Investigation of Air Gap Effects on the Calibration and Neutron Response of Thermoluminescent Dosemeters using Monte Carlo Methods

RadCon

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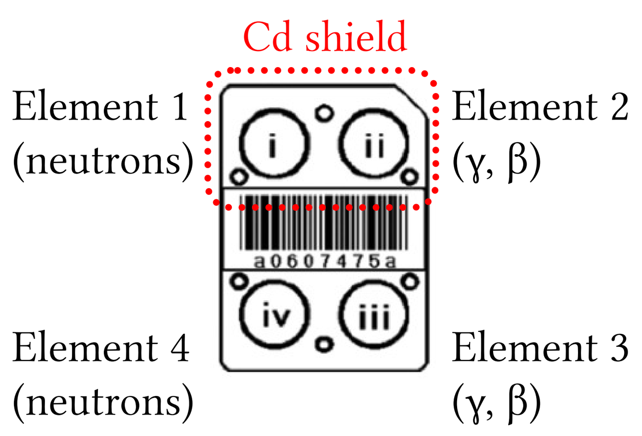
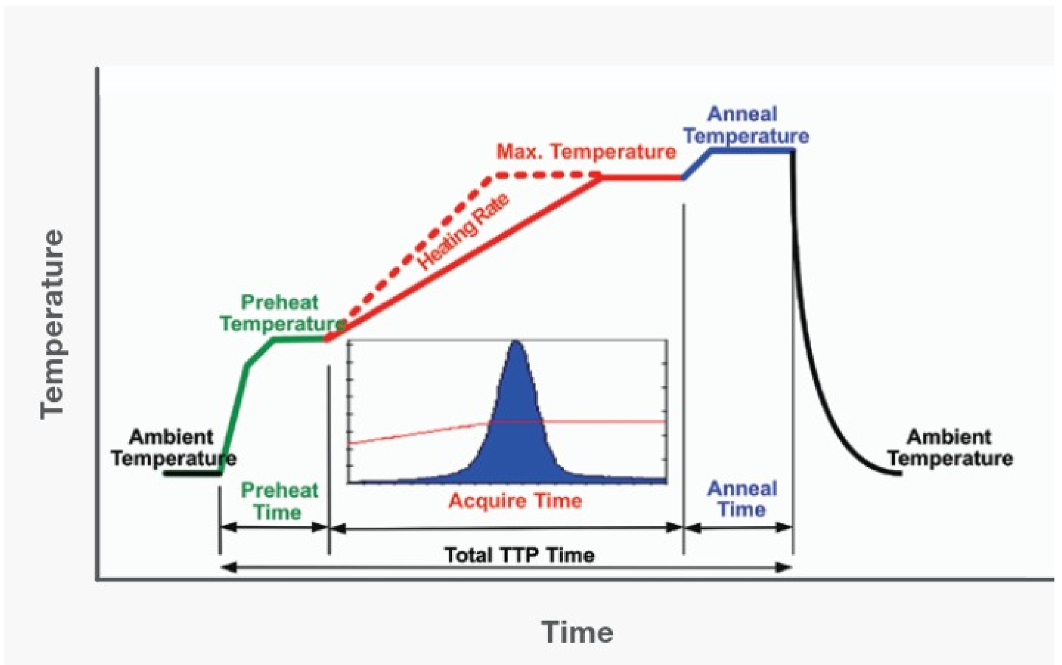
I. Thermoluminescent Dosemeter (TLD)

- **Harshaw 8806**[1] model TLD (Thermo Scientific™ Harshaw™), used at the Y-12 National Security Complex facility
- It holds up to four different elements:
  - 2 x TLD-600: ^{6}Li isotopes in LiF:Mg,Ti for **neutrons**
  - ⟶ **^{6}Li(n,α)^{3}H** reaction, Q = 4.78 MeV
  - 2 x TLD-700: ^{7}Li isotopes in LiF:Mg,Ti for gamma, beta
  - ⟶ electromagnetic interactions in LiF:Mg,Ti
- One of each pair is covered with a sheet of **cadmium filter** for spectral discrimination

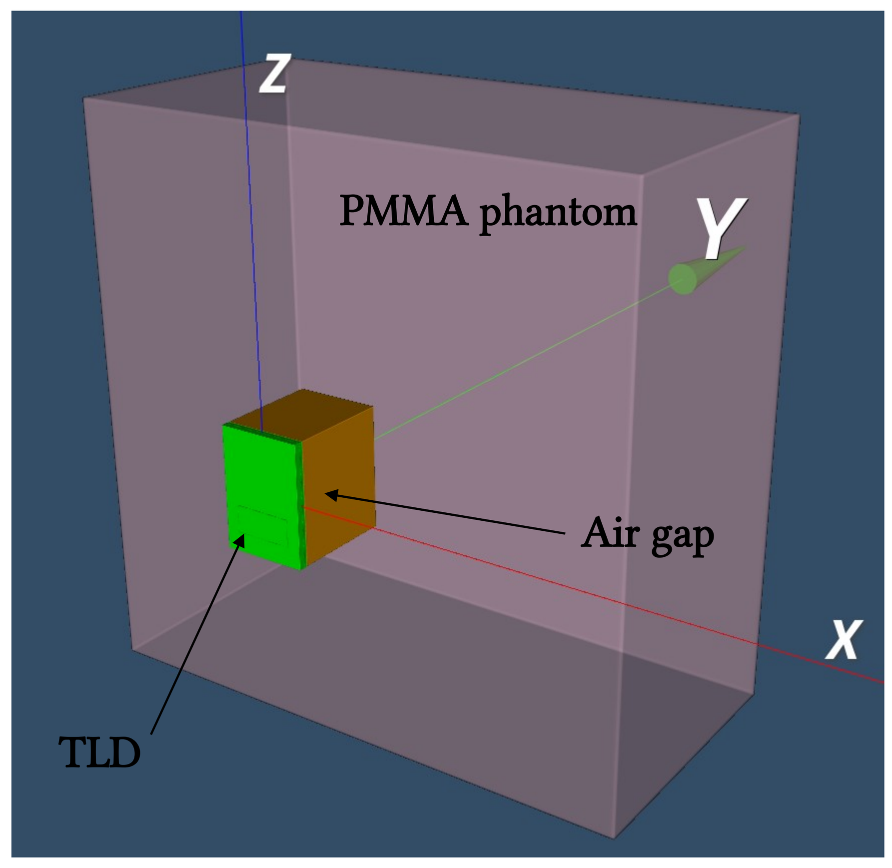




- Exchange cycle ~ 3 months
- Harshaw model 8800 reader used to read luminescence when TLD is stimulated with heat
- Various correction factors applied
- TLDs are normalized to a single population response via various calibration/response factors
- Multiple calibrations done at different times (one short calibration daily, extensive one every two years)
- Spectral correction factors based on assumed neutron spectrum

II. Monte Calo Simulation

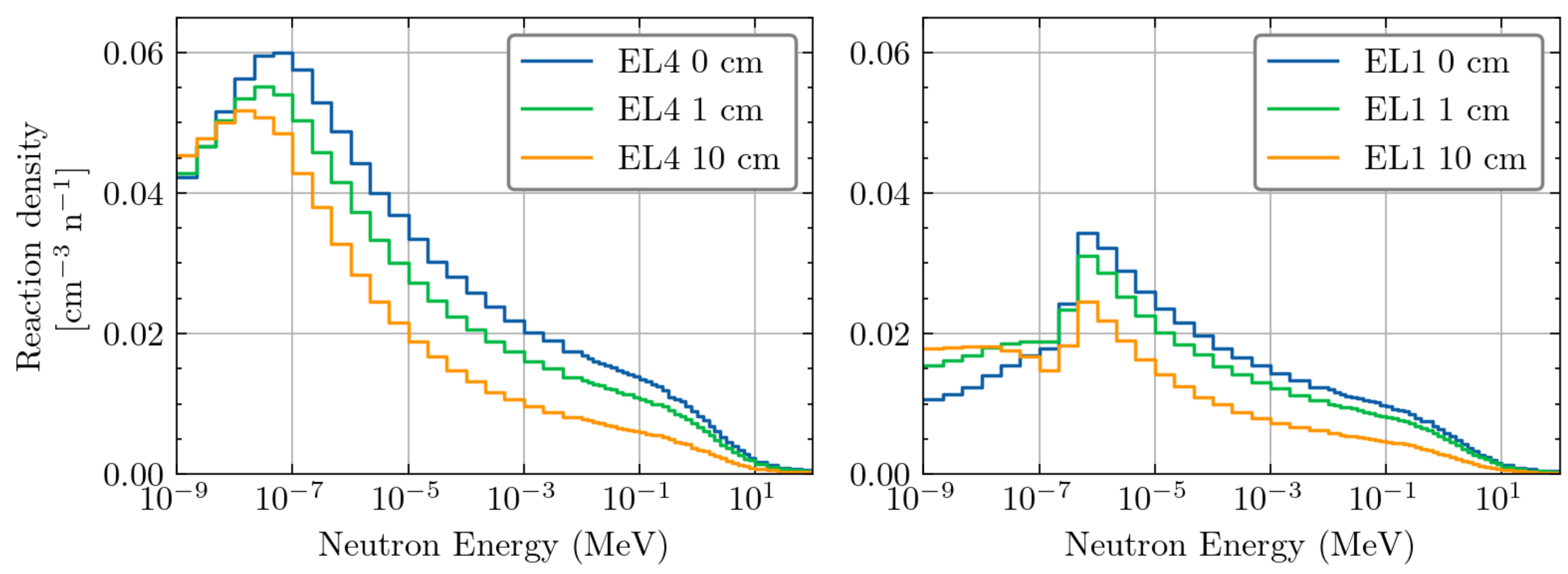
- Simulate **relative response** of TLD using **reference spectra**
- Calibration of TLDs done using polymethyl methacrylate **(PMMA) phantoms** in albedo geometry!
- Change of response with increasing **air-gap**?
- **MCNP6.3**[2] **model**:
  - TLD case: A-150 Tissue-Equivalent Plastic[3]
  - Substrate: Aluminum
  - Cadmium shield covering EL1
  - PMMA slab (15x15x30) cm³
  - Source: Parallel neutron beam
  - 60-Energy-bins: 10^{-9} to 630 MeV



Numbers of **^{6}Li(n,α)^{3}H** reactions inside TLD: MT = 105, ^{6}Li + n ⟶ α + ^{3}H + E(MeV) (ENDF-6 Formats Manual[4]).

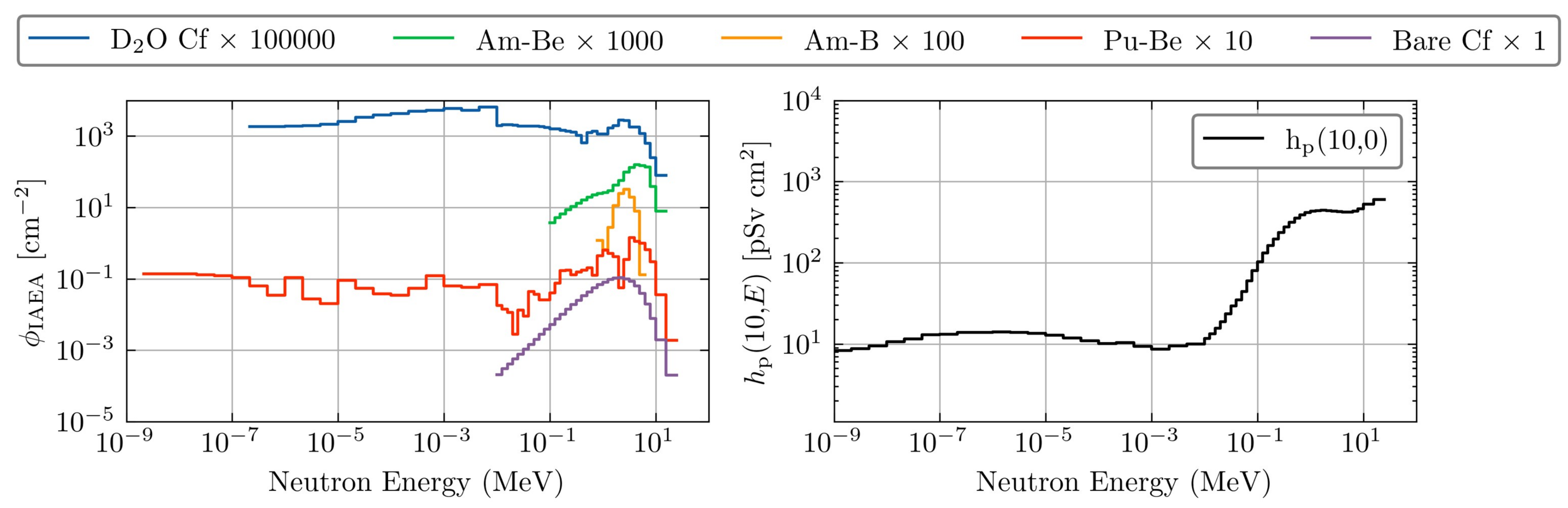
$$T(E) = C \int \phi(E)\sigma_{105}(E)dE \qquad (1)$$

Reaction density [1/cm³]



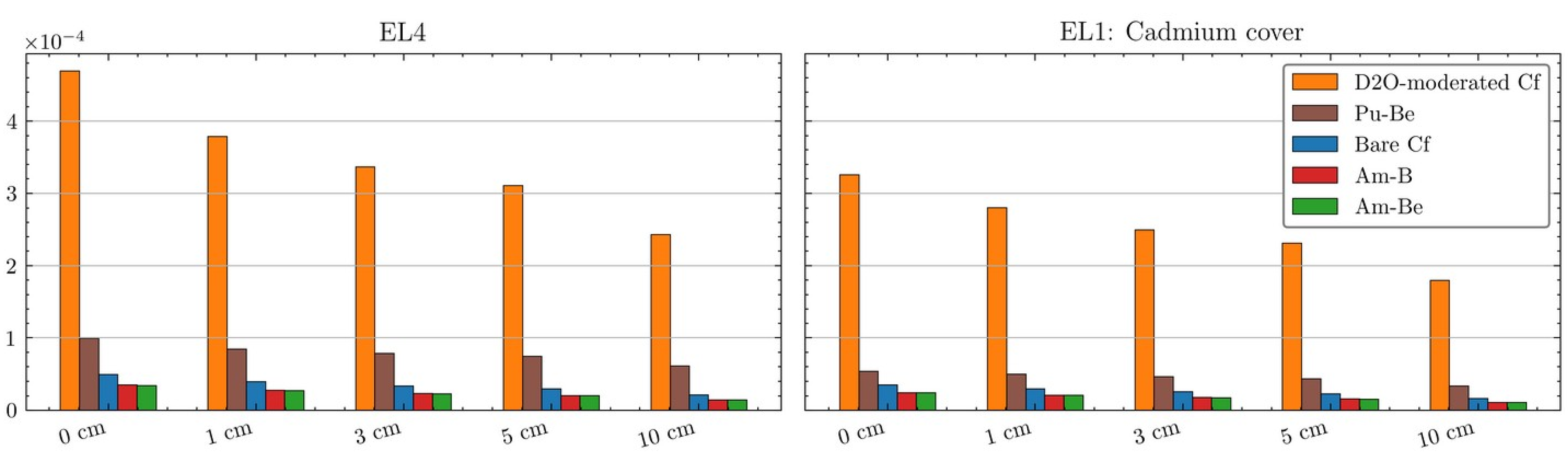
III. Response per Dose Calculation

- Reference neutron spectra from the **IAEA compendium**[7]
- Fluence to dose equivalent conversion coefficients ***h_p*(10,*E*)**[6] with same energy bin structure

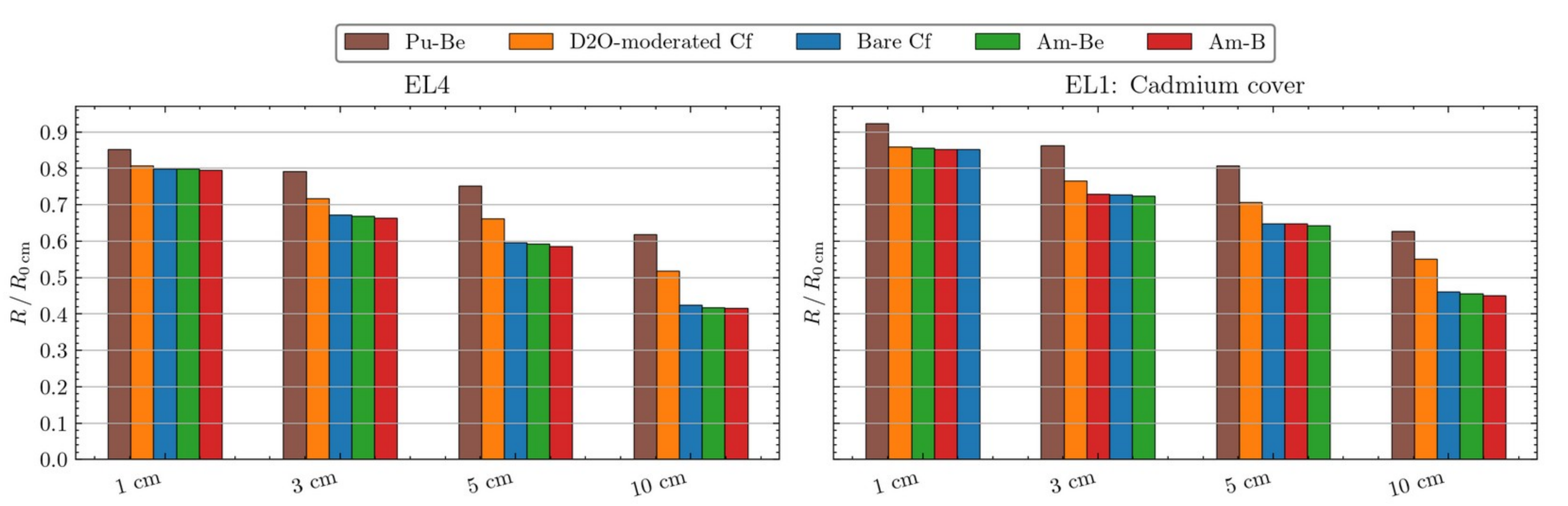


- Calculate **total response per unit dose** as

$$R = \frac{\sum_i T(E_i)\, V_{\mathrm{TLD}}\, A_{\mathrm{source}}\, \phi_{\mathrm{IAEA}}(E_i)}{\sum_i h_p(10, E_i)\, \phi_{\mathrm{IAEA}}(E_i)} \qquad (2) \qquad [\text{(n,α)-Reactions/pSv}]$$



- D_2O moderated Cf source shows largest TLD response due to its long tail into thermal and epithermal neutron energies
- Pu-Be (CERN) spectra second
- Narrow, high energy spectra show smaller TLD response
- Relative to each 0 cm (calibration position) case gives **relative response**



IV. Summary and Conclusion

- Cadmium covered elements less affected by air gap (^{113}Cd(n,γ)^{114}Cd reaction cross section[5] increases 6 orders of magnitude between 10 eV and 1 meV)
- As gap increases, Cd-shielding becomes less effective for low energy neutrons, however response as whole goes down

Relative Response [%]	Bare Cf		D2O Cf		Am-Be		Am-B		Pu-Be	
	EL1	EL4	EL1	EL4	EL1	EL4	EL1	EL4	EL1	EL4
1 cm Gap	85	80	86	81	86	80	85	80	92	85
3 cm Gap	73	67	77	72	72	67	73	66	86	79
5 cm Gap	65	60	71	66	64	59	65	59	81	75
10 cm Gap	46	42	55	52	46	42	45	42	63	62

- TLDs in albedo geometry are calibrated with contact to PMMA, potential exposed workers need to wear the TLD close to the trunk of the body
- Even a **1 cm gap** (due to wearing a jacket, when leaning, walking etc.) show large **differences up to 20 %**
- Tilting the TLD increases this effect, relative responses as little as 25 % possible for 30° rotated TLD at ~ 10 cm (data not presented here)

⟶ TLD-read Doses underestimated!

References

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3 A-150 Tissue-Equivalent Plastic https://physics.nist.gov/cgi-bin/Star/compos.pl?matno=099, last accessed 16.04.2026
4 Brown, David A.. "ENDF-6 Formats Manual - Data Formats and Procedures for the Evaluated Nuclear Data Files ENDF/B-VI, ENDF/B-VII and ENDF/B-VIII." , Sep. 2023. https://doi.org/10.2172/2007538
5 ENDF/B-VIII.0 data, https://www.oecd-nea.org/janisweb/book/neutrons/Cd113/MT102/renderer/1343, last accessed 16.04.2026
6 Compendium of Neutron Spectra and Detector Responses for Radiation Protection Purposes, IAEA, 2002, https://www-pub.iaea.org/MTCD/Publications/PDF/TRS403_scr.pdf
H_p(10,0) Table 2.III Column 3
7 Compendium of Neutron Spectra and Detector Responses for Radiation Protection Purposes, IAEA, 2002, https://www-pub.iaea.org/MTCD/Publications/PDF/TRS403_scr.pdf.
^{252}Cf Table 4.V.
D_2O moderated Cf Table 4.V.
Am-Be Table 4.V.
Am-B Table 4.V.
Pu-Be (CERN) Table 4.X. Column 2

Note: The peak in the low energy of TLD reaction density can be explained due to attenuation inside the A-150 TEP and reaction rate inside the TLD chips.

$$Y(E) = \underbrace{e^{-\Sigma_{\mathrm{H}}(E)\cdot t}}_{\text{AEP-150 case transmission}} \cdot \underbrace{\left(1 - e^{-\Sigma_{^6\mathrm{Li}}(E)\cdot d}\right)}_{\text{TLD absorption fraction}}$$

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