SC&A, inc.

TO: Advisory Board on Radiation and Worker Health Work Group on TBD-6000
FROM: Robert Anigstein and John Mauro, SC&A
SUBJECT: Update of Doses from External Exposure at GSI
DATE: January 12, 2014

Update of Doses from External Exposure at General Steel Industries

During the December 19, 2013, meeting of the ABRWH Work Group on TBD-6000, SC&A was asked to provide an update to our previously calculated doses to GSI employees from external exposure to penetrating radiation. Agreement had already been reached on limiting photon doses to plant personnel during the Radium Era, which, for purposes of dose reconstruction, spanned the period October 1, 1952–December 31, 1962. Agreement had also been reached on photon doses to administrative personnel, with the understanding that such doses shall be assigned only if it can be conclusively established that the employee in question performed administrative functions, that the employee's work station was remote from the production areas of the plant, and that the employee did not frequently enter the production areas. Finally, agreement had been reached on doses to the skin from β rays. The present memo presents the results of our analyses of limiting photon doses during the period of AEC operations following the Radium Era (i.e., January 1, 1963– June 30, 1966), and neutron doses during the entire period of AEC operations.

We have estimated annual photon doses during the Post-Radium Era based on two exposure scenarios: the betatron operator and the layout man. Whichever scenario yields the higher probability of causation should be employed in an individual dose reconstruction.

1 Betatron Operator

1.1 Photon Dose from Hypothetical Residual Radiation from the Betatron Apparatus

As discussed by Anigstein and Olsher (2012, Section 2.1.1), the limiting photon dose to betatron operators is based on the hypothetical exposure to residual radiation from the betatron apparatus in the posteroanterior orientation. This exposure scenario yields a maximum effective dose of 26 mrem/week, as listed in Table 1—the annual dose is listed in Table 2. This limiting dose should be assigned to betatron operators during the Post-Radium Era.

Table 1. Effective Dose to Betatron Operator from External Exposure

Source of radiation	Photons mrem/week	Neutrons mrem/shift
Betatron residual	26	
Uranium handling		0.50
Uranium radiography		1.16
Steel radiography		0.65

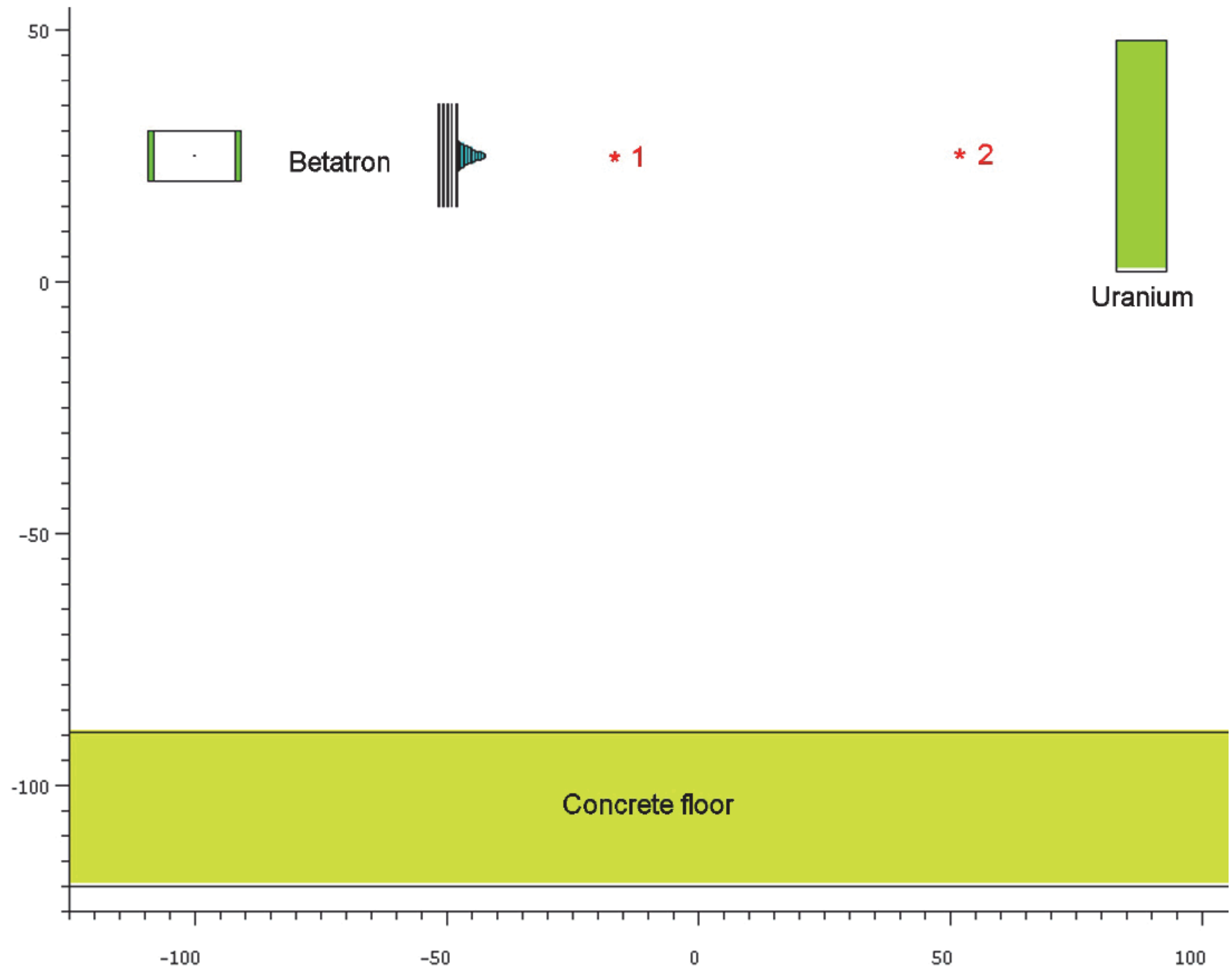

Figure 1. MCNPX Model of Exposure to Irradiated Uranium in Old Betatron Building (scales in cm)

1.2 Neutron Exposures

Betatron operators were also exposed to delayed neutrons from photofission and photoactivation of irradiated uranium and to neutron radiation in the control room during the radiography of uranium and of steel castings.

1.2.1 Exposure to Neutrons from Irradiated Uranium

The exposure of the betatron operator to neutrons from irradiated uranium was simulated by using the delayed neutron feature of MCNPX. We used the code to model neutron emission resulting from photofission and photoactivation in a slice from a uranium dingot, 18 in (45.72 cm) in diameter and 4 in (10.16 cm) thick, as a function of time following exposure to the betatron x-ray beam. Such a disk, radiographed at a distance of 6 ft from the betatron target, would intercept a major portion of the x-ray beam and thus represents a limiting exposure scenario. The exposure was assumed to take place in the Old Betatron Building—the MCNPX model, shown in Figure 1, included the walls, floor, and roof of the shooting room. We assumed that the operator's exposure began 5 s after the betatron was turned off and lasted for 15 min. He was assumed to be at a distance of 1 m from the uranium metal during one-half of this time—location 1, marked by an asterisk in Figure 1—and at a distance of 1 ft during the remaining time—location 2 in Figure 1. The MCNPX model of the betatron, shown in Figure 1, includes the platinum target inside the porcelain doughnut, the ionization chamber, and the aluminum compensator that serves to flatten the x-ray beam in order to produce a more uniform exposure across its cross-section. The electromagnets, which are not in the path of the primary beam, are not part of the model.

MCNPX was used to tabulate the effective dose from delayed neutrons in a series of time bins. According to SC&A(2008, Section 2.1.4),

> After the metal has been irradiated for a period of time, the dose rate from the metal is the sum of contributions from the activation and subsequent decay of nuclides that were created during the period of exposure. To calculate the dose rate at a time after the end of the exposure, we performed a numerical integration over the doses in the individual time bins. [Further details are found in the cited location.]

The resulting dose per 8-h shift, assuming an average of 6.4 radiographic exposures per shift (480 min/shift ÷ [60 min/shot + 15 min setup] = 6.4), is listed in Table 1. The contribution of the uranium handling scenario to the annual neutron effective dose, listed in Table 2, was calculated by multiplying the dose per shift by the number of shifts devoted to uranium radiography during a given year.

Table 2. Annual Effective Dose to Betatron Operator from External Exposure

Year	Betatron residual photons[a] (rem)	Annual number of shifts		Neutrons (mrem/y)			
		Uranium	Steel	Uranium handling	Control room U	Control room Steel	Total
1952-1957	—	54.69	351.56	27.1	63.6	227.1	317.8
1958	—	46.48	359.77	23.1	54.1	232.4	309.5
1959-1960	—	42.19	364.06	20.9	49.1	235.1	305.1
1961	—	48.44	357.81	24.0	56.3	231.1	311.4
1962	—	35.16	371.09	17.4	40.9	239.7	298.0
1963	1.30	9.57	396.68	4.7	11.1	256.2	272.1
1964	1.30	3.52	402.73	1.7	4.1	260.1	265.9
1965	1.30	2.56	403.69	1.3	3.0	260.7	265.0
1966[b]	1.30	0.80	202.32	0.4	0.9	130.7	132.0

[a] Assuming 50 weeks/y of exposure

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

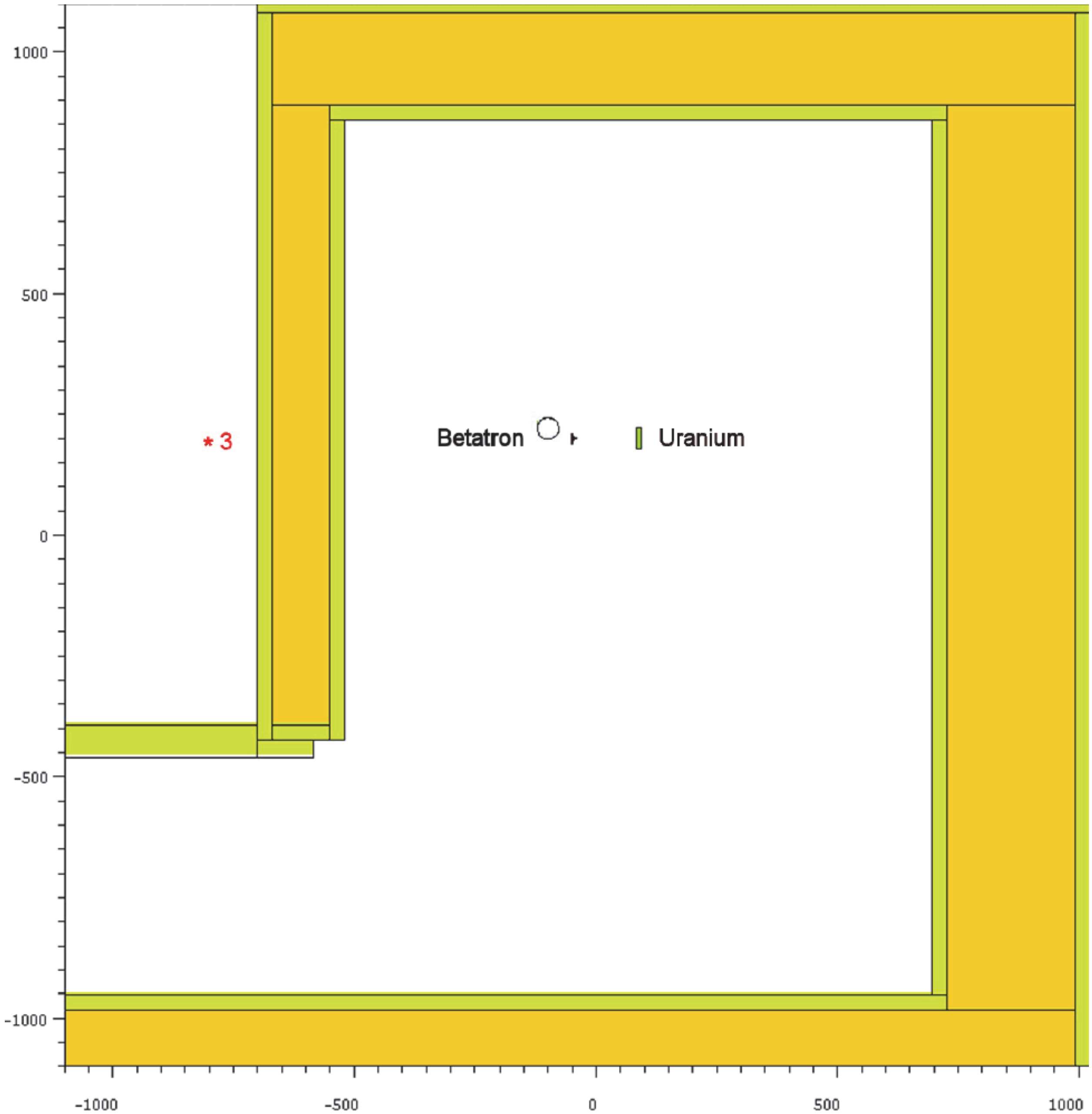

Figure 2. MCNPX Model of Radiography of Uranium in Old Betatron Building (scales in cm)

1.2.2 Exposure to Neutrons in Control Room During Uranium Radiography

The neutron exposure of the betatron operator during uranium radiography was simulated with MCNPX. The operator was assumed to be in the control room of the Old Betatron Building, 1 m from the wall that faced the shooting room—see position 3, marked by an asterisk in Figure 2. The resulting dose, based on an assumed uranium radiographic exposure of 60 min per shot and 6.4 shots per shift, is listed in Table 1. The contribution of this scenario to the annual neutron effective dose, listed in Table 2, was calculated by multiplying the dose per shift by the number of shifts devoted to uranium radiography during a given year.

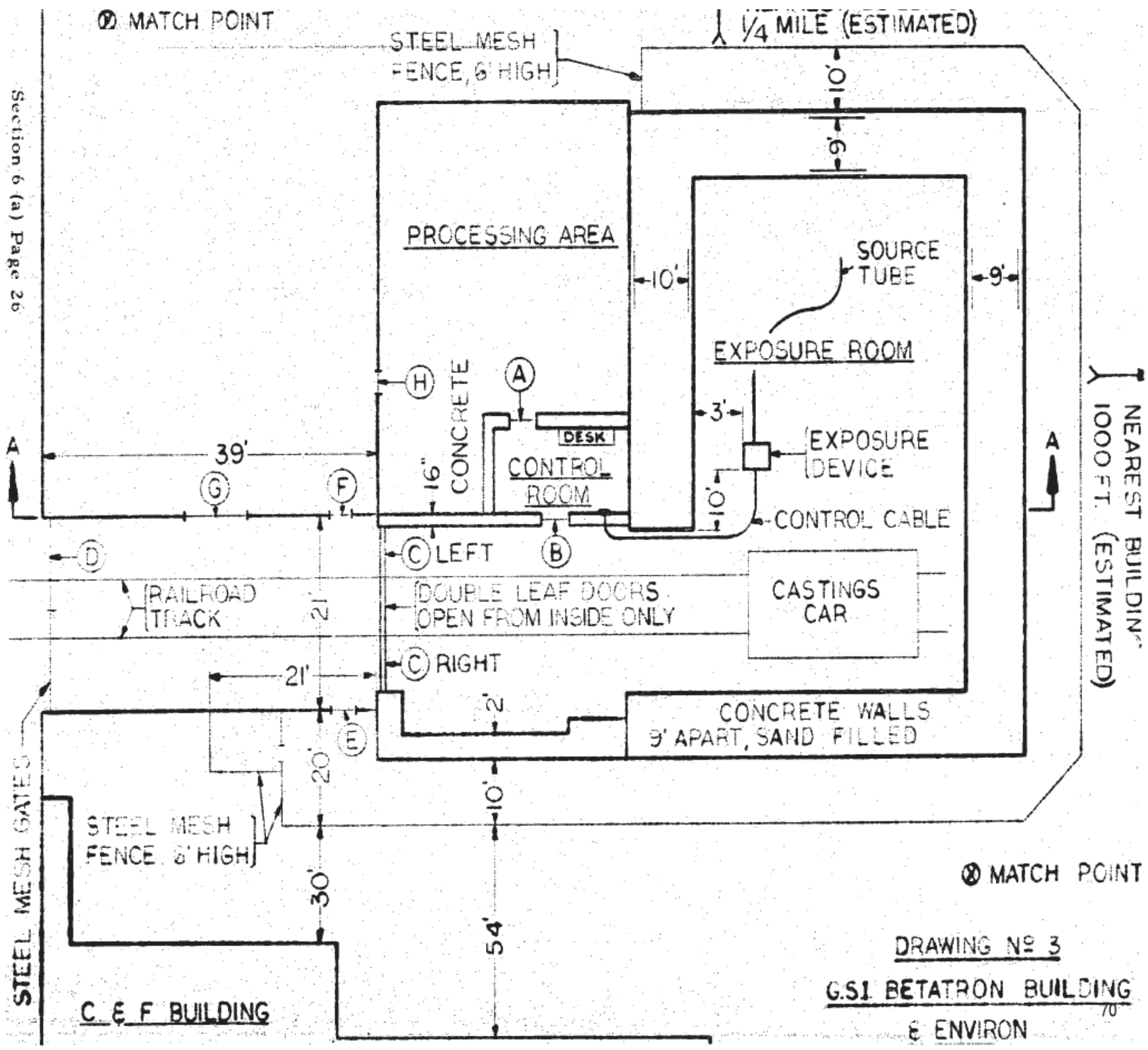

Figure 3. Drawing of New Betatron Building Showing Desk in Control Room (NRC 2009)

1.2.3 Exposure to Neutrons in Control Room During Radiography of Steel Castings

SC&A (2008, Section 2.2.1) described the assessment of stray radiation from the betatron during the radiography of a heavy hollow axle. In the present analysis, we re-evaluated the neutron exposure of the betatron operator, using the latest release of MCNPX. We assumed the operator to be seated at the desk in the control room, as shown in Figure 3. The MCNPX model is illustrated in Figure 4.

The neutron dose to the betatron operator from this scenario was calculated on the assumption that during 64.29% of the shifts, he spent 3 min of each 15 min at the desk in the control room, which is the time for each of the short shots, while during the remaining shifts, which were devoted to long shots, he spent 60 of each 75 min at this location. The result is listed in Table 1. To calculate the contribution of this scenario to the annual neutron effective dose, we postulated that the betatron operator receiving the highest neutron dose spent the maximum number of shifts

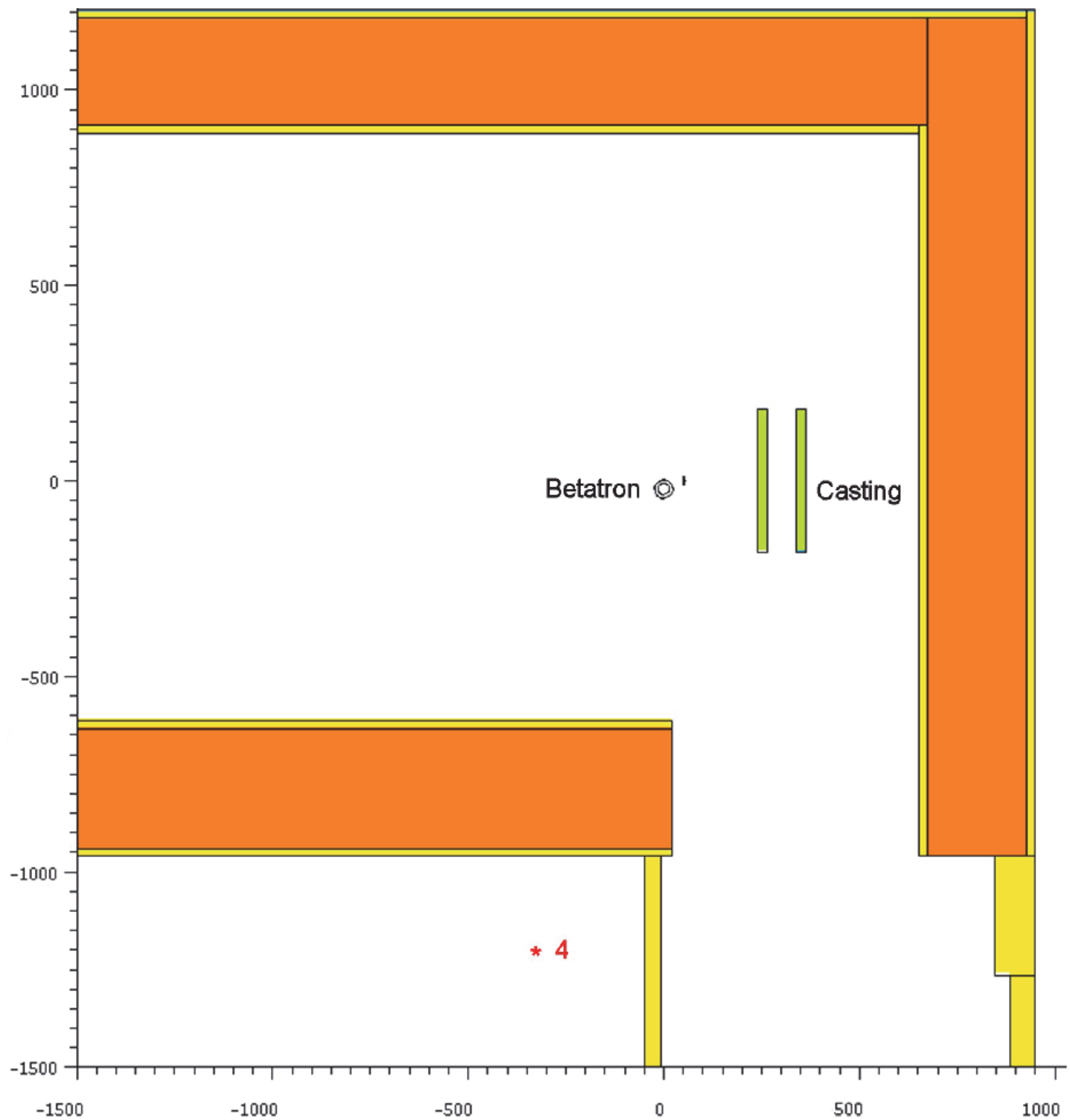

Figure 4. MCNPX Model of Radiography of Steel Casting in New Betatron Building (scales in cm)

during a given year radiographing uranium, which, as shown in Table 1, produced a higher dose per shift than the radiography of steel. We assumed that the remainder of his work year was spent radiographing steel. The annual neutron dosefrom the radiography of steel, listed in Table 2, was calculated by multiplying the dose per shift by the number of shifts devoted to radiography of steel during a given year.

2 Layout Man

SC&A (2008, Section 2.4.2) discussed the exposure assessment of the layout man. A brief updated description of this scenario was presented by Anigstein and Olsher (2012, Section 2.1.2). The primary source of photon exposure was the stray and scattered radiation from the betatron during the radiography of steel castings. The photon dose was assessed at two locations: 10 ft to either side of the railroad track used to transport castings into the New Betatron Building. The location northwest of the tracks received a 72% higher photon exposure —the exposure at this location, reported by Anigstein and Olsher (2012, Table 2), remains unchanged.

The neutron dose to the layout man was re-evaluated for the present analysis. The assessment used the same exposure geometry as the photon exposure assessment. As it happened, a worker at the location that experienced the higher photon exposure received the lower neutron dose. However, the difference between the neutron doses at the two locations was only 12%. Since the numerical values of the photon exposures were an order of magnitude higher than the neutron doses, the neutron dose at the northwest location—the same location that was adopted for the photon exposure assessment—was assigned to the layout man.

The assessment of this worker's photon exposure to irradiated steel was based on the description presented by SC&A (2008, Section 2.4.2),

> The layout man marked up the steel after all shots were completed; therefore, the portion of his time marking up the steel that had been subjected to long shots and short shots is not the same as the fraction of long shots and short shots performed with the betatron. According to [redacted], a former GSI supervisor, the layout man would typically spend a full shift of 8 h marking up a large casting. However, he might sometimes be interrupted to mark up a casting that has just been radiographed and is close to being shipped. . . . We characterized that scenario as involving long (one-hour) shots. . . . We assumed that 10% of his shift consisted of such activity, while 90% was devoted to marking up a single large casting that had been subjected to multiple short shots . . . . Because marking the steel requires continuous close contact with the metal, we assumed that he was at a distance of 1 ft (30.48 cm) 90% of the time and at 1 m the remaining 10%.

During the shifts involving the long-shot scenario, the layout worker was assumed to work on a succession of castings that had each been subjected to 400 exposures prior to his shift, and to spend 75 min marking up each of these castings. He would have marked up an average of 6.4 such castings during such a shift. During each of the remaining shifts, he was assumed to mark up a single casting that had been subjected to 532 short shots.

The results of the updated analysis are presented in Table 3.

Table 3. External Exposure of Layout Man to Direct Penetrating Radiation

Source of radiation		Betatron duty cycle	Duration h/shift	Exposure mR/shift	Neutron dose mrem/shift
Irradiated steel	Short shots–90%	—	—	0.02	
	Long shots–10%	—	—	0.03	
Betatron		41%	8	22.11	1.4
Total				22.2	1.4
Annual			No. shifts/y	R/y	mrem/y
			406.25	9.0	554

References

Anigstein, R., and R. H. Olsher. 2012. "Response to 'Battelle-TBD-6000 Appendix BB General Steel Industries: Dose Estimates for Betatron Operations'." http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/scarespon2dcasgsi.pdf.

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

S. Cohen & Associates (SC&A). 2008. "Review of 'Site Profiles for Atomic Weapons Employers That Worked Uranium and Thorium Metals - Appendix BB: General Steel Industries,' Battelle-TBD-6000, Appendix BB, Rev. 0" (March 17, 2008). http://www.cdc.gov/niosh/ocas/pdfs/abrwh/scarpts/sca-gsisp-r1.pdf