MEMORANDUM

TO: Advisory Board on Radiation and Worker Health, Work Group on Carborundum Company
FROM: Robert Anigstein and John Mauro, SC&A
DATE: March 12, 2017
SUBJECT: Updated Status Report on SC&A Review of NIOSH Response Paper

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We have prepared an interim status report on our review of the "NIOSH Evaluation of Carborundum Company: Response to Site Profile Issues and Comments," dated February 22, 2017. The NIOSH report was distributed at about 5 PM on Thursday, March 2.

Given the short notice and the fact that we had not been given a firm date for the delivery of the NIOSH report, it was not possible for us to perform a thorough review. The following therefore constitutes an account of our impressions and some preliminary conclusions.

1 Surrogate Data Issues

1.1 External Dose Rates

1.1.1 First AWE Period

NIOSH accepted our recommendation to adopt as a source term for external exposure to penetrating radiation from uranium metal the 10 uranium slugs that were shipped to Carborundum in 1943. NIOSH adopted personal dose equivalent, $H_p(10)$, rates of 0.524 mrem/h to an operator, which is 10 times the dose rate from a single slug at a distance of 1 ft (30.48 cm), and 0.0519 mrem/h to a general laborer, which is 10 times the dose rate from a single slug at a distance of 1 m, that are listed in TBD-6000, Table 6.1.

NIOSH assumed that the beta dose rate to the skin of the hands and forearms of the operator was 230 mrem/h, as presented in TBD-6000. The beta dose rate to the skin of the rest of the body was assumed to be 10 times the $H_p(10)$ dose rate.

Because the Hp(10) dose rates were based on MCNP simulations performed in support of NIOSH and published in *Health Physics*, it is reasonable to employ the same model to determine the beta dose rates. We found that the beta dose rate to the skin in contact with a uranium slug with the same dimensions as reported by Anderson and Hertel (2005) was 76.6 mrem/h. This is significantly less that the rate of 230 mrem/h listed in TBD-6000 from a uranium metal slab with an unspecified configuration, but most likely larger than the slugs at Carborundum. Since the contact dose can only be from one slug at a time, there is no need to account for multiple slugs being present. NIOSH should consider adopting a lower beta dose rate for the skin of the hands and forearms.

We also found that the beta dose rate to the skin at a distance of 1 ft from the uranium slug was 0.54 mrem/h, which is consistent with the dose rate of 0.524 mrem/h used by NIOSH that was assumed to be 10 times the $H_p(10)$ dose rate.

NIOSH assumed that the beta dose rates to a general laborer were 50% of the dose rates to the operator.

We conclude that the surrogate data used by NIOSH to estimate external dose rates during the first AWE period are reasonable, except for the skin contact dose rate. We observe that the latter rate is most likely overstated.

1.1.2 Second AWE Period

NIOSH accepted our recommendation to adopt as a source term for external exposure to penetrating radiation from uranium metal during the second AWE period a flat plate that is listed in TBD-6000, Table 6.1. NIOSH adopted personal dose equivalent, $H_p(10)$, rates of 0.231 mrem/h to an operator, which is the dose rate at a distance of 1 ft (30.48 cm), and 0.0278 mrem/h to a general laborer, which is the dose rate from a single slug at a distance of 1 m, that are listed in Table 6.1.

NIOSH again assumed that the beta dose rate to the skin of the hands and forearms of the operator was 230 mrem/h and that the beta dose rate to the skin of the rest of the body was 10 times the $H_p(10)$ dose rate or 2.31 mrem/h. We again performed MCNPX simulations and found that the beta dose rate to the skin in contact with the metal was 182 mrem/h, which is somewhat less than the rate assumed by NIOSH, while the beta dose rate at 1 ft was 9.5 mrem/h, over 4 times greater than assumed by NIOSH. The 10:1 ratio between beta skin dose and photon dose is based on observations on film badge readings which are from exposures to a variety of radioactive sources. For a given shape of uranium metal, this ratio can vary widely. The electrons that contribute to skin dose originate in the surface layer of the metal that is approximately 1 mm thick, while the photons can originate anywhere in the metal but are attenuated by absorption and distance. Thus, a 1-mm-thick sheet of uranium would produce approximately the same beta dose as, say, a 10-cm-thick slab with the same lateral dimensions. The thicker shape would generate 100 times the number of photons, a portion of which would exit through the surface layer. Thus, the beta:photon ratio is very much dependent on the configuration. We recommend that NIOSH reevaluate the beta dose to the skin of the whole body from uranium during the second AWE period.

2 Dose Reconstruction Issues and Observations

2.1 MCNP Simulations of Doses From External Penetrating Radiation to Glovebox Operators From Plutonium

NIOSH has not revised the MCNP model of the plutonium glovebox used to support the original ER. As stated in our ER review, we note that the model of the glovebox is not consistent with available documentation and with TIB-0010. Furthermore, NIOSH assumptions about the isotopic composition of the plutonium are not claimant favorable. The analysis performed by SC&A and reported in our review issued on January 27, 2016, indicates a photon dose rate that is almost 50% higher than the one reported by NIOSH. These differences remain unresolved.

2.2 Summary of Issues and Resolutions

Issue that remain open are discussed below.

Issue 1: Doses to Skin from X-Ray Diffraction (XRD) Apparatus

Issue 1 had been previously closed when NIOSH agreed to assign the doses from external exposure to uranium metal to the skin, which were higher than the doses from the XRD apparatus estimated by NIOSH. With the change in the uranium source term discussed in section 1.1.1 of this memo, the dose rate from uranium metal has been reduced, so the dose rate from XRD equipment previously estimated by NIOSH will now be the limiting dose to some workers during the second AWE period.

Because NIOSH had previously decided not to use the XRD doses in DRs, SC&A did not perform a detailed analysis of this pathway when we first reviewed the ER. We have now performed a preliminary review of the June 13, 2016, NIOSH response paper (Thomas 2016). NIOSH assumed an exposure rate of 2 mR/h, as reported by Lubenau et al. (1969), who used a Victoreen 440RF or a Nuclear Chicago 2586 Ion Survey Meter. According to Els (1971), 90% of the photon flux in the scattered beam is in the 8.0–8.9 keV energy range. Els calculated correction factors of 2.42 and 2.48 for the Victoreen instrument exposed to Cu characteristic x rays. Since his paper explicitly addresses radiation safety concerns over the use of an XRD apparatus, such correction factors are applicable in the present case.

Thomas (2016) cites information obtained in the course of an ORAUT interview with a former Carborundum worker who was familiar with the operation of an XRD machine who had been previously interviewed by one of the present authors (RA). Thomas cited the worker as reporting that the runtime was 40 min/sample, that about 10 samples per day were analyzed, and that the operator left the apparatus after the analysis was started. However, she estimated that he remained in the vicinity of the XRD apparatus for 2 min per analysis, without citing any basis. We therefore contacted the former worker to obtain more information about the whereabouts of the operator while the analysis was in progress. He informed the interviewer that it took about 2–3 minutes to replace the previous sample; however, the operator would also inspect the chart recorder that was about 2 ft from the XRD machine and make notations on the chart, and might stay near the apparatus for other reasons, perhaps to talk with a colleague. He estimated the operator spent a total of 4–5 minutes per sample in the vicinity of the machine.

We believe that it would be appropriate to make the claimant-favorable assumption of 5 min/sample H 10 samples/d H 250 workdays/y = 12,500 min/y = 208.3 h/y. Applying the higher correction factor of 2.48, we obtain an annual exposure of 208.3 h H 2.48 H 2 mR/h = 1,033 mR/y = 1.033 R/y, which is significantly higher than the exposure of 0.167 R/y assigned by NIOSH. However, this increase is more than offset by the fact that, given a photon energy of ~8 keV, the appropriate exposure-to-organ-dose conversion factor is one for the <30 keV range rather than the 30–250 keV range used by NIOSH. In the case of the lung, the DCFs for the two energy ranges are 0.100 and 0.986, respectively, while for the liver, they are 0.106 and 1.064. For both organs, the DCFs are approximately 10 times lower for the lower energy range. The difference is much smaller in the case of skin; however, for this organ, the beta radiation from uranium metal would be the limiting pathway.

We recommend that NIOSH revise its XRD exposure assessment as discussed above.

Issue 2: NIOSH Failed to Address Thorium as a Possible Radiation Source

The thorium issue arose from the account of one former Carborundum worker who was interviewed by both ORAU and SC&A and who reported fabricating fuel pellets from powdered thorium in the mid-1950s, prior to the second AWE period. Since thorium and uranium were handled in the same facility, it was possible that the airborne alpha activities measured in 1959 and 1961, reported as uranium, could include some resuspended residual thorium contamination.

NIOSH responded that uranium was also handled during this earlier period, and that any thorium residue during the later period would have been insignificant. To test this hypothesis, we performed a scoping calculation, based on the following simplifying assumptions and data:

- Equal activities of ^{232}Th and natural uranium were deposited in 1955;
- by 1961, the residual contamination was depleted to 29.4% of its original value, according to OTB-0070;
- the lung DCF from ^{232}Th is 88% higher than from ^{234}U of the same particle size and lung absorption type
- airborne activities measured in 1961 included resuspension of activity deposited in 1961 at the same rate as the combined deposition rates of uranium and thorium in 1955.

The dose to the lung based on the 1961 measurements would increase by 10% if the thorium contribution were included. This is a bounding estimate which overlooks the contribution of uranium generated by production and handling activities during the AWE period, as well as by resuspension. Consequently, we agree that NIOSH has addressed the thorium issue, and concur that this source does not make a significant contribution to doses during the second AWE period.

Issues 4 & 5: NIOSH Failed to Assign Doses from Medical X Rays

The ER and the original example DR did not consistently assign doses from medical x rays during the two AWE periods. A review of the IREP input files furnished by NIOSH for the two example DRs show that doses from medical x rays were included. In the example DR for the lung, a dose is assigned for each year of employment during the two AWE periods as a normal distribution with a mean of 0.0838 rem and σ_D = 0.01675 rem, which corresponds to an uncertainty of ±20%. This is inconsistent with the guidance of ORAT-OTIB-0006, which prescribes an uncertainty of ±30%. In the example DR for the kidney, the mean dose is 0.025 rem, which is the dose listed by OTIB-0006 for organs such as the urinary bladder, rather than the liver, which is the surrogate organ for external exposure to the kidney, and which is used in assigning doses from other sources of external photon radiation. An examination of the anatomical drawings shown in OTIB-0006 shows that the kidneys are just below the liver and are much closer to the x-ray beam used to examine the lungs than is the bladder, which is much lower in the body and thus further from the collimated beam. The dose to the liver is listed as 0.0902 rem in OTIB-0006. We recommend that NIOSH corrects this discrepancy. An uncertainty of ±30% was correctly used to calculate the σ_D in this case.

Issue 6: Inappropriate and Incorrect Use of FGR 12

NIOSH used FGR 12 to calculate doses from submersion in a cloud of radioactive dust and from exposure to contaminated surfaces instead of using the values listed in TBD-6000, Tables 3.9 and 3.10. NIOSH has now employed the appropriate TBD-6000 values to calculate these quantities—this issue is resolved. However, we have not yet performed a detailed audit of the new example DR to verify that the organ doses were assigned correctly.

Issue 7: Dose Calculations in "Example DR" Are Not Reproducible

SC&A was not able to reproduce the five sets of organ doses presented in the original example DR. NIOSH has furnished two new example DRs, in which the target organs are the kidney and the lung. We have not yet performed a detailed audit of these two calculations.

Additional Observation

Carborundum dose calculations_draft 3-2-17.xlsx uses inconsistent annual work-hours:

- External doses during the first AWE period assume 2,400 h/y, consistent with 48-h week assumed in TBD-6000
- Intakes during the first residual period are based on 2,500 h/y.

This memo represents a status report that is current as of this writing. The review of the recent NIOSH documents is continuing, and any new results and conclusions will be communicated during the work group meeting on March 13.