



A Review of ORAUT-OTIB-0092 Correction Factors for Neutron Dose Measured with Nuclear Track Emulsion, Type A Film

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ORAUT-OTIB-0092

- ◆ ORAUT-OTIB-0092, revision 00, issued by the National Institute for Occupational Safety and Health (NIOSH) on February 22, 2024 (“OTIB-0092”)
- ◆ Allows dose reconstructors to apply neutron energy spectrum correction factors (CFs) to recorded neutron doses measured using nuclear track emulsion, Type A (NTA) dosimetry film
- ◆ NTA film used to determine neutron exposure since 1944
- ◆ Eastman Kodak produced fine-grained NTA film in dental packet size, for use as personnel neutron monitor in 1947

NTA neutron dosimetry film

- ◆ Generally worn mid chest
- ◆ Detects neutrons reflected by body into back side of monitoring badge (albedo neutrons)
- ◆ Reflected neutrons produce charged particles in film emulsion
- ◆ Charged particle interactions read by microscope
- ◆ Sharp cutoff in response due to neutron interactions when:
 - Neutron energy is below 0.5 mega-electron volts (MeV)
 - Greater than 20 MeV

Calibration of NTA film

- ◆ NTA film response varies with neutron energy:
 - Calibrated using known neutron standard that closely matches work environment neutron energy spectrum
- ◆ Not always possible:
 - With multiple exposure sources
 - Neutron energy spectrum of exposure is uncertain
 - Neutron energy spectrum determined after NTA film results recorded

Dosimetry NTA film

- ◆ Dose recorded in units of rem at time of processing
- ◆ Dose reconstructor may apply CFs to provide better estimate of neutron dose
- ◆ CFs previously applied as needed:
 - Geometry
 - Fading
 - Threshold energy

ORAUT-OTIB-0092 correction factors

- ◆ Recent 2024 document
- ◆ Used to apply neutron energy spectrum CF to recorded NTA film dose
- ◆ Corrects for differences in neutron energy spectrum that a worker was exposed to compared to neutron energy spectrum used to calibrate NTA

ORAUT-OTIB-0092 outline

- ◆ Section 3.0: Brief history of use of NTA film
- ◆ Section 4.1: Methods for calculating:
 - Spectrum-weighted response (SWR)
 - Spectrum-weighted dose equivalent (SWDE)
 - Dose equivalent spectrum-weighted response (DE SWR)
 - CF using International Atomic Energy Agency (IAEA) 1990 Technical Reports Series (TRS) 318 data
- ◆ Section 4.2: Calculations of SWR and SWDE using IAEA 2001 TRS 403 data and comparison to and interpolation of data obtained in section 4.1 for TRS 318

ORAUT-OTIB-0092 attachments

- ◆ Attachment A: Two examples of common calibration exposure scenarios
- ◆ Attachment B: Comparison of OTIB-0092 derived parameters for determining CFs to values in published literature
- ◆ Attachment C: Table of SWR, SWDE, and DE SWR values for various common neutron sources, which contains important information for dose reconstruction (DR)

TRS 318 versus TRS 403

- ◆ TRS 318 covers neutron energy range 0.025 electron volts (eV) to 435 MeV and uses the upper energy value to label the energy bin of interest (e.g., 1.0 MeV for the 0.794 MeV to 1.0 MeV energy bin)
- ◆ TRS 403 covers neutron energy range of 0.001 eV to 630 MeV and uses the lower energy value to label the energy bin of interest (e.g., 0.794 MeV for the 0.794 MeV to 1.0 MeV energy bin)
- ◆ TRS 403 uses some different energy values compared to TRS 318 for energy bins

NIOSH derived NTA film energy correction factors using TRS 318 data (section 4.1)

- ◆ **SWR:** Spectrum-weighted response is the sum of the tracks per neutron in the NTA film
- ◆ **SWDE:** Spectrum-weighted dose equivalent is the dose equivalent (rem) per neutron per square centimeter (cm^2)
- ◆ **DE SWR:** Dose equivalent spectrum-weighted response is the sum of the tracks per cm^2 per rem
- ◆ DE SWR is derived by dividing SWR by SWDE
- ◆ CF equals DE SWR of calibration source divided by the DE SWR of exposure source

SC&A evaluation of section 4.1: Calculations using TRS 318 data

- ◆ Reviewed methods used in section 4.1 and evaluated data and derivation of the SWR, SWDE, DE SWR, and CF values
- ◆ Used data in TRS 318, table 3-IX, for NTA film response and table 4-X for polonium-beryllium (PoBe) spectrum to verify SWDE values in table 4-3 of OTIB-0092 for NTA film exposed to PoBe neutron source
- ◆ Used data in TRS 318, table 2-II, for dose equivalent (DE) values and table 4-X for PoBe spectrum to verify calculations in section 4.1 of OTIB-0092
- ◆ SC&A concurs with the methods and results in section 4.1 of OTIB-0092 and did not identify any findings or observations

NIOSH derived NTA film energy correction factors using TRS 318 and TRS 403 data (section 4.2)

- ◆ Calculated SWR and SWDE using TRS 318 data, summarized in table 4-4 of OTIB-0092
- ◆ Calculated SWR and SWDE using IAEA TRS 403 data
- ◆ Interpolated results using TRS 318 data and TRS 403 data applying two conditions (slides 13–15)

Condition 1

- ◆ If neutron energy interval is the same in TRS 318 and TRS 403, then NTA film response and DE functions from TRS 318 are applied to the equivalent lower TRS 403 energy interval (i.e., one energy interval down)
- ◆ Example:
 - TRS 318 lists NTA film response function as $2.87\text{E-}4$ tracks per neutron at 1.0 MeV (for the neutron energy interval of 0.794 MeV to 1.0 MeV)
 - Corresponding TRS 403 NTA film response function at 0.794 MeV would be $2.87\text{E-}4$ tracks per neutron (for the neutron energy interval of 0.794 MeV to 1.0 MeV)
 - Same method applied to the DE function

Condition 2

- ◆ If the neutron energy interval was different in TRS 318 compared to TRS 403
 - NTA film response and DE functions from TRS 318 were interpolated from TRS 318 to match corresponding energy interval in TRS 403
 - Interpolation process used to calculate the value of cumulative function at each bin endpoint of TRS 318 and fit a monotone cubic spline to cumulative function at bin endpoints (smooth fit to discrete data points)
 - Derivative of cubic spline was calculated to obtain estimate of underlining function of data in energy bin
 - Function was integrated over new energy bin interval and divided by width of new energy bin (i.e., energy bin used in TRS 403)
- ◆ Results of interpolation summarized in table 4-5 of OTIB-0092

Condition 2 example

- ◆ TRS 318 listed the DE function as $4.09\text{E-}8$ rem per neutron per cm^2 at 10.0 MeV (for the neutron energy interval of 7.94 MeV to 10.0 MeV)
- ◆ Corresponding interpolated value for the TRS 403 DE function at 10.0 MeV calculated to be $4.15\text{E-}8$ rem per neutron per cm^2 (for the neutron energy interval of 10.0 MeV to 15.8 MeV)

SC&A evaluation of section 4.2: Calculations with TRS 403 data

- ◆ Evaluated data and derivation of values in tables 4-4 and 4-5
- ◆ Used data in TRS 318:
 - Table 2-II, column 5, for dose equivalent values
 - Table 3-IX, column 2, for NTA film response
- ◆ Verified corresponding values in table 4-4, columns 2 and 4, of OTIB-0092 (according to neutron energy bins used in TRS 318, which is listed in column 1 of table 4-4)
- ◆ Reviewed NTA film response and DE function fitted spline plots in spreadsheets
 - Found that interpolations fit well with data
 - Did not show large deviations from normal
- ◆ Concurs with the methods and results in section 4.2 and did not identify any findings or observations

SC&A review of section 6.0

- ◆ Reviewed technical summary in section 6.0 and found that it gives an accurate overview of the previous sections of OTIB-0092
- ◆ Had no findings or observations concerning section 6.0

SC&A evaluation of Attachment A: Common calibration exposure scenarios

- ◆ Evaluated technical aspects of two examples in Attachment A
- ◆ Found examples very valuable in illustrating use of data presented in OTIB-0092
- ◆ Concurs with the methods and results
- ◆ Did not identify any findings or observations concerning Attachment A

Attachment B: Benchmarking spectrum-weighted response method with published literature

- ◆ Presents several published documents analyzing NTA film response to various neutron energy spectrum
- ◆ Benchmarks indicate that an estimate of dose using procedure in OTIB-0092 resulted in predicted doses within a factor of less than $\pm 200\%$ (i.e., a factor of 0.5 to 2.0)
- ◆ SC&A reviewed Attachment B and concurs that the method used in OTIB-0092 produces results comparable to those in the cited literature

SC&A review of Attachment C: A summary of various SWR and SWDE values

- ◆ Table C-1 provides most important data in OTIB-0092 for DR
- ◆ Table C-1 summarizes SWR, SWDE, and DE SWR values for use in calculating the CF for a given calibration and exposure scenario that may be encountered in DR process
- ◆ SC&A verified a sample of the recommended SWR, SWDE, and DE SWR values and found them correct
- ◆ SC&A had no findings or observations concerning Attachment C

SC&A conclusions

- ◆ Reviewed methods used in OTIB-0092; reviewed relevant data in TRS 318 and TRS 403; evaluated derivation of SWRs, SWDEs, DE SWRs, and CFs values; and verified various numerical values presented in tables 4-1 through C-1
- ◆ Found that OTIB-0092 used technically sound methods and presented a very complex subject in a concise but illustrative manner
- ◆ Found that OTIB-0092 presents useful and applicable data for DR, summarized in table C-1, for use by dose reconstructor
- ◆ However, SC&A did have one observation (slide 22)

Observation 1: Limited applicability of NTA film correction factor

- ◆ Table C-1 provides a wide array of neutron exposures that potentially could be present at U.S. Department of Energy facilities, along with associated SWR, SWDE, and DE SWR values to determine an NTA film CF
- ◆ Usually, the neutron energy spectrum of the source used to calibrate neutron detectors at a facility is known with a reasonable degree of accuracy
- ◆ However, in many cases, neutron energy spectrum of exposure in the field will vary:
 - Even if neutron energy spectrum is measured at several locations in the field, the actual neutron spectrum the worker is exposed to can vary, influenced by such factors as outlined on slides 23–24

Influencing factors

- ◆ Neutron source (especially for changes in voltage and target materials at accelerators)
- ◆ Shielding materials, thickness, layering, and angle neutrons transverse the shielding
- ◆ Access ports, seams, and voids in shielding
- ◆ Sky shine (reflection of neutrons back down from atmosphere)
- ◆ Ground shine (reflection of neutrons up from ground at an angle from source)
- ◆ Backscattered neutrons from material behind worker

Changing parameters

- ◆ Exposure parameters could change significantly as a worker moves around an area
- ◆ Further complicated when attempting to determine neutron dose from exposure situations that took place over 40 years ago, when NTA film was used
- ◆ Some parameters for deriving neutron dose CFs can be determined with greater accuracy than some neutron exposure spectrum can be known

SC&A's evaluation and recommendation

- ◆ Neutron dose CF should be used with caution because it could lead to a false sense of being able to derive and assign neutron doses with a greater degree of accuracy than is warranted
- ◆ Recommends that given such uncertainties, only a spectrum CF of equal to or greater than 1 be applied to a worker's recorded neutron dose, unless exposure parameters are well documented
- ◆ Should be determined if a neutron energy CF is warranted on a case-by-case basis

Summary of SC&A's evaluation of OTIB-0092

- ◆ SC&A had no findings but had one observation:
 - Observation 1: Limited applicability of NTA film correction factor



Questions?