 6.279 rem, a mode of 9.69 rem, and a maximum of 12 or 15 rem, depending on the year. However, we believe that upper bound of the distribution should be reduced from 15 rem to 12 rem starting in 1961, not 1959, since the lower AEC limits did not take effect until January 1, 1961. Furthermore, we believe that the 6.279, 9.69, 12 rem distribution should apply through 1962, not 1963, since the Radium Era ended with GSI's acquisition of ^{60}Co sources in May 1962.

3.4 External Exposures of Plant Personnel from the Operation of the New Betatron

We believe that the limiting photon exposures of nonadministrative personnel to radiation during the period 1963–June 30, 1966 should be based on the exposure of the layout man to stray photon radiation from the New Betatron—NIOSH applies doses derived from this scenario to the period 1964–June 30, 1966. We disagree with the NIOSH analysis of this scenario: our derived doses are more than twice as high as those calculated by NIOSH. Our analysis shows that the limiting neutron exposures are of the betatron operator, who is estimated to have received slightly higher neutron doses than the layout man. Our calculated neutron doses from either scenario are over three times as high as the maximum neutron dose estimated by NIOSH.

3.5 Skin Doses from Beta Rays

Based on our analyses, we agree with NIOSH that the exposures of the betatron operator to beta radiation constitute bounding scenarios for doses to the skin. However, our calculated doses range from 12% to 258% higher than those listed by Allen (2013b) for corresponding areas of skin and corresponding time periods.

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Attachment 1

3Z CONSULTING INC

To: Bob Anigstein, SC&A
From: Joe Zlotnicki
Date: Tuesday, March 05, 2013
Subject: GSI and Landauer "Control" dosimeters

This memo serves to document recent discussions and email correspondence that I had with you and with Landauer personnel regarding General Steel Industries and the methodology Landauer used to manage control dosimeters.

On 2/21/13 you wrote to me with the following questions that documented our prior phone call:

1. Please clarify that the dose derived for the unnumbered control badge dose is subtracted from all other film badges, including itself, which is why it is almost always reported as "M." It is the actual derived (but unreported) dose that's subtracted, not the M. Please explain the reason for this practice.

2. Best guess regarding the identity of the "BETATRON CTL" badge, badge #001. This badge disappeared in the reports from about March 1966.

3. Historical practices 1963-1966.

I spoke with Dr. Craig Yoder at Landauer on 2/26/13 and the following description of historical film practices at Landauer is based on my knowledge and that discussion:

<u>Underlying information common to film technology</u>

Film dosimetry was complex and there were a number of industry-wide practices and Landauer-specific procedures that were used to address shortcomings in the technology. It is important to understand some of these issues in trying to understand specific practices with Control dosimeters. In addition, nomenclature varied within the industry and differs from other laboratory practices. For example, *spike, control, process control, QC, blank* and *calibrate* need to be viewed with caution as they can have special meanings in the Landauer or industry vernacular.

Film was purchased in batches and developed an increase in base fog (optical density, or O.D.) over time. This increase in base optical density is due to inherent chemical/thermal and radiation processes. Each batch (or emulsion) had a unique tracking number and all processes and procedures were based both on the emulsion and unique chemical processing batch when the dosimeter was developed.

The nature of film technology is that the sensitivity of the film plus densitometer has a minimum step function of about 6 mR (at Cs-137 energy). This corresponds to a change of 0.02 O.D. Thus the reading process is quantized in increments of 6, 12, 18 mR, etc. This is important when considered in tandem with Landauer's rounding and definition of "M" practices that are discussed below.

The densitometer sensitivity was typically ±0.02 optical density while the base fog was about 0.3–0.4. It is clear that statistical swings on the order of 10mR can be caused by small variations from film to film and in chemical processing, etc. It was only with great care and consistent practices that 10mR was utilized as the minimum reportable dose. As the film aged (say 4–6 months from manufacture) it became increasingly difficult to achieve the minimum detectable/reportable. (It is outside the scope of this discussion, but as photon energy has a very large impact on film sensitivity, lower energy x-rays were easily detected at this level whereas high energy gamma was probably only detectable at the 10-mR level under optimum circumstances.)

Landauer Procedures

To correct for base fog, Landauer had several procedures and practices. First, film was always identified by emulsion (batch). Blanks, controls and calibration film were all selected from the same emulsion for a given client film dosimeter. This way, the underlying aging process would largely be the same for in-house Landauer process control dosimeters and client dosimeters. Of course, storage conditions were not identical but at least the film had the same age and underlying properties. Note that film had a relatively short shelf life due to base fog build up and could not be re-zeroed as OSL and TLD can be.

As part of the process for calculating dose, Landauer subtracted the base fog density from all dosimeters in a group of film by utilizing process blanks. Calibration spikes and customer controls had this blank value subtracted prior to use in defining the dose response curve and process zero for the densitometers. In a normal situation, this meant that client controls that were stored in a low background would report as Minimal, or effectively zero.

Control badges were issued to clients to address several concerns. Primarily, they were to ascertain if the dosimeters were exposed in transit going to or from the client site. For larger clients, several controls were sent with the outbound shipment to ensure that spare controls were available when late badges were returned. If everything worked normally, then fog and background subtraction were addressed by Landauer in-house blanks that were subtracted from ALL badges including client control badges. If any residual "dose" remained on the client control (presumably due to transit exposure or elevated natural background) then this was subtracted from the batch of client badges. Effectively, the Control badge was set to zero.

If there were a slight difference in dose between in-house base fog blanks and client badges, then it is possible that a plus or minus 6 mR would be measured on a given badge. However, negative doses were not recorded as such and were assigned a zero. Close oversight was maintained on the statistical batch of film and the distribution of net optical densities was tracked to look for anomalies.

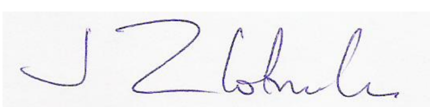
The procedure for defining a "Minimal" dose is important and potentially confusing. All measured client doses were rounded down at 9 mR or less. Thus a 9 mR becomes a Minimal whereas a 10-14 becomes a 10 mR. 15-24 becomes 20 mR, etc. So the unusual rounding practice only applies to the less than 10mR reporting. This process applies to all badges including Control badges. If the Control showed a dose in excess of 50 mR, then a message would have been printed on the report indicating that fact. This was a rare occurrence for any client.

Landauer Numbering Protocol

All Control badges in the Landauer system were given a "0000" I.D. Any other number was not a Control, regardless of the name on the badge. Some clients put "Control" or "CNTL" in the name field for their own purposes, most commonly to monitor the x-ray or accelerator control room as an area monitor. However, the Landauer computer system was programmed to only use a 0000 designation as a Control. Any other badge would have been reported normally after Control subtraction.

Please let me know if you have any additional questions or concerns,

Sincerely,



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