Preliminary Comparison Study on the Dosimetric Characteristics of Personal Neutron Dosimeters in a Nuclear Power Plant

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1、Research Background

Conventional personal dose monitoring in nuclear power plants uses Electronic Personal Dosimeters (EPDs) and Thermoluminescent Dosimeters (TLDs), which are well established for gamma radiation.

However, neutron radiation monitoring presents additional challenges:

- Neutron reaction cross-sections vary significantly with energy.
- Workplace neutron spectra are complex due to moderation and scattering.
- Dose response depends strongly on radiation incidence direction.
- Standard calibration sources (e.g., Am-Be, Cf-252) are monoenergetic and cannot represent actual workplace spectra.

2、Research Objectives

The objectives of this study are to:

① Compare the performance of three personal neutron dosimeters: a domestic EPD, Thermo EPD-N2, and TLD-600/700 system.

② Evaluate their response characteristics under different neutron spectra.

③ Analyze the causes of response deviations.

④ Propose targeted improvements to enhance measurement accuracy.

3、Measurement System

We used **MIRION' s SN-D-2** portable neutron dosimeter (He-3 proportional counter) as the reference instrument.

Tested dosimeters:

① **Thermo EPD-N2:** Industry-standard personal neutron dosimeter.

② **Domestic EPD**: Based on ^{6}LiF and Si-PIN detectors.

③ **TLD-600/700 System**: Thermoluminescent dosimeter system.

All instruments were calibrated and certified.

Standard Reference: According to WS/T 830-2024 (Appendix H), fluence-to-dose conversion coefficients for H*(10) and Hp(10, 0°) differ only slightly across neutron energies.

Test Conditions: All instruments were co-facing the radiation source and placed at the same measurement point (non-worn, no near-field or human coupling).

For more precise analysis, energy-spectrum weighting effects should be further investigated.

3、Measurement System

The table below presents the detailed paramaters of the instruments.

Device Type	Model	Detector Type	Energy Range	Measurement Range	Device ID	Calibration Factor
Neutron Dosimeter	SN-D-2	He-3 Proportional Counter	0.025eV~15MeV	0.3μSv/h~100mSv/h	46071	0.88
Thermo Fisher EPD	EPD-N2	^{6}LiF+Si-PIN	0.025eV~15MeV	0μSv/h~4Sv/h 0μSv~16Sv	07213555	1.11
					07213556	0.95
Domestic EPD	MPDS-N4	^{6}LiF+Si-PIN	0.025eV~15MeV	1μSv/h~10Sv/h	95240026	0.92
					95240028	0.81
TLD	TLD-600	^{6}Li=95.62% ^{7}Li=4.38%	N/A	N/A	N/A	N/A
	TLD-700	^{6}Li=0.007% ^{7}Li=99.993%	N/A	N/A	N/A	N/A

4、Experimental Sites

Two representative scenarios were selected: a full-power reactor building and a Cf-252 source loading operation.

① Reactor Building (Thermal/Intermediate Neutron Field)

- Point A: Entrance to the steam generator compartment, the highest neutron dose rate area accessible at 100% reactor power. Neutrons leaking from the reactor pressure vessel (RPV) are moderated by surrounding materials and multiply scattered. Measurement time: 5 min.
- Point B: Walkway on the reactor maintenance platform, 5 m from Point A, with no structures between them, suggesting similar neutron spectra. Measurement time: 13 min.

4、Experimental Sites

② Cf-252 Neutron Source Loading (Fast Neutron Field)

Conducted during loading of a fuel assembly containing a Cf-252 source (activity: 1.98E+10 Bq, average energy: 2.13 MeV, energy range: 0.1–10 MeV).

The assembly was stored in a fuel rack in the spent fuel pool (new fuel only, dry storage). Neutron absorbers were arranged horizontally, but no significant moderation or shielding occurred vertically.

Measurements were taken on the loading machine for 3 hours when the assembly was totally in the rack , followed by a 4-minute lifting operation using a crane.

5、Results

① Reactor Building (Thermal/Intermediate Neutron Field)

	Point A (High Dose Rate)		**Point B**		**Total**	
Instrument	n-Dose (μSv)	n-Dose Rate (μSv/h)	n-Dose (μSv)	n-Dose Rate (μSv/h)	n-Dose (μSv)	γ-Dose (μSv)
SN-D-2	46	500-600	14	60-80	60	NA
EPD-N2（07213555）	34	410	9	40	43	219
EPD-N2（07213556）	44	530	11	50	55	197
Domestic EPD (95240026)	**280**	**2500-3500**	25	90-110	310	191
Domestic EPD (95240028)	**342**	**3800-5500**	15	50-70	360	181
TLD-1	NA	NA	NA	NA	148	NA
TLD-2	NA	NA	NA	NA	145	NA

- **Thermo EPD-N2**: Shows good agreement with the reference, demonstrating stable accuracy under these conditions.
- **Domestic EPD**: Overestimates by approximately 5–8 times compared with the reference at high dose rates.
- **TLD-600/700**: Overestimates by 2–3 times.

5、Results

② Cf-252 Neutron Source Loading (Fast Neutron Field)

	Non-Lifted		**Lifted (High Dose Rate)**	
Instrument	n-Dose (μSv)	n-Dose Rate (μSv/h)	n-Dose (μSv)	n-Dose Rate (μSv/h)
SN-D-2	155	50	19.2	150-500
EPD-N2（07213555）	60	NA	NA	NA
EPD-N2（07213556）	69	NA	NA	NA
Domestic EPD（95240026）	53	15	**2.7**	**25-50**
Domestic EPD（95240028）	58	16	**3.1**	**30-60**
TLD-1	161	NA	NA	NA
TLD-2	150	NA	NA	NA

- **Thermo EPD-N2**: Underestimates by 2-3 times compared with the reference.
- **Domestic EPD** Underestimates by 5–9 times at high dose rates.
- **TLD-600/700**: Shows good consistency with the reference in this scenario.

6、Causes of Deviations

Possible causes of response deviations:

- **Energy Spectrum Dependence**: Limited internal moderation causes over- or underestimation when the workplace neutron spectrum differs from calibration conditions.
- **High Dose Rate Effects**: Signal processing algorithms may deviate from linearity in high-dose-rate environments, causing distorted readings.
- **Angular Dependence**: Asymmetric moderator design results in direction-dependent response.
- **TLD Design**: Absence of albedo backing or Cadmium shielding contributes to overestimation in thermal fields.

7、Improvement Suggestions

Based on our findings, we propose:

- **Moderator Optimization**: Increase moderator volume and improve symmetry to reduce angular dependence and enhance adaptability to different energy spectra.
- **Multi-Channel Detection**: Integrate multi-channel spectral resolution technology to better characterize mixed neutron spectra.
- **Dynamic Calibration**: Apply energy-dependent calibration factors that adapt to varying neutron energies and workplace conditions.
- **TLD Design**: Adopt albedo-type TLD configurations with thermal-neutron shielding to distinguish between thermal and fast neutron responses.

8、Research Conclusions

Our study reveals performance differences in three personal neutron dosimeters:

- **Thermo EPD-N2**: Maintains stable accuracy in thermal fields, but underestimates in fast neutron fields.
- **Domestic EPD**: Overestimates in thermal fields, underestimates in fast neutron fields.
- **TLD-600/700**: Reliable in fast neutron fields but overestimates in thermal fields.

Key Insight: Accurate neutron dose measurement requires scenario-specific calibration and optimized dosimeter design.

Emphasis: In NPPs, personnel rarely operate in high-neutron-radiation areas such as rooms within the secondary shielding after reactor startup. Given the constrained reliability of EPDs in complex neutron fields, multiple monitoring methods should be used to verify effective dose and ensure compliance with regulatory standards.

Thank You

Thank you for your attention.

I'm happy to answer any questions you may have.

Lizhi Zhang

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