Draft White Paper

REVIEW OF NIOSH REPORT ON PORTABLE RADIOGRAPHY SOURCES AT GSI—AUGUST 2011

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REVIEW OF NIOSH REPORT ON PORTABLE RADIOGRAPHY SOURCES AT GSI—AUGUST 2011	Page 2 of 22
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Review of NIOSH Report on Portable Radiography Sources at GSI—August 2011

In a report issued in August 2011, Allen (2011) estimated doses from the portable radiography sources used at the General Steel Industries, Inc., (GSI) steel foundry in Granite City, Illinois, during the period that GSI was under contract to the Atomic Energy Commission (AEC) (1953–1966). Much of the information is from AEC licensing documents and correspondence which are posted on the Nuclear Regulatory Commission's Web site, and which can be accessed through ADAMS, the NRC document retrieval system. At its meeting on October 12, 2010, the Work Group on TBD-6000 indicated that it expected SC&A to perform a review of the forthcoming NIOSH report on portable radiography sources at GSI. We have accordingly reviewed Allen's report and have a number of comments, observations, and findings.

1 Review

We will first present a review of the report, discussing each issue presented by Allen (2011). We confine the discussion to issues with which we are not in agreement.

1.1 Background

Allen (2011, section 1.0) stated: "In this paper, R (and mR) is used interchangeably with Rem (and mRem) [*sic*]." Furthermore, in a footnote, Allen added: "Although it is recognized that the Roentgen [sic] is a measure of exposure to air and the rem represents dose to the body, for photon x-rays, they are considered to be sufficiently close numerically so that they can be used interchangeably." We disagree with this assertion. Although there is some looseness in the usage of these terms, we do not agree that these quantities are "sufficiently close." Table 1 lists the conversion coefficients for exposure and ambient dose equivalent (H*[10]) per unit photon flux, as a function of photon energy. The ratio of H*(10) (in mrem) to exposure (in mR), ranges from 0.01 to 1.54. In the dosimetrically important region of 30–250 keV (0.03–0.25 MeV), the average ratio is 1.33. This is not an insignificant distinction, given the fact that we have observed a number of dose reconstructions with a POC in the range of 49%–50%. If a measured or calculated exposure value in mR is interpreted as a dose in mrem, the resulting value is not claimant favorable. Given the availability of conversion factors, such as those in Table 1, and the ease of performing these calculations, we do not agree with Allen that "an attempt to distinguish between them [is] impractical."

1.2 X-ray Units

Two 250-kV x-ray machines were listed in an auction notice involving the liquidation of the GSI Granite City facility (Rabin 1973). One was described as a "GE x-ray, model OX-250, industrial size," while the other was an "Andrex x-ray unit, model A1652 . . . 250 kV 8 mA directional unit." Although the tube current of the G.E. machine is not listed, we can infer it from Beatty and Clark (1955), who reported using a G.E. model OX-250 industrial x-ray unit operating at 250 kV and 15 mA to irradiate laboratory mice.

Table 1. Exposure vs. Ambient Dose Equivalent

E (MeV)	Exp/φ[a] (mR cm^{2})	H*(10)/φ[b] (mrem cm^{2})	Ratio
0.01	8.52e-07	6.10e-09	0.01
0.015	3.58e-07	8.30e-08	0.23
0.02	1.93e-07	1.05e-07	0.55
0.03	8.27e-08	8.10e-08	0.98
0.04	4.92e-08	6.40e-08	1.30
0.05	3.70e-08	5.50e-08	1.48
0.06	3.31e-08	5.10e-08	1.54
0.08	3.52e-08	5.30e-08	1.51
0.1	4.25e-08	6.10e-08	1.43
0.15	6.87e-08	8.90e-08	1.30
0.2	9.82e-08	1.20e-07	1.22
0.25[c]	1.28e-07	1.50e-07	1.17
0.3	1.58e-07	1.80e-07	1.14
0.4	2.17e-07	2.38e-07	1.10
0.5	2.73e-07	2.93e-07	1.07
0.6	3.26e-07	3.44e-07	1.06
0.8	4.23e-07	4.38e-07	1.04
1	5.13e-07	5.20e-07	1.01
1.5	7.04e-07	6.90e-07	0.98
2	8.66e-07	8.60e-07	0.99
3	1.14e-06	1.11e-06	0.97
4	1.39e-06	1.34e-06	0.97
5	1.62e-06	1.55e-06	0.96
6	1.85e-06	1.76e-06	0.95
8	2.30e-06	2.16e-06	0.94
10	2.75e-06	2.56e-06	0.93

[a] Source: air kerma, listed by ICRP (1996, Table A.1), converted to exposure, using 0.00872 Gy/R

[b] Source: ICRP (1996, Table A.1), converted to mrem

[c] Values interpolated between 0.2 and 0.3 MeV

Allen (2011, section 3.2) calculated the dose rates from these machines on the basis of an equation relating the dose rates from the GSI x-ray units to the published dose rate from a comparable tube, the G.E. Isovolt 225 M2/0.4-3.0, adjusted for tube current and potential. According to GE (2004), the tube current of the G.E. Isovolt 225 M2/0.4-3.0 is 13 mA at its maximum tube potential, not 15 mA, as stated by Allen. Furthermore, the calculated dose rate at 1 m from the G.E. model OX-250, using the published parameters and Allen's methodology, is 18.42 Sv/h, or 30.7 rem/min, not 20.5 rem/min, as listed by Allen. The latter appears to be an error in calculation, since Allen's value of 16.4 rem/min for the Andrex unit, using the same methodology, agrees with our calculations. Although Allen does not use these calculated dose rates to evaluate worker exposures, we were obligated to verify his calculations as part of our review.

1.3 Radium

1.3.1 Radiation Exposures of Radiographers Employing ^{226}Ra Sources

In order to develop exposure scenarios for radiography with sealed sources outside the radiographic facilities (i.e., the two betatron buildings and the cinder-block structure in No. 6 Building), Allen (2011, section 4.1) discussed the safety practices that he assumed were followed at GSI during such procedures. He stated: "It was reported that when sources were used outside of the radiography room, an area was roped off at a distance 1.5 times the required distance [Neal R. Gross 2009, p. 136]." This observation was based on statements made by [redacted] who participated by telephone in the October 14, 2009, work group meeting. According to the transcript (Neal R. Gross 2009, p. 137), Mr. [redacted] had spoken to "the supervisor over at Isotopes" who furnished the information, which refers to a ^{60}Co source. Later during the meeting, in an attempt to estimate the source strength, Dr. Ziemer asked Mr. [redacted] what was the actual distance that was roped off. Mr. [redacted] responded: "I can't tell you what they roped off, sir. I was in the Betatron" (Neal R. Gross 2009, p. 325). In a following statement, Mr. [redacted] suggested that [redacted] might have first-hand information regarding this practice. Dr. Ziemer subsequently interviewed Mr. [redacted], a former GSI radiographer who was authorized to use sealed sources. According to Mr. [redacted] the "big" ^{60}Co source, which was referred to as the "80-Ci source," was used only in one of the betatron shooting rooms. "He further indicated that during these exposures, radiation surveys were made outside of the walls and doors of the betatron facilities, and areas found to be in excess of 2 mR/hr were roped off." Furthermore, "The small cobalt-60 source was only used to radiograph items in a separate 'small' building whose number he could not recall. He indicated that the area was not roped off for these exposures." (Ziemer 2010)

Allen (2011, sections 5.1 and 6.1) used Mr. [redacted] s account to create an exposure scenario for the use of the small ^{60}Co sources outside the radiographic facilities. In Allen's scenario, one of the sources was placed in an area inside one of the buildings that was accessible to non-radiation workers. Radiographers surveyed the area surrounding an exposed source to determine a contour line corresponding to an exposure rate of 2 mR/h, and then roped off an area of the floor that had a radius equal to 1.5 times the distance to the 2-mR/h isoexposure periphery. Allen assumed that the radiographer remained at this boundary during the radiographic exposure. However, the information furnished by Mr. [redacted] was most likely based on the use of the large source, as described by Mr. [redacted]. Since Mr. [redacted] recommended Mr. [redacted] as a source of first-hand information on this subject, the exposure assessments should be based on Mr. [redacted] s account, which invalidates Allen's assumed scenario. If such a practice was not followed for the small ^{60}Co sources, there is even less reason to assume it had been observed earlier, during the use of ^{226}Ra sources, which ended sometime after GSI procured ^{60}Co sources, ca. May 1962. For convenience, we will henceforth refer to this period as the "radium era."

Thus, Allen's exposure estimates are based on a practice that most likely did not exist. It is possible that the radiographer remained in the area to ensure that neither the source nor the film cassette was moved during the exposure, since this would affect the quality of the image. On the other hand, for an exposure of long duration, he could have been setting up an exposure using the second ^{226}Ra source, taking a break, or developing and inspecting the films from previous radiographic exposures. Thus, the actual distance of the radiographer from the source and his exposure geometry are topics of conjecture. Since there is no information regarding the position of the radiographer during the radiographic exposure, there is an insufficient basis for estimating the dose to the radiographer during this period of time.

Allen (2011, section 6.1) next estimated the exposure of the radiographer while he removed the source from the lead shield, walked to the steel casting, and placed the source in position. He based this part of the scenario on an interview with [redacted] that was conducted by the author of the present review (Allen 2011, Attachment B). Mr. [redacted], who was employed at GSI as a radiographer starting in 1956, had estimated that the source was 4–6 ft from his body, and that positioning the source required 12–15 s; replacing the source in its shield took a similar amount of time. Allen also assumed that the source was moved to the area in a shielded container. During his interview, Mr. [redacted] did not indicate that the shield was movable. He simply described lifting the source out of the shield using a string tied to the "fishpole" and walking with the source to the casting that was to be radiographed.

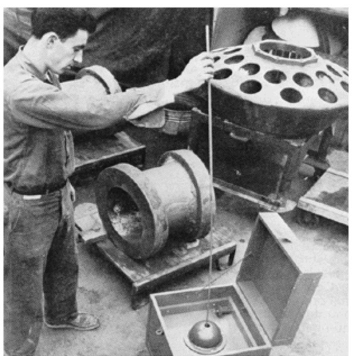

Figure 1. Source Being Removed from its Shield ("pig") (ORAU 1999)

Figure 2. The "Fishpole" Technique (Hellier 2001)

Allen (2011, section 6.1) used the midpoints of the ranges of distances and exposure durations to calculate the radiation exposure of the radiographer from this scenario. We disagree with this approach. One must keep in mind that this information is based on the recollection of a worker 55 years later. Figure 1 depicts a worker handling a source using the fishpole technique. This illustration indicates that the worker would be at arm's length from the source once it emerges from the shield. In another depiction of this technique, shown in Figure 2, the pole appears to be slightly longer than the worker's forearm. In both cases, the distances appear to be about 3 ft. Consequently, the lower bound of Mr. [redacted] estimate is more likely to correspond to the actual distance. To be claimant favorable, NIOSH should use the minimum distance of 4 ft. Similarly, given the range of exposure times based on Mr. [redacted] recollection, the maximum time of 15 s should be used in the exposure calculation. Based on a gamma radiation level of 8.25 R cm^2 h^{-1} mCi^{-1} (BRH 1970), we obtain an exposure rate at a distance of 4 ft from a 500-mCi ^{226}Ra source = 277.5 mR/h. Assuming 15 s to position the source and 15 s to replace it in its shield, 10 exposures per shift, and 406.25 shifts per year (based on the consensus work-hours of 65/wk), the exposure of the radiographer would be 9.39 R/y. This does not account for exposures while the casting was being radiographed.

Allen (2011, section 6.1) assumed that two radiographers shared the duties of positioning the sources. Mr. [redacted] made no mention of this, nor does it seem to be a plausible assumption. Given that the radiographer was actually handling the source for an average of 5 minutes per shift, it would be more appropriate to inquire what he did the rest of the time, not assume that he had a helper or a partner to share this brief duty. Since GSI had two ^{226}Ra sources, it was far more likely that he would set up one exposure, then proceed to another casting and repeat the procedure, making sure that the films were far enough apart and/or sufficiently shielded so that the source used for one radiograph would not expose the other film.

Allen (2011, section 6.1) justified his calculated annual dose of 3,573 mrem to the radiographer by noting that it was equal to 24% of the pre-1958 annual dose limit of 15 rem, and 30% of the quarterly limit of 3 rem in effect in 1958. He notes that this is consistent with the following statement made by GSI in its application to the AEC for the renewal of its byproduct material license submitted February 14, 1963:

> *Up to this time February 1, 1963 no formal written tests have been given. . . . During this period the exposure limits published by the A.E.C. at the applicable time were followed. They were never exceeded and averaged under 25%.* (NRC 2009a)

However, there is no documentation to substantiate this statement. There is no mention of any film badge dosimetry program until 1962, when GSI first applied for an AEC byproduct material license. Allen (2011, section 6.1) cites statements by former workers regarding the use of self-reading pocket dosimeters (SimmonsCooper 2006, pp. 54, 110; Rynders 2006b, p. 23). The workers in question were [redacted] and [redacted]—Mr. [redacted] started work at GSI in early 1964,[1] while Mr. [redacted]'s first film badge dosimetry report was for the week of 2/24/1964. Thus, neither of them were at GSI during the radium era and their statements regarding dosimeter use cannot be applied to that earlier period. The previously cited statement from the license renewal application is in contrast to the following, excerpted from the original AEC license application: "To date, we have used quite satisfactorily two 500 mg radium sources. These have been used with a fish pole technique with *little radiation exposure* [italics added] to our personnel." (NRC 2009b) "Little radiation exposure" is not consistent with exposures up to the then-permissible limit.

We conclude that there is insufficient information for assigning radiation exposures or doses to radiographers who used ^{226}Ra sources.

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[1] [redacted] former GSI employee, private communications with Robert Anigstein, SC&A, Inc., ca. 2007–2010.

1.3.2 Radiation Exposures of Workers Other than Radiographers from ^{226}Ra Sources

Allen (2011, section 6.1) derived doses to other workers at floor level from ^{226}Ra sources. He based the doses on the assumption that a "safe" area was under the surveillance of the radiographer during short exposures, and that a nonradiographer worked at the periphery of this area, but might have walked through this area when it was not under surveillance (i.e., during longer exposures, when the radiographer was assumed to leave the area to perform other duties). Since there is no evidence that such a safe area was roped off, such a scenario cannot be used to assign doses from ^{226}Ra to workers not involved with radium radiography. We thus conclude that there is insufficient information for assigning radiation exposures or doses to workers at floor level who may have been exposed to ^{226}Ra sources.

Allen (2011, section 6.1) also derived doses to crane operators who might have been exposed to ^{226}Ra sources. He assumed that the crane operator could be located anywhere between the two ends of the building. He then calculated the average distance between the crane operator and the location of the radium source and assigned the dose rate at that location to the crane operator. However, due to the inverse square law, the average dose rate is heavily weighted by the dose rates nearer to the source; consequently, the average dose rate over the trajectory of the crane is not the same as the dose rate at the average location. The average exposure rate for this scenario can be calculated by the following equation:

$$<R> = \frac{A\,\Gamma}{X} \int_0^X \frac{dx}{h^2 + x^2}$$

$<R>$ = average exposure rate over crane's range of travel
= 0.867 mR/h

A = activity of source
= 500 mCi

Γ = gamma radiation level for ^{226}Ra
= 8.25 R cm^2 h^{-1} mCi^{-1} (BRH 1970)

X = maximum horizontal distance
= 305 ft
= 9296.4 cm

h = height of crane operator above floor
= 25 ft
= 762 cm

The annual exposure from this scenario is calculated to be 845 mR, rather than 177 mrem, as calculated by Allen—a five-fold increase.

Allen (2011, section 6.1) also derived doses to workers on the roof of No. 6 Building who might have been exposed to ^{226}Ra sources, using the same assumptions and methodology as for the crane operator, except that the height above the floor was estimated to be 38 ft. Inserting Allen's parameters into the above equation, we derived an annual exposure of 540 mR, rather than 158 mrem, as calculated by Allen—more than a three-fold increase.

Although, as part of our review, we are obligated to check Allen's calculations, we do not agree with his description of these last two exposure scenarios. First, the crane mechanism is limited in how close it can approach to the end wall, so the 305-ft limit of travel is unrealistic. Furthermore, the crane did not travel at random, but would have stopped in certain locations (e.g., above the railroad tracks), to pick up a casting and would then deposit it near the radium source to be radiographed. Similarly, workers on the roof would be performing specific tasks—e.g., servicing ventilators—which might place them nearer or further from the exposed ^{226}Ra source than the location corresponding to the average exposure rate. Finally, the exposure could be up to twice as high as calculated by Allen if two sources were simultaneously exposed in nearby locations—a highly probable scenario. Thus, we find that the descriptions of these scenarios are not scientifically valid and may not be claimant favorable.

1.4 Radiography Room

Allen (2011, section 6.2.1), derived doses to various workers inside and outside the radiography room that had been specially constructed for use with the "small" ^{60}Co sources. We agree with the bounding calculations of doses to radiographers and to workers just outside the walls that were based on reports of radiation surveys included in the application for an AEC byproduct material license. However, we do not agree with Allen's calculations of doses to crane operators and workers on the roof that use the same methodology and similar assumptions as we discussed in section 1.3.2 of this review. Using Allen's assumptions about the location of the crane operator, we obtained an annual exposure of 390 mR for the operator, 10 times Allen's value of 39 mR. Similarly, we calculated the annual exposure of the workers on the roof to be 350 mR, rather than 38 mrem, as reported by Allen. We assumed that both ^{60}Co sources—280 mCi and 260 mCi—were exposed simultaneously, the same conditions that existed during the 1962 radiation survey that was reported in the AEC license application. Allen apparently assumed only one source was exposed. That assumption is inconsistent with his use of the survey data, which measured radiation levels from two exposed ^{60}Co sources.

The location of the radiographic facility inside the No. 6 Building is unclear. Allen (2001, Figure 3) shows a site map of GSI, reproduced from NRC (2009c, p. 37), which indicates that the radiographic facility is at the northwest end of the building. However, in a more detailed drawing, NRC (2009c, p. 10) depicts a work area inside the building that starts 20 ft northwest of the facility. Given this ambiguity, it would be more claimant favorable to assume the facility is centered between the two ends of the building, thus reducing the distance to the workers in the elevated locations and increasing the exposure rates. In no case could the sources be located 610 ft from one end of the building, as Allen assumed, since that would place them at the northwest wall, which is inconsistent with the drawings.

1.5 Co-60 Sources Outside the Radiography Room

Allen (2011, section 6.2.2), derived doses to various workers exposed to the "small" ^{60}Co sources being used outside of the radiography room. As discussed in section 1.3.1 of the present review, these sources were not used outside the radiography room in the No. 6 Building during the period of AEC operations at GSI. Consequently, such a scenario is invalid for the assignment of doses to GSI workers.

1.6 St. Louis Testing Sources

Allen (2011, section 6.3) derived doses to GSI workers who may have been exposed to sources used by St. Louis Testing, who performed radiography using sealed sources outdoors on the GSI site. He bases the exposure scenario on the assumption that GSI employees would have remained outside the 2-mR/h perimeter established by St. Louis Testing personnel during the radiographic exposures. Ten radiographic exposures of 180 h each were performed in a 6-month period; extrapolating to one year we obtain 3,600 hours of exposure (10 x 180 h x 12 mo/y ÷ 6 mo = 3,600). Thus, the sources were exposed 41.07% of the time over the course of one year (3600 h ÷ 8766 h/y = 0.4107).[2] A GSI employee who remained at the boundary during his entire work-year would receive an exposure of 2,669 mR (2 mR/h x 0.4107 x 65 h/wk x 50 wk/y = 2,669 mR).

Allen (2011, section 4.3) stated: "Two radiographers working 12 hours shifts kept the area under constant surveillance . . . ." and again in section 5.3: "The boundary was continuously watched to prevent personnel from entering the area." This was based on a misinterpretation of the procedure followed by St. Louis Testing. Anigstein (2010, section 1.1.2) interviewed Paul Sinn, former administrator at St. Louis Testing, who furnished the original information. Mr. Sinn said that there was one radiographer per 12-h shift. With only one radiographer on duty, there would have thus been times when the area was unattended while he took necessary breaks. Some GSI workers could have intruded into the exclusion area, receiving an exposure greater than at the boundary. To estimate the exposure from such an intrusion, we assumed that the 10-Ci ^{60}Co was unshielded, in which case the exclusion zone would be a circle with a radius of 81.24 m. We then assumed that a worker crossed this zone, starting at the periphery, walking in a straight line at an arbitrary angle to the diameter of the circle. Varying the angle in 1,000 increments, from 0.09º to 90º, and assuming a walking speed of 3 mph, we used the equation in section 1.3.2 of this review to calculate an average incremental exposure of 0.8 mR for a round trip, from one side of the boundary to the other, in addition to the exposure the worker would have received if he had remained at the boundary. There would thus be an additional annual exposure of n x 133 mR, where n is the number of round-trip intrusions per shift (0.8 mR x 406.25 shifts/y x 0.4107 ≈ 133 mR). Since such an incursion would only occur when the St. Louis Testing radiographer was away on a break, it is unlikely that the average frequency of occurrence would be more than one per shift. Consequently, we conclude that a bounding exposure of GSI employees to the radiography sources employed by St. Louis Testing would be ~2.8 R/y (2.669 + 0.133 ≈ 2.80), which is numerically similar to Allen's value of 2,771 "mrem."

However, we do not agree with Allen's assumption that this exposure should be only assigned to radiographers, and that other workers should be arbitrarily assumed to be at the 2-mR/h boundary for only one-half the time. Given the uncertainty of this scenario, this bounding value should be assigned to all workers.

[2] We note that Allen (2011) used a figure of 8,750 h/y—a trivial error.

1.7 Dosimetry Data

Allen (2011, section 7.0) discussed the use of ionization chambers as pocket dosimeters at GSI. Although former workers, most of whom were first employed in the 1960s, attested to the use of such dosimeters, no records of dosimeter readings exist. Allen (2011, section 7.0) conjectured that such dosimeters were used at GSI during the radium era: "It is likely these [pocket dosimeter] logs were used by GSI as the basis for the statement in their initial AEC license application that the average dose was less than 25% of the AEC dose limits." However, there is no evidence to support such a hypothesis.

Allen (2011, section 7.0) correctly observed that a large majority of the Landauer film badge dosimetry weekly reports listed readings of *M*, or minimum. However, we question Allen's assertion that all the doses represented by these readings were less than 10 mrem, based on the following observations by Joseph Zlotnicki, CHP, (former Landauer official, currently member of SC&A staff):

> Following is my opinion regarding the Landauer film dosimetry MDL for high energy photons (>250 keV):
>
> While a film dosimeter can readily measure 10 mrem of low energy photons, it is a much more difficult task once the photon energy reaches a few hundred keV or above. The overresponse of the film emulsion to x-rays around 40 keV by a factor of 30 was a blessing and a curse for film badge dosimetry and was one of the reasons that film has largely been replaced.
>
> It is very difficult to say what the MDL would be for high energy photons, but it almost certainly was higher than 10 mrem, even on a good day. Below are some of the factors that one would need to consider in deriving the MDL. Note that some items are systematic and some vary day to day and person to person.
>
> - Film type
> - Base fog (age since manufacture and storage conditions)
> - Processing
> - Storage during the issuance period
> - Background radiation levels
> - Storage and handling of background, calibration, and control film
> - Densitometer calibration, sensitivity, and step size per density unit
> - Calibration methods, energy, and lowest dose point
> - Rounding and truncation preference
> - Film holder design
> - Wear location on body (backscatter)

> As can be seen, there are numerous sources of variation. Based on my experience, a single click (i.e. the smallest quantum of dose) on a good densitometer would have been on the order of 15 mrem for high energy photons. Remember, 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." The subtraction was probably done in terms of dose, not density, however. In other words, the density on the two films being compared was converted to dose and subtracted in the dose, not density, domain.
> Other film system reviews have recommended using 40 mrem as the MDL, including the National Research Council report on atmospheric testing and ORAU reports on DOE sites. This might be a little high for Landauer's system, but 20 mrem to 30 mrem might be a better choice than 10 mrem for high energy photons.

Thus, a worker with 50 weekly readings of *M* might have theoretically received a dose of 1 to 1.5 rem during this period.

2 Conclusions

2.1 Exposure Assessment During the Radium Era (1953–1962)

In our opinion, there is insufficient information to allow NIOSH to reconstruct doses during the time GSI used ^{226}Ra sources to radiograph steel castings: 1953–1962. There are no existing records of radiation exposures during this period. There is also no documentation of an effective radiation safety program during a time when neither AEC nor the State of Illinois exercised any oversight over this facility. In the cover letter to the initial application for an AEC Byproduct Materials License, L. A. Klieber, Vice-President, Manufacturing, of GSI, states: "The State of Illinois has requested that we take immediate steps to discontinue the use of our radium sources using the fishpole technique (NRC 2009b)." This appears to be the first instance of State supervision over the radiography program, and it consists of firm disapproval of existing practices. We further observe that industrial radiography using the fishpole technique is currently prohibited (unless specifically authorized) by the radiation safety regulations of the States of Delaware, Georgia, Iowa, Massachusetts, New Mexico, North Dakota, and West Virginia, and totally prohibited in Minnesota. This observation, coupled with the action taken by Illinois, is a strong indication that the technique is not considered safe.

Furthermore, there are independent accounts by several former GSI employees about the unauthorized removal of a ^{226}Ra source from the plant. One account of this incident was related to the author of this review by [redacted] in the course of an interview on October 10, 2010. Mr. [redacted] volunteered this information at the end of the interview. Since the purpose of the interview was to obtain information about the fishpole technique, the removal of the ^{226}Ra source was not mentioned in the memo summarizing the interview (Allen 2011, Attachment B). According to Mr. [redacted], a metallurgist and a chemist were involved in flying over Granite City in an airplane and using a Geiger counter to locate the source. This was confirmed by [redacted] at a workers' outreach meeting (Rynders 2006a). According to Mr. [redacted], who was a metallurgist, [redacted] went up in the airplane. In the original GSI application for an AEC byproduct material license (NRC 2009b), [redacted] was identified as a [redacted] Metallurgist who has a B.S. degree in chemistry, which is consistent with Mr. [redacted] and Mr. [redacted] accounts. Mr. [redacted] further stated that the source was located from the airplane at an altitude of 200 ft. According to our calculation, a 500 mCi ^{226}Ra source would produce an exposure rate of 111 μR/h at that distance. Given typical exposure rates of 5–10 μR/h due to natural background, it is entirely plausible that the source would have been detected from the airplane. A third confirmation is by [redacted] who was described as a foreman with several months' experience with radium and the betatron (NRC 2009b). Mr. [redacted] in an e-mail to [redacted] an advocate for the GSI workers, confirms the theft of the source that looks like a plumb bob (see Attachment 2). The fact that such an event could take place calls into question the effectiveness of the GSI radiation safety program during the radium era.

2.2 Exposure Assessment of Radiography Using Sealed Sources: 1962–1966

We agree that the limiting exposure of GSI radiographers to sealed sources following the radium era, which ended in May 1962, would be to the sources brought to the GSI site by St. Louis Testing. We believe that the limiting exposure should be 2.80 R/y, which is slightly higher than the 2.671 rem/y assigned by Allen (2011). However, we do not agree that the limiting exposure of nonradiographers should be 1.336 rem/y. There is no sound basis for assuming that nonradiographers would be exposed for one-half as long as radiographers, or that GSI radiographers assisted St. Louis Testing personnel in radiographing castings. Mr. Sinn, administrator of St. Louis Testing, made no mention of this at the meeting of former workers ("Dr. Robert Anigstein . . ." 2007). We therefore find that all workers should be assigned a limiting annual exposure to sealed radiography sources of 2.8 R after May 1962. This is particularly relevant to nonradiographers, for whom there are no radiation exposure records.

2.3 Use of Film Badge Dosimetry Records

Only 89 of several thousand GSI workers were monitored with film badge dosimeters. Thus, the radiation exposures of this small number of workers cannot be used to characterize or limit the potential exposures of unmonitored workers. Since it would be unreasonable to assign radiographers *lower* doses than nonradiographers, all former GSI employees should be assigned the same limiting exposures to sealed sources.

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Attachment 1

ADVISORY BOARD ON RADIATION AND WORKER HEALTH

Summary of a Telephone Interview of a Former General Steel Industries Worker
Conducted by Paul L. Ziemer
Report Date: December 10, 2009
Revised February 5, 2010

Introduction

The Special Exposure Cohort (SEC) Petitioner for General Steel Industries (GSI) provided to the ABRWH the name of an individual who could provide additional information concerning the use of radiography sources at the GSI facility in Granite City, Illinois. On December 7, 2009, at 6:50 pm EST, Paul L. Ziemer, Chairman of the ABRWH contacted that individual, [redacted] by phone. Dr. Ziemer explained that he was calling at the suggestion of the GSI SEC petitioner and that the purpose of the call was to gain additional information on the safety practices relating to a sealed Co-60 source and what had been identified to the Board as a sealed Ir-192 source that had been used at the site for radiography. Dr. Ziemer also indicated that the he was seeking to clarify information concerning the activity of those sources in order to assist the Board in determining the feasibility and reliability of worker dose reconstructions carried out by NIOSH. Mr. [redacted] agreed to share his recollections concerning the uses of those sources.

A draft report was prepared on December 10, 2009, and sent to Mr. [redacted] for review. In late January, 2010, Dr. Ziemer received word that Mr. [redacted] had some corrections in the draft. Dr. Ziemer spoke with Mr. [redacted] by phone on February 2, 2010, and obtained supplemental information and corrections to the draft. This revised report reflects those changes.

Information Provided by [redacted]

Mr. [redacted] stated that he had worked at General Steel Industries during the time period of 1963 to 1973. He indicated that he had worked with both sources and that he was very familiar with the procedures used and the locations involved. He volunteered the following details on each source:

Cobalt-60 ("big" source):

1. The source was always referred to as an 80 curie source. He was unsure of any independent documentation or certification of that amount, but stated that it was always identified and referred to by that nomenclature.

2. He confirmed the information that we had previously received from a site expert, namely that the practice when the source was in use was to rope off the restricted area at the 2 mR/hr level as measured with a survey meter. Dr. Ziemer had originally thought that if Mr. [redacted] could provide an estimate of what physical distances were used to achieve the 2 mR/hr level, a back calculation could be used to provide a confirmation of source activity. However, Mr. [redacted] indicated that for the big

Co-60 source, distance alone was not used. He stated that the source was always used within one or the other of the betatron rooms and that during the exposures the rooms were locked and unoccupied. Thus some shielding was provided by the walls of the betatron rooms. Normally the "big" source was used in betatron room of Building 11. When the source was exposed during radiographic procedures, the radiation levels inside the Betatron Room were off-scale on the survey meter, and were above the 2 mR/hr limit in the Control Room. Thus, the operator(s) went outside of the Control Room to another part of the building (or outside the building) during the cobalt-60 exposures. He further indicated that during these exposures, radiation surveys were made outside of the walls and doors of the betatron facilities, and areas found to be in excess of 2 mR/hr were roped off.

3. Mr. [redacted] indicated that after each use he conducted an area survey to confirm that the source was back in its storage shield.

Cobalt-60 ("small" source):

1. Mr. [redacted] stated that the "small" source was also cobalt-60 and was nominally identified as being a 0.25 curie (250 millicurie) source. He further identified it as an "old" source that may have gone through a number of half-lives so that he believed the activity could be lower than 0.25 curies when he was using it.

2. The small cobalt-60 source was only used to radiograph items in a separate "small" building whose number he could not recall. He indicated that the area was not roped off for these exposures.

Mr. [redacted] was asked if he was aware of any "incident" involving sources outside of the 10 Building involving the St. Louis Testing Company. He indicated that the St. Louis Testing Company did do some radiographic work on the site but that they had their own sources and procedures. He was uncertain about the identity and activity of sources that they used. He provided no information on the "incident." He indicated that he thought that they followed the practice of roping off the restricted area at the 2 mR/hr level.

When asked if he was aware of any AEC inspections conducted at GSI, Mr. [redacted] indicated that there were inspections but that he was not privy to the findings provided to GSI.

Another piece of information that Mr. [redacted] provided was that all of the radiography source operators were required by the AEC to have complete 40 hours of operational and radiation safety related training in order to be authorized to use the sources. Also they were required to receive annual refresher training that was much briefer.

Mr. [redacted] indicated that in addition to the survey meter, he was provided with a film badge, a pocket dosimeter, and a "chirper." The chirper was described as being similar to a pocket dosimeter except that if responded to dose rates by making a chirping sound.

Confirmation of Information

As indicated in the Introduction, a draft of the original report was sent to Mr. [redacted] for review prior to its release to the ABRWH. Dr. Ziemer requested the Mr. [redacted] confirm the report as a correct summary of their telephone conversation or to otherwise indicate appropriate corrections that should be made. Changes were subsequently made, and a revised draft dated February 5, 2010 was sent to Mr. [redacted] for review.

Attachment

Attached is a statement by [redacted] indicating that he agrees that the revised report correctly and fairly summarizes the information that he provided (or specifies additional corrections that should be made in the report).

Report prepared by:

____

Paul L. Ziemer, Chairman, TBD 6000/6001 Work Group
Advisory Board on Radiation and Worker Health

Attachment 2

Subj:	**Fwd: "Stolen" plumb bob in 10 Building**
Date:	5/21/2011 11:52:49 PM Eastern Daylight Time
From:	*[redacted]@sbcglobal.net ([redacted])*
To:	*jmauro@scainc.com (John Mauro), anigstein@verizon.net, Anigstein@cs.com*

FYI: [redacted]

Begin forwarded message:

> **From:** [redacted]
>
> **Date:** February 7, 2011 7:19:31 PM CST
>
> **To:** [redacted] [redacted]@sbcglobal.net>
>
> **Subject: Re: Fwd: "Stolen" plumb bob in 10 Building**
>
> [redacted] the plumbob looks like the ones we used.And yes they were used in any building that they needed to hasen the job.The man that stole the source was either a chipper or a grinder I am not sure and I am not too sure just how long it was gone before he led the authorities to it. I did find my film badge it's # is [redacted] and was rented from R S landaur Jr. and co. Matteson Ill.

[redacted]

From: [redacted] [redacted]@sbcglobal.net> To: [redacted] [redacted]@yahoo.com> Sent: Sun, February 6, 2011 10:01:30 PM Subject: Fwd: "Stolen" plumb bob in 10 Building

Begin forwarded message:

> From: [redacted] [redacted]@sbcglobal.net> Date: February 3, 2010 11:27:53 PM CST To: [redacted]@yahoo.com> Cc: [redacted] <[redacted]@charter.net>, [redacted] <[redacted]@sbcglobal.net> Subject: "Stolen" plumb bob in 10 Building
>
> [redacted] I hope all is well. The input you gave us has proven most helpful. Your photo below turned out "Great"!

Note the (Bendix) Dosimeter "pen" in [redacted] s pocket, "Just like the other GSI workers told us" (no records so far).

Your information regarding the **"Stolen" plumb bob** in 10 Building really got [redacted] and my attention when we all met for breakfast.

We had heard the story before but your "first hand details" were very helpful. Knowing where this happened was most informative. We shared your concerns about using sources "in various parts of the Plant" . Now we have additional confirmation (yours & many other workers) that #6 Building and The Betatron Buildings were not the only NDT testing areas.

Did you say the man who took the source was a grinder ? How long did it take to locate the stolen source? Does this look like the plumb bob that was used at GSI ?

Please consider joining "some of the GSI workers" for lunch. You will know some of them.

Thanks, [redacted]

AUTHOR'S NOTE:

PHOTOS DELETED TO AVOID REVEALING PERSONAL IDENTITY