Draft White Paper

UPDATE ON THE USE OF SEALED RADIOACTIVE SOURCES AT GENERAL STEEL INDUSTRIES

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Update on the Use of Sealed Radioactive Sources at General Steel Industries

During its meeting on September 20, 2011, the ABRWH Work Group on TBD-6000 assigned several action items to SC&A, including follow-up interviews with [redacted] site experts: [redacted], a former General Steel Industries (GSI) [redacted], and [redacted], a former administrator of St. Louis Testing Laboratories (SLTL). We were also asked to obtain descriptions and/or illustrations of the radiographic cameras (containing sealed sources) identified in GSI's AEC byproduct material license applications. We were later directed by Ted Katz, Designated Federal Official to the ABRWH, to interview [redacted], a former [redacted] at GSI, as well as [redacted], former [redacted] of Nuclear Consultants Corporation (NCC).

The purpose of conducting these interviews and collecting other information was to determine the degree of administrative control that was exercised over the use of portable radiation sources at GSI. The information which we acquired casts a new light on this subject. The present report comprises the following parts:

- the main body of the report, which presents a summary of the information that was collected and discusses the implications and conclusions regarding the radiation safety practices with respect to sealed sources used for radiography;
- Appendix A, which contains detailed reports of interviews with four site experts;
- Appendix B, which presents the details of the calculations of exposure and dose rates from the use of ^{226}Ra sources in the radiographic facility in No. 6 Building;
- Attachment 1, which contains part of the radiation exposure record of [redacted], a former GSI worker; and
- Attachment 2, which contains a brochure describing the Radionics radiographic cameras, one of which was procured by GSI in 1968.

1 Film Badge Dosimetry

A question had been raised about the use of film badge dosimeters at GSI prior to November 1963, when dosimetry records obtained from Landauer indicated that film badges had been furnished to the facility. During the recent interview, [redacted] stated that he always used a film badge when he worked as a radiographer (section A.1).[1] He recalled starting work at GSI in 1953, later going [redacted], and returning to GSI [redacted] in 1956. His "Occupational External Radiation Exposure History" (Attachment 1) indicates a period of exposure at GSI of 18 quarters up to [redacted], 1962. He stated that he started to work as a [redacted] at GSI only after he returned from [redacted]. This work was done on weekends—it was in addition to [redacted] Monday–Friday [redacted] in the laboratory, which involved no radiation exposure. If we assume that his period of radiation exposure spanned 18 contiguous quarters ending in the last quarter prior to the date of the report, then his exposures would have started during the quarter that began on July 1, 1957. Thus, we can conclude that film badge dosimeters were in use at GSI by that time.

[1] All sections starting with "A" are found in Appendix A.

In addition, Figure 1 shows a photograph of a General Steel Castings (former name of General Steel Industries, Inc.) worker wearing what appears to be a film badge on his belt. Since he appears to be wearing a T-shirt which most likely did not have a pocket, it is quite plausible that he would have worn the film badge on his belt. This photo appeared in a 1953 General Steel magazine (House 1953) and is assumed to have been taken at that time. The outline of the film badge and the open window resembles the Tracerlab film badge illustrated in Figure 2, which was used in the late 1940s and 1950s. Together, this evidence indicates that film badge dosimeters were used at GSI as early as 1953, which is the first year of the covered period. This lends credence to 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, p. 26)

In our earlier report (Anigstein 2011), we questioned this statement, since, without a film-badge dosimetry program, GSI would have had no basis for such an assertion. Given that such a program had been in place and that the records were presumably available for inspection by

Figure 1. William Greer at the Control Board in the Betatron Building (House 1953)

Figure 2. Tracerlab Film Badge (late 1940s, 1950s) (ORAU 2009)

AEC, this claim appears to be credible.

According to [redacted], NCC furnished film badges that it procured from Landauer to monitor GSI workers during the time he was a radiation safety consultant to GSI in 1962–63. He no longer has those film badge dosimetry records. [redacted] could not recall any instance of a GSI worker being “overdosed” during the time he was involved with that facility.

It was common practice for Landauer, especially in its early years, to provide film badge services to consultants who then furnished the badges to their clients. In such cases, the accounts and records would be maintained under the name of the consultant.[2]

Landauer has furnished NIOSH an index of clients to whom they provided film badges during their early years. Inspection of these records does not show any entries for "Nuclear Consultants," "Konneker," or Mallinckrodt,[3] or any plausible variant of these names, during the years in question, nor for GSI prior to November 1963. The possible explanations are that [redacted] might have been mistaken about his use of Landauer film badges, or he might have obtained the film badges through a middleman who had an account with Landauer. However, we could not identify any plausible source of Landauer film badges among the Landauer customers in the St. Louis area (where NCC was located) during the years in question.

2 Use of Radium Sources

2.1 Information From Worker Interviews

[Redacted] stated that ^{226}Ra sources were stored and used inside the special radiographic facility in No. 6 Building. In an earlier interview, he noted that they were kept in No. 6 Building "99% if not more."[4] In a follow-up interview, he said they were used outside that facility "once in a blue moon" (section A.1.2). He clearly remembered that the radiographic facility was there when he returned from [redacted] in 1956, and may have been there when he started in 1953. Mr. [redacted]'s background is summarized in GSI's original application for an AEC byproduct material license as follows:

> Mr. [redacted] has had over 2 years experience in radiography at General Steel Industries doing standard x-rays, 24 MEV betatron and 500 mg sources of Ra 226, some informal training and courses as listed above (NRC 2009b, p. 18).

Furthermore, Mr. [redacted] stated that he was a "[redacted]"[4] We conclude that Mr. [redacted] is a knowledgeable source of information and appears to have a clear recollection of his work at GSI.

A somewhat different account was provided by [redacted], who said the source was taken "anywhere they needed it." It may be instructive to compare Mr. [redacted]'s and Mr. [redacted]'s activities at GSI. We note the following description of Mr. [redacted]'s position and duties that appears in AEC Form 313, dated February 1, 1963, part of the GSI application for renewal of its byproduct material license (NRC 2009a, p. 17):

> We further request the addition of Mr. [redacted] to our license as an approved Radiographer. Mr. [redacted] has attended the lecture course mentioned above

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[2] Joe Zlotnicki, SC&A Associate and former vice-president of Landauer, private communication with Robert Anigstein, SC&A, Inc., October 2011.

[3] NCC became a division of Mallinckrodt in 1966.

[4] [Redacted], private communication with Robert Anigstein, SC&A, Inc., October 9, 2010.

> and has been judged by Messrs. [redacted] as competent in the operation of all our radiographic and monitoring devices. He is a [redacted], assisting Mr. [redacted] in supervision of the Chemical & Testing Laboratory, and as a [redacted] should have access to and knowledge of our procedure. Although fully capable of being a "radiographer", he will not do any actual work as a radiographer. He has had several months experience with the Betatron and radium prior to our purchase of the Budd Co. Unitrons and Co-60.

During his first interview, Mr. [redacted] could not recall when he started work at GSI. During a follow-up telephone call on October 11, 2011, that I placed to elicit his comments and corrections to the draft interview report which I had sent to him, he placed the start of his employment at about 1955. He also remembered that the radiographic facility was there when he started.

We note that Mr. [redacted] was one of only [redacted] individuals authorized to act as radiographers under the original AEC license, while the request to add Mr. [redacted] was submitted later. Furthermore, Mr. [redacted] appeared to have a detailed recollection of the radiographic procedures, and was quite firm in his statements. Thus, while Mr. [redacted] was actively engaged in radiography, albeit only on weekends, Mr. [redacted]'s [redacted] appears to have been in the "Chemical & Testing Laboratory."

It would be illogical for GSI to have constructed a special radiographic facility and not used it. Performing radiography inside that structure would also appear to have been more efficient— the radiographer could set up the shot and go into the "office" inside the radiographic facility, or leave the building and lock the door behind him. There would be no need to perform a new radiation survey for each shot and to put up ropes and warning signs. It seems most likely that castings that could be lifted by a crane and would fit inside the radiography room (which was 18 ft wide and about 56 ft long) would be radiographed inside that facility, while the occasional oversize casting would be radiographed in another location. Mr. [redacted] described the cordoning off of a "safe" area while the sources were used outside the radiography room, which indicated an awareness of radiation safety. However, he was critical of the fact that, under such circumstances, the exposed source was not continually monitored: the radiographer would occasionally leave the area.

The preponderance of the evidence indicates that radiography using ^{226}Ra sources was primarily performed inside the radiographic structure in No. 6 Building. On the infrequent occasions that it was necessary to use the sources outside this facility, the radiographer cordoned off an area and kept other personnel outside the 2 mR/h isoexposure perimeter. Some incursions into the higher exposure area may have occurred when the source was left unattended. In our previous report (Anigstein 2011, section 1.6), we derived the exposure of a person intruding into a roped-off area surrounding a radioactive source. Applying the same method to the 500-mCi ^{226}Ra source, we derived an exposure of 0.07 mR for a single intrusion. This represents a trivial contribution to a worker's annual exposure.

2.2 Radiological Assessment of Radium Radiography

In our previous report (Anigstein 2011), we derived a bounding exposure of a radiographer transporting ^{226}Ra sources by means of the fishpole technique of 9.39 R/y. At that time, we did not have sufficient information to estimate [redacted] exposure while the radiography was in progress. We have learned from Mr. [redacted]'s most recent interviews that [redacted] spent much of the time that the exposure was in progress inside the radiographer's office—a small room inside the radiographic facility. We therefore performed an analysis of the exposure within that facility, using the MCNP radiation transport code. The external exposure and personal dose equivalent, $H_p(10)$, rates were calculated in two locations: the center of the office and 1 m outside the entrance to the facility. According to Mr. [redacted], it was possible to radiograph two castings simultaneously by placing sufficient shielding between the two sources to avoid exposure of the film from the adjacent source. We therefore modeled the source as 1 Ci of ^{226}Ra (two 500-mCi sources). A detailed description of the MCNP model is presented in Appendix B.

The results of the analysis are presented in Table 1. The annual work-hours are based on the consensus estimate of former GSI workers ("Dr. Robert Anigstein . . . " 2007). The exposure duration (i.e., the fraction of the time the ^{226}Ra sources were outside their shielded containers) was based on the initial AEC license application, which states that "[a] maximum of 30% of each shift is used for actual exposure" (NRC 2009b, p. 12). In the interest of a bounding assessment, the radiographer was assumed to remain in the office while the exposure was in progress; thus, the occupancy factor was assumed to be 100%.[5]

Table 1. Assessment of Exposure to ^{226}Ra in Radiographic Facility in No. 6 Building

Location	Annual work-hours	Exposure duration[a]	Occupancy	Exposure rate		Dose rate—$H_p(10)$	
				mR/h[b]	mR/y	mrem/h[b]	mrem/y
Office	3,250	30%	100%	0.303	296	0.333	324
Outside door			25%[c]	8.56	2,087	8.94	2,179

[a] Based on initial AEC materials license application (NRC 2009b, p. 12)

[b] Results of MCNP analysis

[c] "Partial occupancy factor" assumed in NRC 2009c, p. 6

Thus, a bounding annual exposure of a radiographer to ^{226}Ra sources, based on our exposure model, is estimated to be 9.69 R/y (9.39 + 0.296 ≈ 9.69), while the exposure of non-radiographers to ^{226}Ra is estimated to be ≈ 2.09 R/y.

Another approach to estimating the doses to radiographers from ^{226}Ra sources is based on Mr. [redacted]'s "Occupational External Radiation Exposure History" (Attachment 1). We note that [redacted] a whole-body dose of [redacted] rem over 18 calendar quarters, or an average annual dose of [redacted] rem. We also note that Mr. [redacted] performed radiography only on weekends—during the week [redacted] in the testing laboratory, where [redacted] not

[5] In reality, the radiographer sometimes left the facility to develop the film from a previous exposure, or for other reasons.

knowingly exposed to radiation and would therefore not have been wearing [redacted] film badge. We used the furnished information to estimate the doses to a hypothetical full-time radiographer. We assumed that a part-time radiographer received an average annual dose of 2.02 rem. To derive a high-end dose to a full-time radiographer, we assumed that a part-time radiographer worked one shift per weekend, 80% of the time. Thus, he would have worked 40 shifts per year. Based on this assumption, a full-time radiographer working 406 shifts per year would have received an annual dose of 20.5 rem (2.02 rem × 406 shifts/y ÷ 40 shifts/y = 20.5 rem). A low-end estimate is based on the assumption that a part-time radiographer worked two shifts each weekend, working such weekends 90% of the time. He would have thus worked 90 shifts per year, and the prorated dose to a full-time radiographer would be 9.1 rem/y, which is close to the dose derived from the exposure model described above.

Finally, we can base a bounding dose on the statement in the AEC license application, cited in section 1 of the present report: "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, p. 26) Although the actual limits were not stated, we assume that the standard was 15 rem/y prior to 1954. In 1954, the 5 × (n − 18) rem rule was adopted (lifetime dose of 5 rem for every year after the age of 18), with a quarterly maximum of 3 rem. An employee well past the age of 18 with no known prior exposure history could receive as much as 12 rem/y in the years following 1954. Therefore, a plausible dose limit would be 15 rem/y for 1953–1954, and 12 rem/y for 1955–1962. We observe that the three methods of estimating plausible upper bounds of exposures to ^{226}Ra yield values within the range of 9–20 rem/y.

2.3 Use of ^{60}Co Sources

Mr. [redacted] said that the ^{60}Co sources were used either in the radiographic facility in No. 6 Building or in one of the betatron buildings. They were rarely used in open areas. This is consistent with the account of [redacted], who was interviewed on the telephone by Paul L. Ziemer, then Chairman of the ABRWH, on December 7, 2009 (see Anigstein 2011, Attachment 1). Mr. [redacted], who was [redacted], stated that the small ^{60}Co source was only used to radiograph items in a separate "small" building, whose number he could not recall. His description fits that of the radiographic facility in No. 6 Building. It is also consistent with his earlier statement, that the ¼-Ci ^{60}Co source was used in the No. 6 Building.[6] On the other hand, Mr. [redacted] said that the radiographic cameras containing the ^{60}Co sources were lifted out of the radiographic facility by the overhead crane and taken to other locations, such as the No. 10 Building, as needed.

As stated earlier, Mr. [redacted] [redacted] original radiographers listed on the AEC license application. [redacted] first 18 workers who were issued film badges under the Landauer program, which started about [redacted], 1963. Mr. [redacted] and Mr. [redacted] were both issued their first film badges under the Landauer program the week of [redacted], 1964—in fact, they had successive film badge numbers. This date is consistent with Mr. [redacted]'s account that he started work in 1963, since new workers were typically assigned to Magnaflux testing for approximately six months before being qualified as radiographers. Although Mr. [redacted] was

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[6] [redacted], private communication with Robert Anigstein, SC&A, Inc., January 21, 2008.

employed by GSI much earlier, he was apparently not involved in radiography during the first three months of the Landauer program.

We thus have statements from [redacted] workers actively engaged in radiography that, with rare exceptions, GSI complied with the terms of its AEC license and confined the use of the ^{60}Co sources to the designated facilities.

As was the case for the radium sources, the preponderance of the evidence indicates that radiography using the small ^{60}Co sources was primarily performed inside the radiographic structure in No. 6 Building. Allen (2011, section 6.2.1), derived doses to various workers inside and outside this radiography room. We agree with his bounding calculations of exposures of radiographers and of workers just outside the walls of 1.17 R/y that were based on reports of radiation surveys included in the application for an AEC byproduct material license.

2.4 Other Radioactive Sources

2.4.1 ^{192}Ir

Mr. [redacted] stated that the only ^{192}Ir sources at GSI were those brought onto the site by St. Louis Testing Labs. GSI workers did not perform radiography using those sources, but only showed the SLTL radiographers which shots were needed. Since ^{192}Ir is not mentioned in the GSI AEC license correspondence, we conclude that GSI did not own such sources.

2.4.2 "Large" ^{60}Co Source

According to the AEC license correspondence, GSI acquired an 80-Ci ^{60}Co in 1968, which is after the covered period. However, J[redacted], a former [redacted] operator, stated during the course of a TBD-6000/6001 work group meeting on October 14, 2009: "I assisted an operator in a large curie cobalt source in the new Betatron one time. They brought a large cobalt source in to x-ray nuclear channel heads . . . . This was done . . . [b]y a fellow named [redacted]. [Redacted], who was an isotope man." (Neal R. Gross 2009, p. 194 et seq.) Since Mr. [redacted] left GSI in 1966 (his last film badge dosimetry report was for the week [redacted]/66–[redacted]/66), this would imply that GSI had an unlicensed source, perhaps during the covered period.

Before we received the AEC licensing records, I had asked Mr. [redacted] when GSI had acquired the 80-Ci source in order to estimate its activity during the period in question—he did not recall when the source was acquired (see footnote 6, p. 8). I also asked Mr. [redacted] about his recollections of a large source. He recalled an incident in which a ^{60}Co source could not be retracted and someone had to be called in to fix it—he thought it might have been a large source (section A.1.3). I likewise asked Mr. [redacted] if he knew if GSI owned an 80-Ci ^{60}Co source. He responded: "No, I wasn't familiar with the 80 Ci. The mCi source I was, because it became disconnected one time and I retrieved it. I didn't know they had an 80 Ci." (section A.2.1) This would appear to be the incident which Mr. [redacted] cited; we thus conclude that one of the small (nominally 260- or 280-mCi) ^{60}Co sources was involved. Furthermore, the late [redacted] stated in an interview that he knew of no 80-Ci ^{60}Co source at GSI while he was there. Although he left the nondestructive testing (NDT) department to become [redacted] in Cleaning and

Finishing at the end of 1964, he said he kept in touch with the NDT department and would have known if GSI had such a source. (Anigstein 2010)

During the May 12, 2010 meeting of the Work Group on TBD-600, [[redacted]], GSI copetitioner, said that some former workers suggested that the GSI Granite City foundry might have obtained a high-activity ^{60}Co source from the GSI foundry at Eddystone, Pennsylvania, when the latter facility was shut down in 1963 (Neal R. Gross 2010, p. 270 et seq.) I therefore filed a FOIA request with NRC requesting any records on the Eddystone facility to determine if they had any ^{60}Co sources and, if so, how were they disposed of. NRC responded that the records, under the earlier name of General Steel Castings Company (GSCC), had been turned over to the National Archives and Records Administration (NARA). NARA responded that they did have records for GSCC in Pennsylvania, but only for the Avonmore facility, which they furnished at my request.

By way of background information, Avonmore was the location of the National Roll and Foundry Company, which was acquired by GSCC in 1955. The records contained correspondence between AEC and GSCC during 1957–1959 regarding a license for a 10-Ci ^{60}Co radiography source, which was issued on September 27, 1957, and was due to expire on September 30, 1959. In response to various deficiencies that were cited by AEC, GSCC stated that they had dispensed with the casting business that required radiography and that they intended to sell the radiographic camera containing the ^{60}Co source to "one of our other facilities." The final record in the file, dated October 12, 1959 (which is after the September 30, 1959, expiration date) was a signed statement that the source had "been disposed of in compliance with 10 CFR 20"—no further details were given.

It is not plausible that this source was transferred to the Granite City plant. The source was assayed at 9.6 Ci on September 12, 1957. On March 7, 1962, when the Granite City facility made an urgent request for an AEC license for two 300-mCi ^{60}Co sources, the Avonmore source had an activity of 5.3 Ci. Why would they have made such a request if they had a much stronger ^{60}Co source on hand? How could the State of Illinois, which knew of and disapproved the use of the ^{226}Ra sources with the fishpole technique, not know of the ^{60}Co source?

A plausible explanation for the report of a high-curie source is based on the size and appearance of the radiographic cameras. Although GSI requested a license for two 300-mCi sources and subsequently acquired 260- and 280-mCi ^{60}Co sources, the radiographic cameras housing these sources were designed for sources of up to 10 Ci (NRC 2009d, p. 18). Although we were not able to find any information on the Budd Unitron radiographic cameras acquired by GSI, we did obtain a brochure on the Radionics cameras, one of which was acquired by GSI to house the 80-Ci ^{60}Co source licensed and procured in 1968 (see Attachment 2). It is quite likely that the Budd cameras had a similar design. The sketch of the Budd cameras shown in Figure 4 suggests that the units are mounted between two wheels, like the Radionics camera illustrated in the brochure. This is consistent with the description of the "large" ^{60}Co source being on a two-wheel cart. According to the Radionics brochure, the head of a 10-Ci camera weighed 600 lb, while the camera had a shipping weight of 750 lb. Since the cameras were shipped in their carriages, this would have been the actual weight of the unit. Mr. [[redacted]], in his interview, stated that SLTL used a camera containing a 10-Ci source inside a 400-lb lead sphere. This would have been the weight of the head—the entire assembly would have weighed more. Thus, the Budd camera, designed for a 10-Ci ^{60}Co source, most likely weighed more than 400 lb and as much as 750 lb.

We note that Mr. [redacted] was a betatron operator not an “isotope” operator (i.e., he was not certified to handle radioactive sources under the AEC license). Therefore, in assisting the isotope operator, he would have helped set up the shot, but would not have performed the radiograph. The radiographer would have to know the strength of the source in order to calculate the time required for the exposure; his assistant would not necessarily need such knowledge. Mr. [redacted] may have made the reasonable assumption that the camera contained a high-activity source, judging from the size and weight of the housing.

We conclude that GSI most likely did not have an unlicensed ^{60}Co source during the period of AEC operations.

Appendix A

REPORTS OF WORKER INTERVIEWS

Prepared by

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A.1 Interview with [redacted], Former GSI [redacted]

A.1.1 Initial Interview: September 26, 2011

On September 26, 2011, at approximately 2 PM EDT, David Allen, NIOSH, [redacted], GSI copetitioner, and I joined a conference call arranged by NIOSH. Once we were connected, I called [redacted], a former GSI worker, and connected him to the call. The purpose of the call was to obtain additional information from Mr. [redacted] about radiography using radium sources, as requested by the ABRWH Work Group on TBD-6000 at its meeting on September 20, 2011. This was a follow-up to the interview I had conducted with Mr. [redacted] on October 10, 2010. Mr. [redacted] provided the information that is summarized below.

Mr. [redacted] said he was employed at GSI and performed radiography using the radium sources, starting in 1956. I noted that he had furnished [redacted] a copy of his record of radiation exposure for 1962, as recorded on film badges, and asked if he recalled being issued film badges prior to 1962. He answered “yes.” He then clarified his position in that department by saying that [redacted] in the laboratory Monday through Friday, where he was not exposed to radiation. If there was any work on weekends, he performed radiography on Saturday and/or Sunday. He confirmed handling the radium source using a pole made of wood or other material that was about 6 ft long. He described the radium source as resembling a plumb bob. I described the illustration of a radium source capsule on the Web as resembling a brass plumb bob with an eyelet on each end—he agreed that was correct.

I then asked about the location of the radium radiography. Mr. [redacted] replied that it was in No. 6 Building, near the foundry, on the west side of the building. There was a concrete block room that was isolated from people outside who could be working on grinding or chipping. He recollects the room being there ever since the 1950s. The source was kept in a metal cabinet. He recalls that while he was away [redacted], someone got in and took the radium source home. After he came back from [redacted] in 1956, there was a lock on the door. I mentioned that the building described in the AEC application was about 20 × 60 ft—Mr. [redacted] said that that sounded right. I mentioned that the AEC application described 10-ft-high walls with three strands of barbed wire on top of the walls—he could not confirm that. He added that when they started using sources other than radium, they added steel blocks, four by four and 8–10 in thick in front of the office. He confirmed that no one entered the room during an exposure besides the radiographer, and that no one would get any direct exposure to the radium source. When I mentioned the potential exposure of workers outside the room, he stated that he did not perform any radiation surveys outside the radiographic room. He thought it may have been checked out by supervision, but he doesn’t know if they did that or not. He did use a survey meter in the office to check if the source was in or out, so that they would not be out in the field working while the source was out. I asked if he left during long exposures to develop films, etc. He said they did not have that many shots. He doesn't recall the shots being very long, but they could have left the room, since it was kept locked.

Mr. [redacted] then asked if we were in touch with [redacted], and mentioned he has found a piece of literature on a cobalt source that Mr. [redacted] might be interested in, and that he was welcome to copy. In response to my question, he said he thought that the film badges were always supplied by Landauer. He mentioned that in addition to the film badges, every so often the radiographers were sent to St. Elizabeth Hospital in Granite City for blood tests, but [redacted] never given the results. The blood tests were in addition to film badges and were performed on a quarterly or semiannual basis.

A.1.2 Follow-Up Interview: September 27, 2011

I called Mr. [redacted] again on September 27, 2011 to ask some follow-up questions. The following are his responses.

During his weekend shifts as a [redacted], he did both radium and betatron radiography—perhaps 50–60% of the time using the betatron, the remainder using radium. He worked 80–90% of the weekends, one or two shifts per weekend. Sometimes there was one person per shift (in the beginning), later increased to two or three per shift, since it made the work go faster and they got more shots. Two radium sources could be used to make separate exposures, with lead blocks used to shield each film from the source used for the adjacent exposure. When not in use, the sources were kept in a lead-shielded cabinet in the middle of the radiography room—the cabinet stayed in one place and wasn't moved. The castings were placed in the center of the room or towards the far end, away from the office, to reduce the radiation exposures of the radiographers. I said I heard from other workers that the sources were used in other buildings. He said he recalled one time that they had to radiograph a railroad undercarriage and the source was taken by wheelbarrow or a motor vehicle to the No. 9 or 10 Building. However, removing the source from the shooting room was not a common occurrence—it was something that happened "once in a blue moon."

A.1.3 Calls to Confirm Draft Interview Report: October 5 and 12, 2011

Following these two telephone calls, I prepared the above text and enclosed a hard copy in a letter which I mailed to Mr. [redacted] on September 27. On October 5, 2011, I called Mr. [redacted] and asked if he had reviewed the report of the interviews. He said the reports were very accurate, and he had no corrections. In another call, on October 12, 2011, he confirmed that the ^{60}Co sources were also used either in the radiographic facility in No. 6 Building or in one of the betatron buildings. They were rarely used in open areas. He was not sure if GSI possessed a large ^{60}Co source while he was there. He recalled an incident in which a ^{60}Co source could not be retracted and someone had to be called in to fix it—he thought it might have been a large source.

A.2 Interview with Paul [redacted], Former Administrator, St. Louis Testing Laboratories

A.2.1 Initial Interview: September 28, 2011

On September 28, 2011, at approximately 10 AM EDT, David Allen, [redacted], and I joined a conference call arranged by NIOSH. Once we were connected, I called [redacted], a former administrator of St. Louis Testing Laboratories, and connected him to the call. The purpose of the call was to obtain additional information from Mr. [redacted] about radiography using sealed sources of ^{60}Co and ^{192}Ir at the GSI site in Granite City, Illinois, as requested by the ABRWH Work Group on TBD-6000 at its meeting on September 20, 2011. This was a follow-up to the information which Mr. [redacted] furnished at a meeting with former GSI employees held on October 9, 2007, in Collinsville, Illinois. I asked Mr. [redacted] a series of questions, which are listed below, along with his responses. The account is not verbatim.

I sent Mr. [redacted] a preliminary draft of this report by e-mail. On October 6, 2011, he responded by e-mail with some corrections, which are incorporated into the present draft.

Q: You had described how the radiographers of your company came to the GSI site and brought either a 10-Ci ^{60}Co source or a 50-Ci ^{192}Ir source and set up a shot on a rail siding on the GSI property. They surveyed the area and set up a 2-mR/h boundary and kept GSI workers outside the boundary.

A: Yes, but the ^{192}Ir was used in different locations inside the plant, wherever there was a large casting and there might be just one or two repair shots. Only ^{60}Co shots were performed on the rail spur. Everything was roped off with yellow/magenta ropes and radiation warning signs, whether in the plant or on the rail spur.

Q: If you had one man there, did anyone watch the perimeter while he was on a break?

A: While the source was exposed, the perimeter was under constant surveillance—there was always someone there. If there was only one man and he had to go on a break, he secured the source by retracting it back into the lead shield and locked it up.

Q: The source was retracted?

A: Yes.

Q: This was a radiographic camera with a remote cable?

A: The radiographic exposure device (camera) did not use a cable and crank device. Instead, the source was moved from the exposure device by means of a rigid vertical tube and a long nylon string which ran through the rigid tube and was attached to a weighted pencil-shaped source holder. To expose the source, the exposure device was unlocked and the source holder raised into position by pulling on the string. To retract the source, you simply slowly released the string and the weighted pencil-shaped source holder dropped back into the exposure device, where it could be locked in its shielded position. The 50-curie iridium device operated in a similar manner. We did have iridium exposure devices that were of the cable and crank type, but they only housed a maximum of 10 curies. The iridium exposures in the plant used a collimator, so the radiation was directional, since we were exposing only one film at a time. The cobalt exposures were panoramic (i.e. 360 degrees) so no collimator was used. However, the source was inside the 5-in thick cup-shaped casting, which shielded it somewhat. The cobalt was shielded in a 400-lb lead sphere and the iridium in a 50-lb lead sphere.

Q: Did any GSI workers assist or participate in this?

A: Not inside the ropes.

Q: During what years did this take place?

A: I think mid-60s, maybe early 60s. I think it started when we were working on the [St. Louis] Arch,[7] in the mid-60s, and I am not too sure how long—60s, 70s.

Q: At the meeting in 2007, you said there were ten ^{60}Co shots, and they spanned a 6-month period. Maybe that was just one campaign?

A: I do remember the exposure time—that was the longest exposure we ever made. The iridium was before and after.

Q: You had said some shots were made in the repair area. Was that in the finishing buildings?

A: I am not sure which building it was, but it was where they repaired—where they ground out defects—it was indoors—it was easier to go in and take the one shot than for them to move the casting back to where they x-rayed it. Any time the source was out, the GSI people had to be outside the rope area.

Q: Did the cable extend to the roped area?

A: Yes, you could be 40 ft. The iridium was directional shooting, so the radiation was fairly well contained in one direction, towards the casting. The cobalt was a different story: that was a large area roped off. There, the radiographer was probably inside the rope.

Q: You also said St. Louis Testing calibrated the survey meters used in the betatron building. Was that during the same time? Earlier, based on the AEC records, Nuclear Consulting Corporation was doing the calibration. Did your company take over from them?

A: I kind of suspect they did. We took over when [redacted] was still there.[8]

Q: Do you remember dealing with [redacted]?

A: Yes.

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[7] According to the U.S. National Park Service, Construction of the Arch began in 1963, and was completed on October 28, 1965 (NPS 2011).

[8] According to the late [redacted], [redacted] took over as manager after [redacted] was promoted and transferred to another department. Mr. [redacted]'s last recorded film badge was for the week of [redacted], 1964. Thus, it was most likely that St. Louis Testing first came on site in late 1964, since [redacted] became manager of NDT at the end of 1964.

Q: Were you involved with radiation safety at GSI, besides your own radiography on site? Did you consult with them about their own safety?

A: No, other than [redacted] or [redacted] might have asked me about that.

Q: According to the records, we know that in 1962 GSI bought 260- and 280-mCi ^{60}Co sources, and in 1968 they bought an 80-Ci ^{60}Co source. Do you know if they had any other large sources in between these times?

A: No, I wasn't familiar with the 80 Ci. The mCi source I was, because it became disconnected one time and I retrieved it. I didn't know they had an 80 Ci.

Q: It may have been after you were no longer involved with them.

A: That could be.

David Allen then asked a question.

Q: Do you remember how often the iridium source was used for the repair shots?

A: It might be several times in a week, and then not for a while. We used it whenever they had a repair shot. We did the ground-out areas to see if they got it all. After they welded it up, at first they x-rayed it a couple of times, but our method with the iridium showed more than the betatron, so after that, they used the betatron on the final shots.

Mr. [redacted] and I then had a brief discussion in which he explained that GSI had to furnish the films of the final repair shots to its customers. The films had to show a certain minimum sensitivity, which could be achieved by the betatron, while the ^{192}Ir was too sensitive and showed more defects.

A.3 Interview with Leroy Dell, Former GSI Supervisor

A.3.1 Initial Interview: October 6, 2011

On October 6, 2011, at approximately 12:30 PM EDT, David Allen, [redacted], and I joined a conference call arranged by NIOSH. Once we were connected, I called [redacted], a former GSI [redacted], and connected him to the call. The purpose of the call was to obtain additional information from Mr. [redacted] about radiography performed at GSI.

In response to my questions, Mr. [redacted] said he did not recall when he started work at GSI. He did recall that the concrete block building used for radiography with sealed sources, located inside the No. 6 Building, was there when he started. He mentioned having some differences with Mr. [redacted] [a GSI official] and that he worked for only a short time as a [redacted] operator. He objected to the fact that GSI did not police the sources when they were used to radiograph steel castings. He was a [redacted], but did not actually perform any radiography. The first time he went to the 6 Building, there was a casting that needed to be x-rayed. At that time, the source was inside a lead container and was removed using a 10-ft pole and set in a little cup wherever it was needed. The area was roped off or taped off, and posted with signs that said: "Caution, radiation danger." But, after [redacted] roped it off, he went to the betatron to get more film, etc., and Mr. [redacted] went back to the lab. Thus, they did not police the source. The source was taken "anywhere they needed it"—it was not just used inside the concrete block building. The ^{60}Co cameras, which were heavy, were lifted by a crane and were taken to the 10 Building if needed.

In response to my question, Mr. [redacted] confirmed that the area was roped off and people were kept back. He confirmed that the radiographer was inside the roped area while setting up the shot. The control cable was 10–15 ft long, while the cable to which the source was attached protruded about 10 ft. Altogether the source was about 30 ft from the crank that controlled its position. Once the shot was set up, the radiographer would go outside the roped area.

I then asked about sources other than the 260- and 280-mCi ^{60}Co sources acquired in 1962. Mr. [redacted] responded that there was an ^{192}Ir source, but it was not used by GSI men—it was brought in by an outside source—he thought it was St. Louis Testing Labs. [redacted] or another GSI worker went around with the St. Louis Testing radiographer to show him the castings and what they wanted shot, but the GSI workers did not perform the radiography. When I asked about a very large ^{60}Co source, Mr. [redacted] stated that they said they had a ^{60}Co 80-Ci source, but he does not remember it. When I mentioned the AEC records that showed that the 80-Ci ^{60}Co source was acquired in 1968, he confirmed that he was there in 1968.

Mr. [redacted] then recounted the incident involving [redacted], who reported having lost his film badge. According to Mr. [redacted], the film badge was left inside the concrete radiographic facility inside the No. 6 Building for 16 hours, until [redacted] came back for his next shift. They found the film badge just inside—the source may not have been properly secured.

I then asked about the radium source that someone had removed. I asked Mr. [redacted] if he was working at GSI at that time. He thought it was when he first started. He recounted that the worker had it in the back of his car, but when he found out how dangerous it was, he took it out on the railroad track and threw it out. They took Geiger counters and found it. In response to a further question, Mr. [redacted] wasn't sure if the incident happened before he started working at GSI or just after.

A.3.2 Call to Confirm Draft Interview Report: October 11, 2011

Following the interview, I sent Mr. [redacted] a copy of the above draft report by e-mail. On October 11, 2011, at about 2:30 PM, I called him to ask if he had any comments on this draft. He responded that, although he did work as a [redacted], he occasionally performed radiography, both with the betaron and with ^{60}Co sources. He did not handle the ^{226}Ra sources with the fishpole, but did participate in setting up shots (e.g., placing the film in position). He also developed a clearer recollection of when he began work at GSI. He said he was hired to replace [redacted] when [redacted] went [redacted], which was ca. 1954, so Mr. [redacted]'s best guess is that he started in 1955.

A.4 Interview with [redacted], Former [redacted] of Nuclear Consultants Corporation, October 12, 2011

On October 12, 2011, at approximately 11 AM EDT, I called [redacted], former [redacted] of Nuclear Consultants Corporation (NCC), to ask him about his recollection of his activities in connection with the radiation safety program for the GSI foundry in Granite City, Illinois, in the early 1960s. [Redacted] said that the radiation safety work was a sideline to his main business, which was supplying radioisotopes for medicine. He said that he obtained his film badges from Landauer, and confirmed my observation that he served as a middleman in these transactions. I asked about any radioactive sources that GSI might have had during that time, other than the two licensed ^{60}Co sources and radium, he responded that they were not using radium during his time and mentioned no other sources. He could not furnish any information on their radiographic practices. When I asked about any incidents, he replied that he does not recall any instances in which anyone was overdosed. He could not tell me who supplied film badges to GSI prior to his involvement, but guessed it might have been Landauer, because they were a major supplier.

Given the sparse information I obtained from [redacted], I did not send him this report for his confirmation.

Appendix B

MCNP SIMULATIONS OF EXPOSURES FROM ^{226}RA IN NO. 6 BUILDING

Prepared by

Robert Anigstein and Richard Olsher
S. Cohen & Associates

We simulated the exposures and dose rates from ^{226}Ra in the radiographic facility in No. 6 Building at GSI using the MCNP5 radiation transport code. The model of the radiographic room was based on a sketch in the GSI application for an AEC byproduct material license (NRC 2009e, p. 31), which is replicated in Figure 4. The walls are described as being 10 ft high (NRC 2009b , p. 8). There is some ambiguity about the thickness and the material of which they are constructed. NRC (2009b, p. 8) refers to them being constructed of "16 inches of solid concrete block." However, the report of the radiation survey by the Nuclear Consultants Corp. (NCC) (NRC 2009c, p.4) states that the walls are "24 inches thick (minimum)," the accompanying sketch (Figure 4) indicates that only three of the outside walls, as well as one inner wall of the small room used as an office for the radiographers, are 24 inches thick, while the other walls are 16 inches. Furthermore, a drawing in NRC 2009f, p. 10, states that the walls are made of sand-filled concrete block. Since the drawings appear to give more detailed dimensions, we adopted the wall thickness shown in Figure 4. However, given the ambiguity in the description of the construction of the walls, and the range of densities of concrete used in building blocks, we modeled the walls as consisting of sand with a density of 1.586 g/cm^3, which is the bulk density of sand (Smico 2002). The doors to the office and to the outside are assumed to be hollow and made from $\frac{1}{16}$-in steel sheet. They are modeled as a single sheet ⅛-in thick. A cross-sectional diagram of the MCNP model is shown in Figure 3.

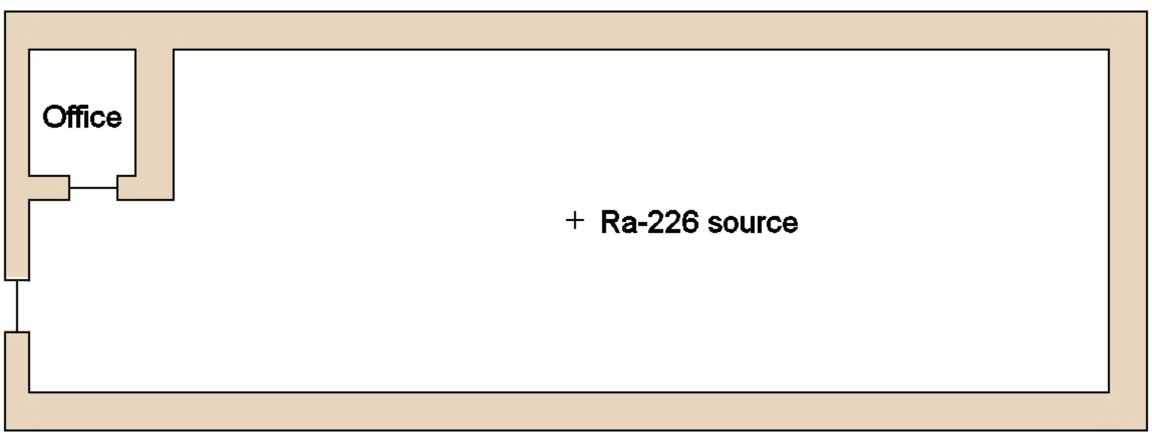

Figure 3. MCNP Model of Radiographic Facility

The source was assumed to be 1 Ci of ^{226}Ra, in full secular equilibrium with its entire progeny.[9] The exposure and personal dose equivalent, $H_p(10)$, rates were calculated at two locations: the center of the office (see Figure 3) and 1 m outside the door shown at the left side of Figure 3.

[9] We assume that both 500-mCi sources were exposed simultaneously to radiograph two separate castings.

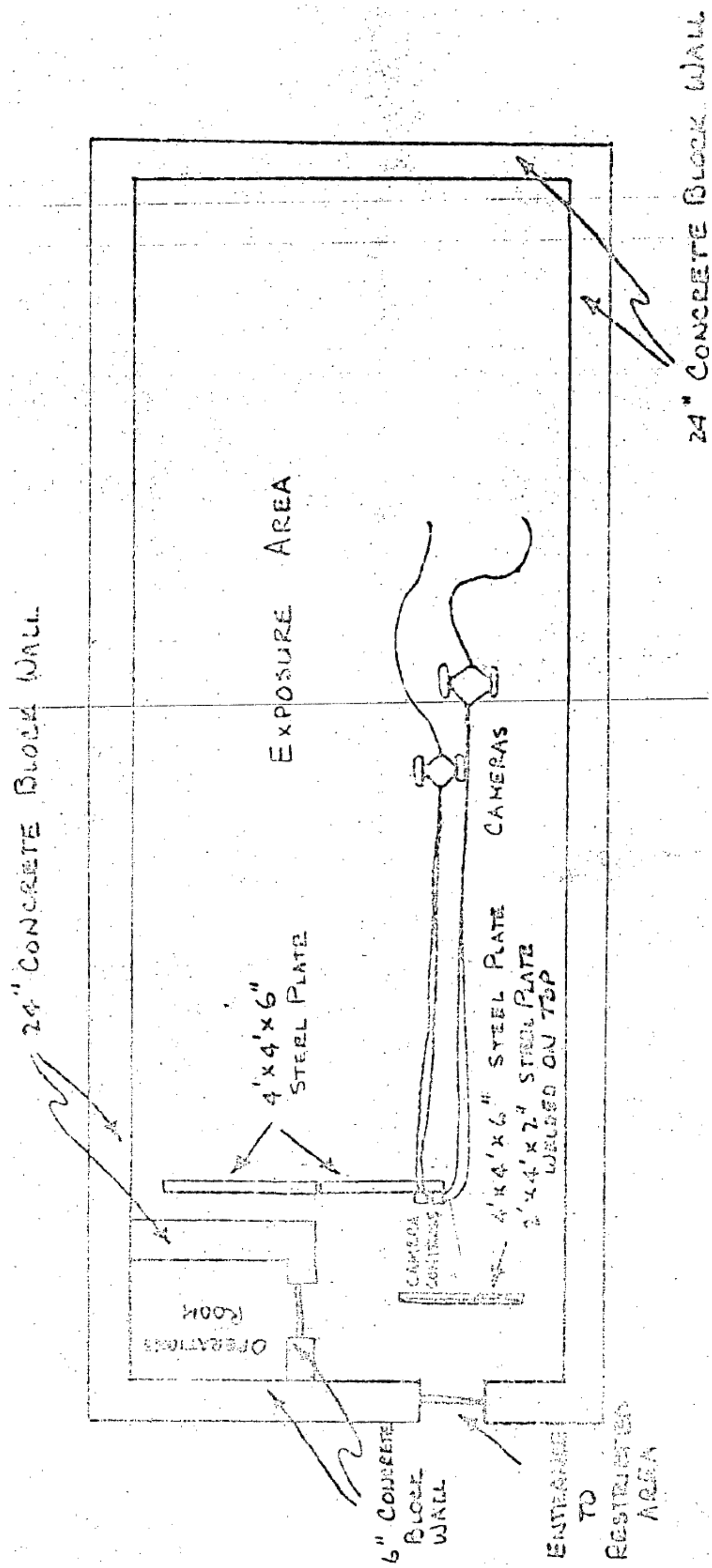

Figure 4. Sketch of Radiographic Facility in No. 6 Building at GSI (NRC 2009, p. 31)

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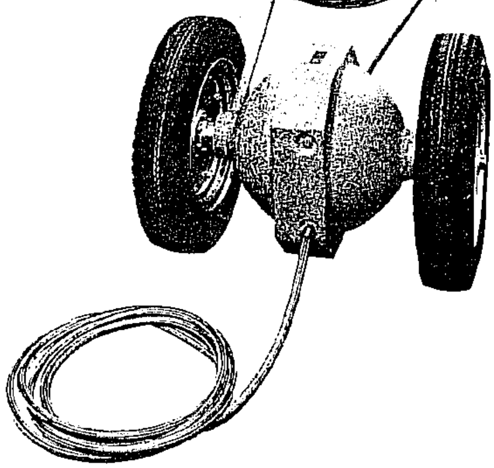
Attachment 1

Attachment 1 has been redacted in its entirety.

Attachment 2

gamma RADIOGRAPHY

ENGINEERING FILE



NOTE:
ALL MODEL NUMBERS IN THIS SERIES SHOULD BE PRECEDED BY THE LETTER P

PANORAMIC EXPOSURES with the 60 series

MULTIPLE SOURCE POSITIONS

All RADIONICS cobalt 60 cameras may be obtained with provisions for containing and using more than one radioactive source. In this fashion, the operator has a choice between a stronger or a weaker cobalt 60 source, or between a cobalt 60 source and an iridium 192 source. The multiple units, then, are really two or three machines in one, and the cost of the extra source positions is far, far less than that of an additional camera.

The number of source positions is indicated in the model number by a final numeral separated from the basic model number by a dash. For example, model 60-100-2 is a 100 curie cobalt 60 unit with two source positions. Model 60-5-1 is a five curie cobalt 60 unit with one source position.

Up to 100 curies of iridium 192 may be contained in any multiple position cobalt 60 unit, even when loaded to capacity with cobalt 60.

RADIONICS offers 5 basic models of its 60 series panoramic radiography cameras. Models 60-1, 60-5, 60-10 and 60-100 are all similar in function and appearance to the 60-30 pictured above. (The capacity in curies of cobalt 60 is indicated by the digits following the first dash in the basic model number.)

RADIONICS INCORPORATED
LAFAYETTE & WATER STS., NORRISTOWN, PA.
BROADWAY 2-3656

Attachment 2 (continued)

featuring

LOW COST
Only a fraction of the price of x-ray.

VERSATILITY
3/4" - 12" range in steel.

PORTABILITY
Easily wheeled about the shop.

REDUCES EXPENSE
Saves set-up time - reduces exposures required.

RUGGEDNESS
No delicate components - built for hard use.

LOW MAINTENANCE
Entirely mechanical - no circuitry to service.

COBALT 60 RADIOGRAPHY

Cobalt 60 is useful in radiographing from 3/4" to over 12" of steel. The sensitivity attainable ranges from less than one to two per cent of section thickness.

Focal spot diameters depend on the strength of the source, and range from 1/8 inch for up to 10 curies to one centimeter for 1,000 curies.

Because cobalt 60 radiation is nearly monoenergetic - i.e., all of its radiation is "hard", averaging 1.25 MeV - it does not scatter or "bounce" as much as x-radiation, reducing both the hazard and the cost of the installation. This property also makes cobalt 60 more suitable for thick section radiography. Above about four inches of steel, cobalt 60 will take higher quality radiographs than will a 2,000,000 volt x-ray machine.

The relatively long half-life of cobalt 60 of 5.2 years means that the source seldom requires replacement - usually only every three to five years - thus further reducing the cost.

CONSTRUCTION

All RADIONICS cameras are fabricated of painted carbon steel, except for stainless steel moving parts, and are filled with lead. All are designed to serve as shipping and storage containers for their source. No extra containers are required. All are fitted with locks to prevent use by unauthorized personnel.

The RADIONICS source control assembly serves to move the source to the exposed position and to return it to the shield by simply turning a crank. The control assembly indicates the position of the source at all times. The panoramic source tube is flexible, and will pass through a hole only one inch in diameter.

The model 60 series machines are mounted on pneumatic tired wheels and are provided with handles which permit them to be moved about easily.

OPERATION

Operation of all RADIONICS panoramic cameras is simplicity itself. After unlocking, the control assembly and source tube are attached to the camera and it is ready for use.

The end of the source tube is positioned as desired, and the control assembly and source tube are extended to full length. Simply turning the handle moves the source to the end of the tube. At the end of the exposure the source is returned to the camera by turning the handle the other way. The control assembly indicates the position of the source at all times to the nearest inch with a digital output.

SPECIFICATION

	MODEL				
	60-1	60-5	60-10	60-30	60-100
Capacity (curies of cobalt 60)	1	5	10	30	100
Focal Spot Dia.	0.040"	0.125"	0.125"	0.200"	0.200"
Weight of Head	190#	450#	600#	675#	1100#
Shipping Weight	300#	550#	750#	900#	1300#

Maximum Surface Dose Rate (all models) - Less than 200 mrhr when fully loaded. Less than 10 mrhr at 36" from surface.

Length of Source Tube (all models) - 14 feet standard, longer lengths available.

Length of Control Assembly (all models) - 15 feet standard, longer lengths available.

RADIONICS INCORPORATED