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TO: Advisory Board on Radiation and Worker Health, Work Group on Mound Plant
FROM: Robert Anigstein, Ron Buchanan, Joe Fitzgerald, and John Mauro, SC&A
SUBJECT: Comments on NIOSH Evaluation of NTA Neutron Film Fading at Mound
DATE: January 20, 2011

The recent NIOSH (2010) report is a response to our earlier report (Anigstein and Olsher 2010) and to observations made by SC&A staff members at the July 27, 2010, meeting of Work Group on the Mound Plant. SC&A has a number of comments on the NIOSH report that we would like to communicate to the Work Group, which are discussed below.

First, SC&A would like to clarify a statement in the first paragraph on page 2 of NIOSH (2010) in which NIOSH quotes from SC&A's comments during the July 27–28, 2010, Mound work group meeting: As a result, the fading values used by NIOSH in the site profile are: 33% in the first week after exposure and 56% in the subsequent week may not be favorable to the claimant. SC&A made this statement on the basis that the workplace neutron energy spectrum could have been moderated compared to the bare calibration sources and therefore contained lower energy neutrons, increasing the fading factors compared to those derived from unmoderated calibration sources.

The site profile (Proctor and Alguitifan 2004) discusses the history of neutron dosimetry, using NTA film, at Mound during the period 1949–1976. The profile mentions the corrections for fading—33% in 1 week and 56% in 2 weeks—that were applied by the Mound dosimetry section to all films processed on or after July 15, 1968. (A correction of 56% was also applied to 4-week films.) Starting January 13, 1969, calibration films "were exposed progressively over a four week period to match the time different groups wore their film badges. This compensated for an image fading problem." (Meyer 1994) However, the site profile does not direct dose reconstructors to apply a fading correction to NTA film badge records. Faust et al. (2009, Table 4-3) list a fading correction of 9% per week to be applied to MESH neutron data prior to 1969. We are not sure if the statement by NIOSH (2010) quoted above was meant to imply that the fading values of 33% in 1 week and 56% in 2 weeks were applied by NIOSH in reconstructing neutron doses from NTA film records; such an assertion is not supported by the available documentation, nor in NIOSH's recent responses.

NIOSH (2010) highlighted a typographical error in Anigstein and Olsher (2010, p. 9). Our report stated that the predicted fading of NTA film after 2 weeks is 87%. The correct value is 57%, which is obtained from our Equation 6, and is consistent with the 56% reported by Mound.[1]

NIOSH (2010) discussed a note by Kahle et al. (1969) that described experiments performed at Mound to study the dependence on fading of NTA films on neutron energies. Kahle et al. summarized two Mound reports on the fading of NTA films as a function of time after exposure. The first report, a study of fading following exposure to a $^{238}PuF_4$ source, was the basis of the fading rate of 34% per week discussed by Anigstein and Olsher (2010).

[1] We informed the Work Group of this error in an e-mail dated December 29, 2010.

The second was a Monsanto draft report (Arnett 1994) that claimed that a PuO_2 source moderated with 8 inches of polyethylene had an average neutron energy of 0.9 MeV.[2] This may or may not be correct. What is important is the average energy of the neutrons that are actually recorded by the NTA film.

Eight inches of polyethylene has about the same hydrogen cross-sectional density (atoms/cm^2) as 10 inches of water. We can therefore compare the average energies yielded by our MCNPX calculations for a PuO_2 source inside a 10-inch water sphere with those from a bare PuF_4 source. These results are shown in Table 1.

Table 1. Average Energies of Two Neutron Sources, as Recorded by NTA Film

E_0 (MeV)	$E_{ave} > E_o$ (MeV)	
	Bare PuF_4	PuO_2: 10" H_2O
0.5	1.40	2.11
0.6	1.44	2.29
0.7	1.50	2.46
Lehman	1.49	2.54

The table lists the average energies of neutrons above three threshold energies—0.5, 0.6, and 0.7 MeV—as well as the average energy of the neutron spectrum weighted by the energy-dependent efficiency of the neutrons in producing tracks on the NTA film, based on Lehman (1961) and described by Anigstein and Olsher (2010). As can be seen, regardless of which assumption one makes about how the neutrons are registered, the average energies of the attenuated $^{238}PuO_2$ source that are measured by the NTA film are significantly higher than the energies of the bare $^{238}PuF_4$ source, and much higher than the 0.9 MeV cited by Arnett (1994).[3] MCNP calculations for the neutron spectra of both sources were performed at the simulated location of the film badge worn by a worker 60 cm from the source.

Consequently, Arnett's findings, that the films exposed to the moderated $^{238}PuO_2$ source experienced less fading than the films exposed to a bare $^{238}PuF_4$ source, are consistent with the observation that fading is greater for NTA films exposed to lower-energy neutrons. Kahle et al. (1969), apparently unaware of the mischaracterization of the average energy of the neutrons emitted by the moderated $^{238}PuO_2$ source, ascribed the seemingly anomalous finding—that the films exposed to this source exhibited less fading—to the need to consider the detailed neutron spectrum, not just the average energy.

[2] This review of Arnett’s report was performed in the process of preparing our earlier report (Anigstein and Olsher 2010). It was mentioned briefly, but was not included in its entirety because it was not germane to that report. Since NIOSH (2010) discussed at length the Kahle et al. (1969) report, we felt it was appropriate to present this review at this time.

[3] Curiously, Arnett cites an average energy of 1.3 MeV for the bare $^{238}PuF_4$ source, which is not markedly different from the 1.49 MeV listed above, the difference being most likely due to ignoring or under-weighting the low-energy neutrons in the above analysis. This leads us to believe that the 0.9 MeV value is simply an error.

NIOSH (2010) agreed to apply the correction factors derived by Anigstein and Olsher (2010, Tables 2 and 3) for the "observer" exposed to a neutron source moderated by 8 inches of water to NTA film dosimetry data for the various time periods listed. However, for three of these time periods, spanning the era from January 25, 1956, through August 8, 1965, NIOSH used the factors derived for ^{210}Po-Be sources, and did not note the higher correction factors for $^{238}PuO_2$ sources and the even higher ones for $^{238}PuF_4$ during these time periods. According to a time chart, "Radioisotopes of Significance Handled at Mound—External Dosimetry" (Meyer 1994, Vol. 1 [SRDB Ref ID 3268, p. 9]), ^{239}Pu was present from the beginning of 1956, while ^{238}Pu was there from 1959. Since ^{239}Pu has a lower-energy alpha spectrum than ^{238}Pu, the neutron spectrum from the (α,n) reaction in compounds of ^{239}Pu is expected to have lower energies than the neutron spectrum from sources containing ^{238}Pu. Consequently, absent a specific analysis of ^{239}Pu, the correction factors derived for $^{238}PuF_4$ should be applied in the time periods spanning January 25, 1956, through August 8, 1965. In cases for which NIOSH is certain that a given employee was only exposed to neutrons from ^{210}Po-Be or $^{238}PuO_2$ sources, the smaller correction factors appropriate to these neutron spectra can be employed.

It is not clear if NIOSH recognized that the correction factors listed by Anigstein and Olsher (2010, Tables 2 and 3) need to be multiplied by the factor of 1.33 to account for angular dependence, as derived by Kathren et al. (1965) and accepted by Faust et al. (2009). The suggested, claimant-favorable correction factors for the various time periods are listed in Table 2, below. Corrections for fading of NTA film are not included.

Table 2. Adjusted Correction Factors[a]

Dates	C.F.[b]	C.F. angular[c]
August 1949 through September 1951	4.5	6.0
October 1951 through December 1954	2.2	2.9
January 1955 through January 24, 1956	1	1.3
January 25, 1956 through December 1958	2	2.7
January 1959 through August 8, 1963	3.7	4.9
August 9, 1963 through August 8, 1965	4.7	6.3
August 9, 1965 through November 30, 1968	2.2	2.9
December 1, 1968 through December 31, 1969	1.7	2.3
January 1970 through December 1977	0.9	1.2

[a] Correction for fading not included

[b] Correction factors for "observer" exposed to neutron source attenuated by 8 inches of water

[c] Correction factors in column 2, multiplied by 1.33 to account for angular dependence of film response

The major unresolved issue deals with the energy-dependence of track fading in the NTA film. Another, potentially more significant, issue is the effect of temperature and humidity on track fading. The literature on NTA track fading cites these factors much more often than neutron energy dependence. We note that the 33%-per-week fading factor used at Mound is based on a single set of films exposed and developed during a single 2-week period. No mention was made of the temperature or humidity in the film storage area. The fading rate could be different during other periods.

Retrospective fading corrections are basically suspect, since the exposure conditions are unknown. The Mound dosimetry section recognized this problem, and starting in November 1968, the calibration films were exposed to neutron sources over the same period as the film badges were worn by workers. Prior to this time, the calibration films were exposed for periods of a few hours and developed the same or the next day, so the fading was not experienced by these films. Thus, the accuracy of the NTA film dosimetry at Mound prior to November 1968 is degraded.

A cursory review of the available literature shows a number of studies of fading of the latent images on NTA film. These studies utilized a variety of radiation sources; the films were stored under various environmental conditions between exposure and development. In principle, it should be possible to review these studies and construct a matrix relating fading rates to exposure and storage conditions. It may then be possible to develop a claimant-favorable fading factor by relating the known exposure conditions at Mound to those reported in the literature and performing a curve fit or some other mathematical analysis.

SC&A finds these correction factors to have the same level of uncertainty as other uncertainties and assumptions inherit in the dose reconstruction process; therefore, we conclude that, at this point, NTA fading is a site profile and not an SEC issue. At a minimum, we find that to address the fading issue, it would be necessary for NIOSH to apply the fading factors that we derived from the experiments performed at Mound—34% per week and 57% per 2 weeks—to all NTA film readings, unless:

- They were already corrected by these factors.
- They were already on a fading-compensation exchange cycle.
- It can be assured that the exposures only consisted of neutrons from ^{210}Po-Be or $^{238}PuO_2$ sources. In such cases, a 9% per week fading factor for ^{210}Po-Be or the 16% per week fading factor derived by Arnett (1994) for $^{238}PuO_2$ would be acceptable.

This is in addition to the MCNP correction factors for low-energy neutrons, and the angular correction factor of 1.33. However, not applying the source-specific fading correction factor would be considered an SEC issue because lost neutron dose due to fading would not be accounted for; therefore, dose reconstruction with sufficient accuracy would not be provided.

References

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