MEMORANDUM

TO:	Advisory Board on Radiation and Worker Health, Work Group on Carborundum Company
FROM:	Robert Anigstein, SC&A
DATE:	April 24, 2019
SUBJECT:	Reply to NIOSH Response to Findings on the MCNP Analysis for Carborundum

Background

On August 10, 2018, NIOSH released a white paper (Guido 2018) in response to our review of the NIOSH MCNP[1] analyses of the external exposures of Carborundum Company workers to uranium-plutonium fuel pellets handled in a glovebox (Anigstein 2016, App. B). SC&A reviewed the NIOSH white paper in a memo issued November 27, 2018 (Anigstein 2018) that included three findings. NIOSH responded to our findings in a white paper issued January 18, 2019 (Tomes and Taulbee 2019).

Review of NIOSH White Paper

<u>Finding 1: NIOSH used H*(10) conversion coefficients from photon fluence, based on outdated data, that resulted in a reduction of approximately 2% in the H*(10) doses from ^{241}Am.</u>

According to Tomes and Taulbee (2019), the ambient dose equivalent (H*[10]) fluence-to-dose conversion coefficients used in the MCNP simulations were calculated by multiplying the conversion coefficients for air kerma per unit fluence, K_a/Φ, of monoenergetic photons listed by ICRP (1996, Table A.1) by the conversion coefficients for the ambient dose equivalent from air kerma, $H^*(10)/K_a$, listed by ICRP (1996, Table A.21, col. 2). Anigstein (2018) noted that

> Such a calculation is not needed because the H*(10) conversion coefficients from photon fluence are listed in Table A.21, col. 5. These values are slightly different from those calculated by NIOSH because, as noted in a footnote to Table A.21, they are derived from later values of air kerma per unit fluence, which are listed in Table A.21, col. 4. MCNP calculations of dose rates using both sets of conversion coefficients show that the coefficients used by NIOSH result in a reduction of approximately 2% in the H*(10) doses from ^{241}Am.

[1] MCNP is a generic term that can be applied to the MCNP family of codes that includes MCNPX and MCNP6.

Table 1 lists several sets of conversion coefficients for H*(10) and for air kerma free-in-air (which will henceforth be referred to as "air kerma"). The coefficients listed in cols. 2–4 were copied from ICRP (1996, Table A.21). As noted by ICRP (1996, Table A.21, footnote a): "Data compiled from ICRU Report 47 ([1992]) using Hubbell and Seltzer (1995). The K_a/Φ data are slightly different from those used for the protection quantities (see Table A.1) which used earlier data from Hubbell (1982)."

Table 1. Conversion Coefficients for the Ambient Dose Equivalent, H*(10), from Photon Fluence and Air Kerma Free-in-Air

Photon energy (MeV)	$H^*(10)/K_a$ (Sv/Gy)[a]	K_a/Φ (pGy/cm^2)[a]	$H^*(10)/\Phi$ (pSv cm^2)[a]	K_a/Φ (pGy/cm^2)[b]	K_a/Φ (pGy/cm^2)[c]	$H^*(10)/\Phi$ (pSv cm^2)[d]	$H^*(10)/\Phi$ (pSv cm^2)[e]
0.010	0.008	7.60	0.061	7.43	7.400	0.059	0.011
0.015	0.26	3.21	0.83	3.12	3.125	0.81	0.81
0.020	0.61	1.73	1.05	1.68	1.684	1.02	1.02
0.030	1.10	0.739	0.81	0.721	0.7217	0.79	0.79
0.040	1.47	0.438	0.64	0.429	0.4289	0.63	0.63
0.050	1.67	0.328	0.55	0.323	0.3229	0.54	0.54
0.060	1.74	0.292	0.51	0.289	0.2889	0.50	0.50
0.080	1.72	0.308	0.53	0.307	0.3067	0.53	0.53
0.100	1.65	0.372	0.61	0.371	0.3714	0.61	0.61
0.150	1.49	0.600	0.89	0.599	0.5994	0.89	0.89
0.200	1.40	0.856	1.20	0.856	0.8567	1.20	1.20
0.300	1.31	1.38	1.80	1.38	1.383	1.81	1.81
0.400	1.26	1.89	2.38	1.89	1.892	2.38	2.38
0.500	1.23	2.38	2.93	2.38	2.379	2.93	2.93
0.600	1.21	2.84	3.44	2.84	2.844	3.44	3.44
0.800	1.19	3.69	4.38	3.69	3.702	4.39	4.39
1.000	1.17	4.47	5.20	4.47	4.481	5.23	5.16
1.500	1.15	6.12	6.90	6.14	6.147	7.06	7.06
2.000	1.14	7.51	8.60	7.55	7.557	8.61	8.61
3.000	1.13	9.89	11.1	9.96	9.977	11.25	11.25
4.000	1.12	12.0	13.4	12.1	12.14	13.55	13.55
5.000	1.11	13.9	15.5	14.1	14.18	15.65	15.65
6.000	1.11	15.8	17.6	16.1	16.17	17.87	17.87
8.000	1.11	19.5	21.6	20.1	20.13	22.31	22.31
10.000	1.10	23.2	25.6	24.0	24.13	26.40	26.4

[a] ICRP (1996, Table A.21)

[b] ICRP (1996, Table A.1)

[c] ICRP/ICRU (2017, Table A.6)

[d] Col. 2 × col. 5

[e] NIOSH MCNP file *GB_CRBRNDM.AM.Ph.AM241_.i*

Col. 5 lists the air kerma coefficients from ICRP (1996, Table A.1), while col. 6 lists the air kerma coefficients from ICRP/ICRU (2017, Table A.6) cited by Tomes and Taulbee (2019). Col. 7 lists the conversion coefficients that we calculated by multiplying the col. 2 values by the corresponding values in col. 5, as stipulated by Tomes and Taulbee. The final column lists the coefficients actually used in the NIOSH MCNP analyses.

We observe that the coefficients in cols. 7 and 8 match within the listed precision, with the exception of the values corresponding to photon energies of 0.01 and 1.0 Mev. There is a 5-fold difference between the calculated value and the one used in the MNCP analysis for 0.01 MeV (10 keV) photons, and a 1.4% difference between values for 1.0 MeV. Because 10 keV photons make relatively small contributions to organ doses (except in the case of skin), this difference is usually not significant, while the difference in the 1.0 MeV coefficients is relatively minor. Both discrepancies indicate a possible QA problem.

<u>Observation: There are discrepancies between the H*(10) to photon fluence conversion coefficients described by Tomes and Taulbee (2019) and the values actually employed in the NIOSH MCNP analyses.</u>

We make this an observation rather than a finding, because the NIOSH H*(10) conversion coefficients are already the subject of Finding 1.

Tomes and Taulbee (2019) presented three reasons why the H*(10)/Φ values derived by NIOSH, shown in Table 1, cols. 7 and 8, of the present memo, should be used in the MCNP analyses instead of the values shown in col. 4, listed by ICRP (1996, Table A.21).

1. Consistency with OCAS-IG-001

   The purpose of the dose rates calculated from this effort are to estimate organ doses for EEOICPA claimants. As such, these doses will be multiplied by dose conversion factors (DCFs) found in OCAS-IG-001 [OCAS 2007] in order to calculate organ dose. For H*(10), those DCFs were derived from ICRP [1996] values in Tables A.2 through A.20 divided by the column 2 values from Table A.21.

   The values in Tables A.2 through A.20 come from several published studies listed in ICRP [1996, Table 4]. Some of those listed specifically mention Hubbell (1982) as a source of data. All the studies were completed prior to 1995 so none of them used Hubbell [and Seltzer] (1995) as a source of data.

   The OCAS-IG-001 DCFs were therefore created using values derived in part from Hubbell (1982) and no data from Hubbell [and Seltzer] (1995). Given a choice, it then appears most appropriate to use Hubbell (1982) values for the dose rate calculations. That way, the dose rate and DCFs will be consistently using the same data. (Tomes and Taulbee 2019)

We disagree with this reasoning. According to OCAS (2007, section 4.1.1.2), the photon H*(10)-to-organ-dose conversion factors listed by OCAS (2007, App. A) were derived by the following formula:

$$DCF_{H^*(10)\rightarrow D_T} = \frac{\frac{D_T}{K_\alpha}}{\frac{H^*(10)}{K_\alpha}}$$

where

D_T = absorbed dose in target tissue (Sv)

K_α = air kerma (Gy)

The term in the denominator, $H^*(10)/K_\alpha$, is taken from ICRP (1996, Table A.21), reproduced in Table 1, col. 2, of the present memo. According to ICRP (1996, Table A.21, footnote a): "Data [were] compiled from ICRU Report 47 ([1992]) using Hubbell and Seltzer (1995)." Thus, the DCFs listed by OCAS (2007, App. A) do, in fact, incorporate data from Hubbell and Seltzer. The International Commission on Radiological Protection (ICRP) apparently does not consider these values to be inconsistent with the conversion coefficients listed in Tables A.2–A.20.

Finally, we observe that the DCFs in question are to be used in the revised analyses, which are to be performed by NIOSH using MCNP version 6.2, which was released November 29, 2017. This version is assumed to contain the most current atomic cross sections and mass attenuation coefficients, which are most likely to be more consistent with the Hubbell and Seltzer data published 22 years earlier than with the 35-year-old Hubbell (1982) data. Thus, use of the latest available data, which is based, to the extent practicable, on current science, is more consistent than the use of calculated data based on much earlier determinations.

The second reason presented by NIOSH is: "The variability in the values is trivial compared to the uncertainty in the other factors that go into the Probability of Causation (POC) calculation [Tomes and Taulbee (2019)]." We disagree with this argument. Tomes and Taulbee are correct in observing that in listing the DCFs, OCAS (2007, App. A) binned the photon energies together in only three categories. OCAS could have chosen to tabulate DCFs for all the photon energies listed by ICRP (1996, A.2–A.20) and then combine the resulting doses from the ranges of energies required for input into the Interactive RadioEpidemiological Program (IREP). The resulting uncertainty is therefore a result of the calculational methodology employed by NIOSH. However, since this methodology has been used in dose reconstructions (DRs) throughout the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) program, it would not be appropriate to revisit it at this time.

The last reason given by NIOSH is:

3. The older values are not outdated.

   In 2017, the International Commission on Radiation Units and Measurements (ICRU) and the ICRP released for public comment a draft report on the Operational Quantities for External Radiation Exposure (ICRU/ICRP 2017). Table A.6 of that report once again provides values for the parameter in question

(K_a/Φ) that more closely resembles Table A.1 than Table A.21 of ICRP 74. (Tomes and Taulbee 2019)

We agree that the K_a/Φ values listed by ICRU/ICRP (2017, Table A.6), listed in Table 1, col. 6, of the present memo, closely resemble the values listed by ICRP (1996, Table A.1), shown in Table 1, col. 5. ICRU/ICRP states:

> Air kerma coefficients, $K_{air}/\Phi = (\mu_{en}/\rho)\ E\ (1\text{-}g)^{-1}$ are used for the conversion from *dose per fluence to dose per air kerma* [emphasis added]. The values for (μ_{en}/ρ) are from the calculations of Seltzer (1993) and Hubbell and Seltzer (1995) with renormalized Scofield photoeffect cross sections (ICRU 2014). The values for *g* are from Seltzer (2017).

The air kerma coefficients are listed by ICRU/ICRP (2017) to enable the calculation of dose per unit kerma if the dose per fluence is known, not to calculate dose per fluence. Furthermore, since the values do utilize the most recent data, including Hubbell and Seltzer (1995), the differences between these values and those listed by ICRP (1996, Table A.21) are most likely the result of the calculational methods used for the air kerma approximation, not the physical data. Thus, the recalculation of $H^*(10)/\Phi$ by NIOSH rather than the use of the authoritative values presented by ICRP (1996, Table A.21) is not justified.

A further concern over use of the ICRU/ICRP (2017, Table A.6) data is that this document is a draft for comment that is "not to be referenced." To the best of our knowledge, it has not been issued as a final report, although almost two years have elapsed since its release in July 2017. ICRU/ICRP has received 40 comments before the close of the comment period in November 2017. A check of a random sample of these comments indicates that some respondents had substantive questions about this document. We believe that it should not be used as a reference for the present analysis.

In conclusion, we do not agree that NIOSH should substitute its own recalculated values of $H^*(10)/\Phi$ for the authoritative values presented by ICRP (1996, Table A.21, col. 5), for the following reasons:

- ICRP's $H^*(10)/\Phi$ values are consistent with the organ dose coefficients listed by ICRP (1996, Tables A.2–A.20) and represent current science.

- The $H^*(10)/\Phi$ values calculated by NIOSH resulted in a reduction of approximately 2% in the $H^*(10)$ doses from ^{241}Am, the principal contributor to external doses from the uranium-plutonium fuel pellets.

- ICRU/ICRP (2017) is a draft document that has not been adopted by the sponsoring organization and is therefore irrelevant to the present discussion.

- NIOSH intends to repeat the MCNP photon dose analyses for 15 radionuclides to resolve Findings 1 and 2. As observed earlier in the present memo, the values of the $H^*(10)/\Phi$ coefficients for photon energies of 0.01 and 1 MeV in the NIOSH MCNP input files are inconsistent with the methodology described by Tomes and Taulbee (2019)—presumably, these values need to be corrected in any case. We do not believe that revising the values of all the H*(10)/Φ coefficients, which occupy four lines of data in the input files, represents a significant effort.

Finding 2: NIOSH used incorrect source biasing in the MCNP analyses

According to Tomes and Taulbee (2019), NIOSH recalculated the dose rates from ^{241}Am in the uranium-plutonium fuel pellets using MCNP version 6.2. We agree that using MCNP 6.2 for simulating the photon doses from ^{241}Am and the remaining radionuclides, as well as for the assessment of neutron doses, would resolve Finding 2.

Finding 3: The simulated dosimeters in the glovebox geometry modeled by NIOSH are partially shielded by the floor of the glovebox, which reduces the calculated doses.

Tomes and Taulbee (2019) stated that "the settings in MCNP were modified such that the source (pellet) and dosimeters are now at a height 24 cm above the work surface of the glovebox." We agree that this change would resolve Finding 3.

Conclusion

Tomes and Taulbee (2019, Table 2) compared the updated NIOSH calculations of the photon H*(10) rates from ^{241}Am in the uranium-plutonium fuel pellets to those presented by Anigstein (2018) and found that the NIOSH results are approximately 2% lower than the corresponding SC&A values. NIOSH has thus resolved the major discrepancies addressed by Findings 2 and 3. The remaining discrepancy appears to be due to the choice of H*(10) fluence-to-dose conversion coefficients cited in Finding 1.

NIOSH and SC&A have reached agreement on two major issues in the MCNP analyses of photon and neutron doses from plutonium fuel pellets: incorrect source biasing and erroneous exposure geometry. These issues are the major source of discrepancies between the SC&A and NIOSH analyses. The third issue, the recalculation by NIOSH of the conversion coefficient H*(10)/Φ, while of lesser significance, still awaits resolution.

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