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SC&A's Evaluation of the Pantex External Coworker Model: ORAUT-OTIB-0086

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ABBREVIATIONS AND ACRONYMS

AP	anterior-posterior
BWXT	Babcock & Wilcock Transmission Technologies
cm	centimeter
DOE	(U.S.) Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
DoRMs	Dosimetry Records Management System
eV	electron volt
GM	geometric mean
GDS	geometric standard deviation
keV	kilo electron volt
LANL	Los Alamos National Laboratory
LOD	limit of detection
MCNP	Monte Carlo n-particle
MeV	million electron volts
MDL	minimum detectable level
MRD	minimum recordable dose
N	number of workers
NIOSH	National Institute for Occupational Safety and Health
NTA	Neutron Track Emulsion, Type A (film)
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT Technical Information Bulletin
PA	posterior-anterior
PuO_2	plutonium oxide
PuF_4	plutonium tetrafluoride
SC&A	S. Cohen & Associates (SC&A, Inc.)
SSN	Social Security Number
TLD	thermoluminescent dosimeter
WB	whole body
β	beta particle
γ	gamma ray

1.0 INTRODUCTION AND BACKGROUND

ORAUT-OTIB-0086 (ORAUT 2015a), which will be referred to as OTIB-0086 in this report, provides information and coworker data for the dose reconstructor concerning assigning dose to Pantex workers that had no, or limited, external dose records; this information can also be used to assign dose when there are gaps in the monitored worker's records. OTIB-0086 also provides some recommendations on how to handle zeros, blanks, dashes, slashes, and hash marks in the dose records.

The major items in OTIB-0086 are:

- Recommendations concerning entries containing zeros, blanks, or marks
- External dose data development methodology
- Coworker photon, neutron, and skin doses for 1960–2010 (Tables 7-1, 7-2, and 7-3, respectively)
- Attachment A: Details of coworker dose development for photon, neutron, and skin exposures
- Attachment B: Details of neutron NTA film (1960–1976) correction factors for energy response, angular response, and fading

An evaluation of each item is provided in the following sections.

2.0 NIOSH'S RECOMMENDATIONS CONCERNING DOSE RECORD ENTRIES CONTAINING ZEROS, BLANKS, OR MARKS

Section 1.1 of OTIB-0086 recommends:

- **Recorded "0" –** This entry is assumed to mean that the dosimeter was issued and processed, and that no exposure or dose was detected in excess of the dosimeter limits of detection (LOD).
- **Blanks –** Indicates that no dosimeter was issued during this exchange cycle, or that the dosimeter was lost, damaged, or a processing error occurred.
- **Marks –** Dash, slash, or hash marks indicate that no dosimeter was issued during this exchange cycle, or that the dosimeter was lost, damaged, or a processing error occurred.

According to page 5 of OTIB-0086, the dose reconstructor will assign dose before[1] 1988 as follows:

> *In such cases for years before 1988, NIOSH intends to apply (after consideration of the worker's job title and the totality of the monitoring record), either:*
>
> *(1) Unmonitored dose based on external coworker data*
>
> *(2) Missed dose*
>
> *(3) Ambient dose*

After 1988:

> *After 1988, all personnel who entered the operational areas of the plant were required to wear a dosimeter as a condition for entry. The absence of a listed result, or the presence of a dash, slash, or hash mark for a given dosimeter exchange cycle in 1988 and later years, should be interpreted to mean that the worker was not monitored because he or she was not present in the operational areas. Therefore, ambient dose should be assigned for those exchange cycles.*

SC&A finds NIOSH's recommendations concerning zero, blank, or marks in the entries to be consistent with those used for other Department of Energy (DOE) sites and dosimetry records in general, and has not found data that are in conflict with these recommendations. However, it appears that the term 'before 1988' should be changed to 'before 1989' and the term 'in 1988' should be changed to 'in 1989' on page 5 of OTIB-0086.

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[1] According to ORAUT-TKBS-0013-6 (ORAUT 2007), Section 6.4, page 11, starting in 1989, all personnel entering the operational areas were required to wear a dosimeter; therefore, the terms "before 1988" should be changed to "before 1989" and "in 1988" should be changed to "in 1989" in this section of OTIB-0086.

3.0 EXTERNAL DOSE DATA DEVELOPMENT METHODOLOGY

Sections 3.0 through 7.0, pages 6–8, of OTIB-0086 provide the general approach to the development of the Pantex coworker external doses. In summary:

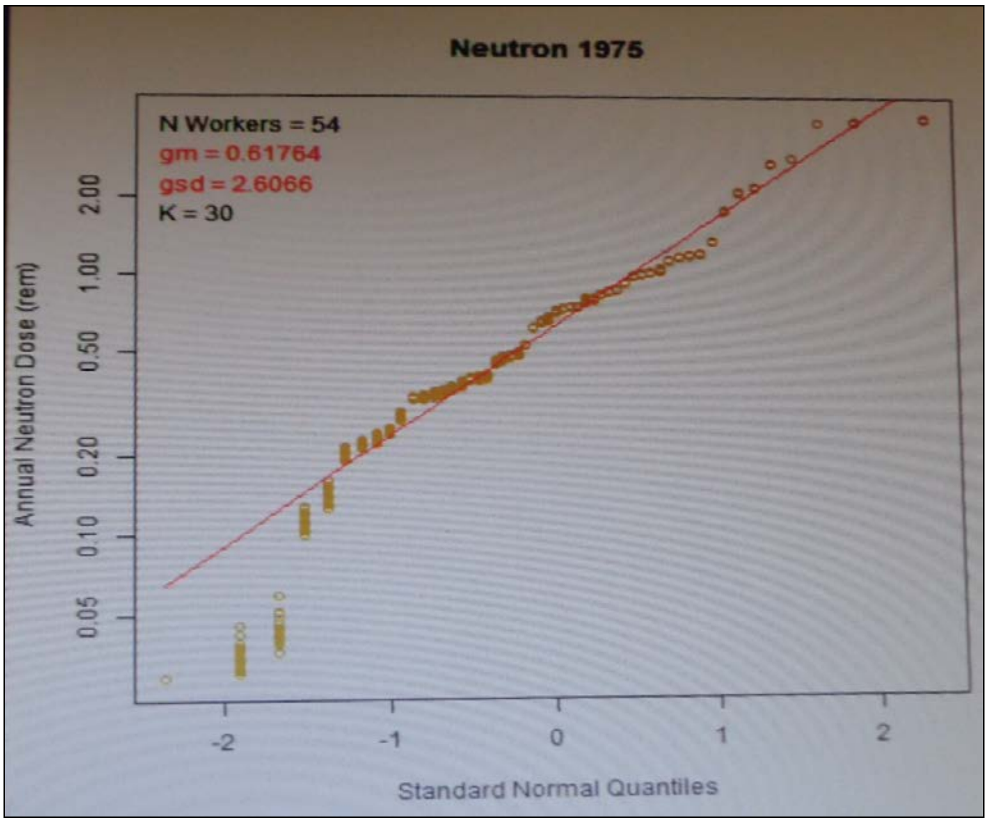
- NIOSH used ORAUT-RPRT-0071 (ORAUT 2015b) to analyze recorded values less than the LOD, instead of the former method that used ½ LOD values.
- The greater of the dose in BWXT 2011 or BWXT 2013 was used if there was a difference in dose for a given person for a given badge cycle.
- The neutron dose results using the Stanford algorithm [applicable to thermoluminescent dosimeter (TLD) results only] are likely biased high, because an unmoderated Cf-252 source was used for calibration, rather than a moderated Cf-252 source that would have been more representative of Pantex workplace neutron spectra ([redacted] 2004).

The details of the coworker dose analyses are provided in Attachments A and B of OTIB-0086, which will be evaluated in the following sections of this report. SC&A did not evaluate ORAUT-RPRT-0071 (ORAUT 2015b) in this report; this would be evaluated under a separate tasking.

4.0 TABLES OF COWORKER PHOTON, NEUTRON, AND SKIN DOSES FOR 1960–2010

Tables 7-1, 7-2, and 7-3 of OTIB-0086 provide the recommended coworker doses for photon, neutron, and skin, respectively, for the time period 1960–2010. The data for these tables were obtained from the BWXT Pantex 2011 database (BWXT 2011) (which contained the original recorded photon, neutron, and skin doses), and the BWXT Pantex 2013 database (BWXT 2013), which contains the algorithm-modified TLD doses for 1980–1993. The results of analyzing the data in these databases are detailed in plots for each type of radiation for each year in ORAUT 2015c. These plots show the annual geometric mean (GM), the geometric standard deviation (GSD), and number of workers (N) for each year for photon, neutron, and skin doses. An example of one of the plots is provided here as Exhibit A.

Exhibit A. Example of Dose Plot from ORAUT-RPRT-0071



Source: ORAUT 2015c

SC&A spot checked the tables and the plots and did not locate any abnormalities; except for the 1975 neutron dose. The 1975 neutron dose in Table 7-2 of OTIB-0086 and in the plot on page 64 of ORAUT 2015c is a factor of 10 to 100 times the other annual neutron doses; whereas, the photon and skin doses for 1975 did not show any increase for this year. Additionally, the 1975 neutron dose in Table 6-5 of Pantex TKBS-0013-6 (ORAUT 2007) does not indicate any abnormalities for 1975. SC&A recommends that the neutron dose for 1975 be reviewed to determine why there is such an increase for that one year.

5.0 DETAILS OF COWORKER DOSE DEVELOPMENT FOR PHOTON, NEUTRON, AND SKIN EXPOSURES – ATTACHMENT A OF OTIB-0086

The dosimetry systems used at Pantex are summarized in Table A-1, page 17, of OTIB-0086, which is reproduced here as Exhibit B.

Exhibit B. Summary of Dosimetry Systems Used at Pantex

Table A-1. Dosimeter types, periods of use, exchange frequencies, MRDs, and MDLs (mrem) (derived from Table 6-2 of ORAUT 2007).

Dosimeter type/ provider	Period	Exchange frequency[a]	Skin MRD	β/γ deep MRD	Neutron MRD	Skin MDL	Deep MDL	Neutron MDL
βλ film/Tracerlab	01/1952–12/1959	Weekly	30[b]	10[b]	None	40[c]	40[c]	None
βγ film and NTA film/ Tracerlab	01/1960–03/1961	Weekly	30[b]	10[b]	15[b]	40[c]	40[c]	None
	04/1961–05/1963	Monthly	30[b]	10[b]	15[b]	40[c]	40[c]	None
βγ film and NTA film/ Eberline	06/1963–09/1964	Monthly	10[b]	10[b]	10[b]	40[c]	40[c]	None
βγ film and NTA film/ Landauer	10/1964–12/1968	2/month	40[b]	10[b]	10[b,d]	40[c]	40[c]	None
βγ film and NTA film/ Landauer	01/1969–12/1972	Monthly	40[b]	10[b]	20[b,e]	40[c]	40[c]	None
TLD 2-element/in-house and NTA film/Landauer[f]	01/1973–12/1975	Monthly	10	4	10[b,d]	30	30	None
TLD 6-element/in-house	01/1977–13/1979	Monthly	10	4	50	30	30	50
Panasonic 802/in-house[g]	01/1980–12/1990	Monthly	20	20	50	30	30	50
Panasonic 802/in-house[g]	01/1992–12/1999	Monthly	15	10	70	30	30	50
Panasonic 802/in-house[g]	01/1992–12/1999	Quarterly	20	15	85	30	30	50
Panasonic 809/812/in-house[h]	01/1994–present	Monthly	10	10	5[i], 25[j]	30	30	50
Panasonic 809/812/in-house[h]	01/1994–present	Quarterly	15	15	10[i], 65[j]	30	30	50

a. Exchange frequencies were established from dosimetry reports. The initial weekly exchange frequency was changed to monthly in March 1961 (Tracerlab 1962–1963). A monthly exchange frequency continued with Eberline (Ashton 2003). An exchange frequency of twice per month for both beta/gamma and neutron films was established with Landauer in October 1964; this frequency changed, for both beta/gamma and neutron films, to monthly in January 1969 (Adams 2003). NTA film provided by Landauer was used with the two-element TLD and exchanged monthly (Adams 2003).
b. Based on minimum doses recorded on dosimetry reports (Adams 2003; Ashton 2003; Tracerlab 1962–1963).
c. Estimated MDL typical of film dosimeter capabilities (Lalos 1989; NIOSH 1993; Wilson 1960, 1987; Wilson et al. 1990).
d. MRD for thermal neutrons (Adams 2003).
e. MRD for fast neutrons (greater than 1 MeV) (Adams 2003).
f. The Pantex in-house two-element TLD was implemented in 1973 for monitoring only beta/gamma radiation exposures. Use of NTA film continued for monitoring neutron exposures until the implementation of the six-element TLD system in 1977.
g. In 1992, the algorithms were changed for the Panasonic 802 to the Stanford algorithms (BWXT Pantex 2001). The dosimeter exchange frequency for nonradiation workers was changed from monthly to quarterly in 1992.
h. Beginning in January 1994, the Panasonic 809/812 dosimeter was provided to radiation workers and exchanged monthly. The Panasonic 802 dosimeter was provided to all other Pantex workers and exchanged quarterly. Between 1994 and 2000, Panasonic 802 dosimeters were gradually phased out and replaced by Panasonic 809/812 dosimeters for all workers.
i. DOELAP performance testing with moderated Cf-252 neutrons.
j. DOELAP performance testing with unmoderated Cf-252 neutrons.

Source: ORAUT 2015a, Table A-1

In general, OTIB-0086 separates the dosimetry at Pantex into the following eras. However, SC&A noted that the text in Table A-1 in OTIB-0086 and the text in Table 6-2 in ORAUT-TKBS-0013-6 (ORAUT 2007) do not always agree on the year NTA film ended, and also on the years 2-element TLDs were used:

- 1952–1959: Used film for photons and betas, no adjustment factor to be applied (use BWXT 2011 dose data as is).
- 1960–1972: Used film for photons, betas and neutrons; NTA film requires adjustment factors (neutron and skin doses were assigned for one period during 1960–1963, because

of insufficient data for any given year) (use BWXT 2011 dose data with no adjustment factor for photons or betas).

- 1973–1977: Used 2-element TLDs for photons and betas, and used NTA film for neutrons; NTA film requires adjustment factors (use BWXT 2011 dose data with no adjustment factor for photons or betas). Note that in Column 2 of Table A-1 of OTIB-0086, the year 1976 is omitted and the TLD 6-element is included in 1977.

- 1978–1979: Used 6-element TLDs with no adjustment factors for photons, betas, or neutrons (use BWXT 2011 dose data as is).

- 1980–1993: Used Panasonic-802 TLDs with algorithm applied later after recording of TLD element readouts (for 1983, use interpolation between 1982 and 1984 because of the lack of 1983 original TLD readings) (use BWXT 2013 dose data that have Stanford algorithm applied).

- 1994–2010: Used Panasonic-809 TLDs with algorithm applied at time of TLD readouts (use BWXT 2011 dose data as is).

The databases used for Pantex coworker modeling were the BWXT Pantex 2011 database (BWXT 2011), which contained the original recorded photon, neutron, and skin doses, and the BWXT Pantex 2013 database (BWXT 2013), which contained the doses from BWXT Pantex 2011 modified by using an algorithm (called the Stanford Algorithm developed by Stanford Dosimetry, LLC, for Pantex's in-house Panasonic dosimetry system).

Data that appear in BWXT 2011 but not in BWXT 2013, or vice versa, are to be discarded ([redacted] 2015), because the algorithm could only be applied to the original TLD element readout values, and not the final assigned dose value in the records.

A summary of the database usage is provided in Table A-2 of OTIB-0086, and reproduced here as Exhibit C.

Exhibit C. Summary of Data Used in Pantex Coworker Model

Table A-2. Sources of dose information.

Period	Year	Month	Individual ID[a]	Dosimeter Dose
1960–1979 and 1994–2010	BWXT Pantex 2011, Column G	BWXT Pantex 2011, Column H	BWXT Pantex 2011, Column B	BWXT Pantex 2011, Column K, WB skin dose; Column L, WB gamma dose; and Column M, WB neutron dose[b]
1980–1993	BWXT Pantex 2013, Column A, and BWXT Pantex 2011, Column G	BWXT Pantex 2013, Column B, and BWXT Pantex 2011, Column H	BWXT Pantex 2013, Column C, and BWXT Pantex 2011, Column A	BWXT Pantex 2013, Column E, WB skin dose; Column F, WB gamma dose; and Column G, WB neutron dose as well as BWXT Pantex 2011, Column K, WB skin dose; Column L, WB gamma dose; and Column M, WB neutron dose

a. SSN is preferred over badge number.
b. NTA correction factor is 2.9 for 1960 to 1977.

Source: ORAUT 2015a, Table A-2

These data, as described above, contained in the BWXT 2011 and BWXT 2013 databases were used to create the photon, neutron, and skin dose plots for 1960–2010, as shown in ORAUT 2015c. These data were used to create the annual coworker doses in Tables 7-1, 7-2, and 7-3, of OTIB-0086, for photons, neutrons, and skin, respectively, for the time period 1960–2010.

SC&A's review of the resulting annual coworker doses in Tables 7-1, 7-2, and 7-3 of OTIB-0086 for photons, neutrons, and skin, respectively, for the time period 1960–2010 did not identify any issues, except for the relatively large coworker neutron dose for 1975, as previously discussed.

6.0 DETAILS OF NEUTRON NTA FILM (1960–1977) CORRECTION FACTORS FOR ENERGY RESPONSE, ANGULAR RESPONSE, AND FADING – ATTACHMENT B OF OTIB-0086

1.5.1 NIOSH recommendations

In OTIB-0086, NIOSH recommends using the originally recorded neutron dose from NTA film, multiplied by a correction factor of 2.9, which was derived from an energy response factor of 1.4, an angular response factor of 1.33, and a track fading factor of 1.56 (i.e., 1.4 × 1.33 × 1.56 = 2.9). These factors were derived as follows:

1. **Energy response –** NIOSH used their MCNP model generated for Mound Laboratory of an observer located at 240 cm from a glovebox (shielded with 4 inches of moderator) located in a concrete room. In this model, the NTA film would miss 29% of the dose equivalent because of the NTA film's 500 keV neutron energy threshold. The correction factor would be 1/(1-0.29) = 1.4.

2. **Angular response –** NIOSH used the angular correction factor of 1.33 for NTA film from Kathren et al. (1965) for anterior-posterior (AP) geometry neutron exposures.

3. **Track fading –** NIOSH used the NTA film track fading correction factor of 9% per week (Kahle et al. 1969) for a total of 4 × 0.09 = 0.36 per month; for a derived track fading factor of 1/(1-0.36) = 1.56.

At this point, it is uncertain if NIOSH plans to apply the 2.9 factor to all recorded neutron doses through 1977. Page 7 of OTIB-0086 recommends it be applied to 1960–1977, but Table A-1, page 17, of OTIB-0086 lists NTA film used through 1975, and ORAUT-TKBS-0013-6 (ORAUT 2007), Table 6-2, page 15, lists NTA film used through 1976. This point needs to be clarified and consistent instructions provided to the dose reconstructors.

6.1 SC&A's Evaluation of NTA Film Correction Factors

Following is SC&A's evaluation of the NTA film correction factors recommended in OTIB-0086.

1. **Energy response –** OTIB-0086 uses the term "THERMAL NEUTRONS" on page 21; however, SC&A assumes that this is a general term referring to neutrons with energy below 500 keV, since thermal neutrons are defined as 0.025 eV in energy. In evaluating the recommended energy correction factor of 1.4, SC&A does not find that the MCNP model generated for Mound Laboratory of an observer located at 240 cm from a glovebox with 4 inches of moderator necessarily represents the situation and neutron energy fields for a worker at Pantex with potential exposure to multiple neutron sources (such as in a bay, cell, etc.). This is especially true for situations where a Pantex worker was exposed to posterior-anterior (PA) geometry neutron sources, because the Mound model was for AP geometry neutron sources. Additionally, SC&A could not find that NIOSH had performed an MCNP model particular to Pantex, as implied in the statement on page 21 of OTIB-0086:

> *A Monte Carlo n-particle (MCNP) model was developed to determine the amount of dose that was missed due to a sensitivity threshold of 500 keV for the conditions likely to have been encountered by workers who received neutron doses at Pantex (LANL 2003).* [Emphasis added.]

SC&A found that NIOSH apparently applied the MCNP model for Mound to Pantex. SC&A also found that the reference of LANL 2003 in the above quoted statement was to the LANL MCNP program in general, which was not specific to either Mound Laboratory or Pantex.

2. **Angular response –** The angular correction factor of 1.33 for NTA film from Kathren et al. (1965) was derived for only AP geometry exposures. However, personnel at Pantex were potentially exposed to multiple sources of neutrons, which could include PA geometry. Neither the NTA film calibration nor the AP angular correction factor address PA geometry for neutron exposure.

3. **Track fading –** OTIB-0086 used the moderated $^{238}PuO_2$ (average energy of 0.9 MeV) exposed NTA film track fading correction factor of 9% per week (Kahle et al. 1969) for a total of 4 × 0.09 = 0.36 per month, for a derived track fading factor of 1/(1-0.36) = 1.56. However, the same referenced article (Kahle et al. 1969) also provides data that show that a $^{238}PuF_4$ neutron source (average energy of 1.3 MeV), under identical exposure conditions, produced a fading factor of 33% after 1 week and 56% after 2 weeks. ORAUT-TKBS-0017-6 (ORAUT 2007) does not provide information concerning the timing of the neutron calibration cycle (i.e., if it was performed at the beginning, mid, or the end of the badging cycle); and Section 6.5.3.2 and Table 6-8 indicate that no detailed information was available concerning neutron dosimetry at Pantex prior to 1980. However, Table 6-13, page 36, of ORAUT-TKBS-0017-6 (ORAUT 2007), does recommend using a neutron energy range of 0.1–2 MeV; hence, both the 0.9 MeV $^{238}PuO_2$ and the 1.3 MeV $^{238}PuF_4$ neutron sources fall in that energy range. There does not appear to be any supporting evidence to select the lower fading factor of 9%. In NIOSH's Mound white paper (NIOSH 2010), it is stated on page 4:

   > *NIOSH continues to support the fading values of 33% in the first week after exposure and 56% after two weeks. This fading correction is to be applied independent of other corrections such as angular response or energy response.*

   Therefore, it is not obvious why the value of 9% fading per week was selected to be applied at Pantex.

6.2 Summary

OTIB-0086 provides information concerning the following items at Pantex:

1. **Zeros –** Dose reconstruction recommendations for entries containing zero, blank, and marks in the dose records.

2. **Coworker doses –** Coworker photon, neutron, and skin doses for the period 1960–2010 are provided in Tables 1, 2, and 3, respectively. The information for these tables was obtained from the dose data from BWXT 2011 for the periods 1960–1979 and 1994–2010 and from BWXT 2013 for the period 1980–1993.

3. **NTA film –** Recommendations for application of neutron dose correction factors for energy response, angular response, and track fading for NTA film.

6.3 Conclusions and Issues

1. **Zeros –** SC&A finds the recommendations in OTIB-0086 concerning zero, blank, or marks in the records to be consistent with those used for other DOE sites and dosimetry records in general, and has not found data that are in conflict with these recommendations.

2. **Coworker doses –** SC&A's spot review of the coworker photon, neutron, and skin doses for the period 1960–2010 in Tables 1, 2, and 3, respectively, did not reveal any issues; *except for the fact that the neutron dose for 1975 was a factor of 10 to 100 times the other annual neutron doses* (the photon and skin doses for 1975 did not show any increase for 1975). SC&A did not perform a complete recalculation of the data in the coworker tables because the use of resources for such a task was not warranted at this time.

3. **NTA film –** SC&A evaluated the recommendations in OTIB-0086 for application of neutron dose correction factors for energy response, angular response, and track fading for NTA film and found:

    - **Energy response –** *In evaluating the recommended energy correction factor of 1.4, SC&A does not find that the MCNP model generated for Mound Laboratory of an observer located at 240 cm from a glovebox with 4 inches of moderator necessarily represents the situation and neutron energy fields for a worker at Pantex with potential multiple sources of exposure*.

    - **Angular response –** *The angular correction factor of 1.33 for NTA film did not include the fact that Pantex workers were potentially exposed to multiple sources of neutrons, which could include PA geometry. Neither the NTA film calibration nor the AP angular correction factor addresses PA geometry for neutron exposure.*

    - **Track fading –** *There does not appear to be any supporting evidence as to why the lower fading factor of 9% was selected, when other studies indicate higher fading factors.*

- **Period to apply –** *The time period that these adjustment factors should be applied to recorded neutron doses should be confirmed and provided to the dose reconstructor for consistency; i.e., 1960–197? This also requires determining the correct period that the 2-element TLD was used.*

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