Designation: E2450 – 06

Standard Practice for Application of CaF_2(Mn) Thermoluminescence Dosimeters in Mixed Neutron-Photon Environments[1]

This standard is issued under the fixed designation E2450; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes a procedure for measuring gamma-ray absorbed dose in CaF_2(Mn) thermoluminescence dosimeters (TLDs) exposed to mixed neutron-photon environments during irradiation of materials and devices. The practice has broad application, but is primarily intended for use in the radiation-hardness testing of electronics. The practice is applicable to the measurement of absorbed dose from gamma radiation present in fields used for neutron testing.

1.2 This practice describes a procedure for correcting for the neutron response of a CaF_2(Mn) TLD. The neutron response may be subtracted from the total response to give the gamma-ray response. In fields with a large neutron contribution to the total response, this procedure may result in large uncertainties.

1.3 More precise experimental techniques may be applied if the uncertainty derived from this practice is larger than the user can accept. These techniques are not discussed here. The references in Section 8 describe some of these techniques.

1.4 This practice does not discuss effects on the TLD reading of neutron interactions with material surrounding the TLD to ensure charged particle equilibrium. These effects depend on the surrounding material and its thickness, and on the neutron spectrum (**1**).[2]

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E666 Practice for Calculating Absorbed Dose From Gamma or X Radiation

E668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices

E720 Guide for Selection and Use of Neutron Sensors for Determining Neutron Spectra Employed in Radiation-Hardness Testing of Electronics

E721 Guide for Determining Neutron Energy Spectra from Neutron Sensors for Radiation-Hardness Testing of Electronics

E722 Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics

E1854 Practice for Ensuring Test Consistency in Neutron-Induced Displacement Damage of Electronic Parts

F1190 Guide for Neutron Irradiation of Unbiased Electronic Components

3. Terminology

3.1 *Definitions:*

3.1.1 *absorbed dose*—see Terminology E170.

3.1.2 *exposure*—see Terminology E170.

3.1.3 *kerma*—see Terminology E170.

3.1.4 *linear energy transfer (LET)*—the energy loss per unit distance as a charged particle passes through a material. Electrons resulting from gamma-ray interactions in a material generally have a low LET. Heavy charged particles resulting from neutron interactions with a material generally have a high LET.

3.1.5 *neutron sensitivity m(E)*—the ratio of the detector reading, that is, the effective neutron dose, to the neutron fluence. Thus,

$$m(E) = \frac{M(E)}{\Phi(E)} \quad (1)$$

where:

$\Phi(E)$ = the neutron fluence, and
$M(E)$ = the apparent dose (extra light output) in the TLD caused by neutrons of energy E.

4. Significance and Use

4.1 Electronic devices are typically tested for survivability against gamma radiation in pure gamma-ray fields. Testing their response against neutrons is more complex since there is invariably a gamma-ray component to the neutron field. The

[1] This practice is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.07 on Radiation Dosimetry for Radiation Effects on Materials and Devices.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

gamma-ray response of the device is subtracted from the overall response to find the response to neutrons. This testing thus requires a determination of the gamma-ray exposure in the mixed field. To enhance the neutron effects, the field is sometimes selected to have as large a neutron component as possible.

4.2 CaF_2(Mn) thermoluminescent detectors are often used to monitor the gamma-ray dose for this type of testing. Since they are exposed along with the device under test to the mixed field, their response must be corrected for neutrons. In a field rich in neutrons, the uncertainty in the TLD response grows, but this may be unimportant since the gamma-ray effects on the device under test may be relatively small. In fields with relatively few neutrons, the TLD response may be used to make a relatively large correction for gamma response on the device under test. Under this condition, the relative uncertainty in the TLD response shrinks.

4.3 This practice gives a means of estimating the response of CaF_2(Mn) to neutrons. This neutron response is then subtracted from the measured response to give the response to gamma rays. The procedure has relatively high uncertainty because the neutron response of CaF_2(Mn) may vary depending on the source of the material, and this procedure is a generic calculation applicable to CaF_2(Mn) independent of source. The neutron response given in this practice is a summary of responses reported in the literature. The associated uncertainty envelops the range of results reported, and includes the variety of TLDs used as well as the uncertainties in the determination of the neutron response as reported by various authors.

4.4 Should the user find the resulting uncertainties too large for his purposes, the neutron response of the particular TLDs in use must be determined. This practice does not supply guidance on how to determine the neutron response of a specific batch of TLDs.

4.5 Neutron effects on electronics under test are usually reported in terms of 1 MeV equivalent fluence (E722). Neutron effects of TLDs, as discussed here, are reported in units of absorbed dose, since they are corrections to the gamma-ray dose.

5. Exposure Procedure

5.1 Determine the neutron and gamma-ray environments. Calculate the relative neutron response of the TLDs. If this response is negligible, document this result. No further measurements are required for the purpose of neutron sensitivity of the TLDs.

5.2 Expose the TLD along with the device under test (see Practice E1854 and Guide F1190). If there is a non-negligible fast-neutron or thermal-neutron response, a fast-neutron monitor (for example, nickel) or thermal-neutron monitor (for example, gold) must also be exposed with the device under test.

5.3 The neutron spectrum must be known (see Guides E720 and E721). This may be determined in a separate exposure. The device under test must not significantly perturb the neutron spectrum.

5.4 Practices E668 and E1854 provide information on the calibration and use of CaF_2(Mn) dosimeters.

6. Neutron Sensitivity of CaF_2(Mn)

6.1 *Thermal Neutrons*:

6.1.1 Thermal neutron responses of CaF_2(Mn) ranging from 0.06 to 0.89 Gy(CaF_2(Mn)) (6 to 89 rad (CaF_2(Mn))) per 10^{12}n/cm^2 are reported (**2**). The sensitivity may depend on the manganese doping of the TLD. The sensitivity may also be a function of dosimeter size, since the dosimeter surface-to-volume ratio affects the portion of the charged particles born within the TLD that deposit their dose outside the TLD. Horowitz (**3**) calculates a thermal neutron response of 0.34 Gy(CaF_2) (34 rad (CaF_2)) per 10^{12} n/cm^2 for CaF_2(Mn (2 % by weight)) for TLD of dimensions 0.165 by 0.165 by 0.083 cm.

NOTE 1—Thermal neutron response is typically reported in terms of TLD response relative to a Co-60 equivalent Roentgen (R)/n/cm^2. For Co-60 decay gamma rays, the conversion from Roentgen to Gy(air) is 0.00869 Gy(air)/R. The conversion from Gy(air) to Gy(CaF_2) is 0.975. Thus Gy(CaF_2) is 0.0085 times the exposure in Roentgen.

6.1.2 A value of 0.45 ± 0.45 Gy (45 ± 45 rad) (1 σ) (CaF_2(Mn)) per 10^{12} thermal n/cm^2 shall be used for CaF_2(Mn) TLDs.

NOTE 2—The variation in measured thermal neutron sensitivities for CaF_2(Mn) is as large as the average sensitivity.

6.2 *Fast Neutrons*—A recommended fast-neutron response is displayed in Fig. 1 and listed in Table 1. For the purpose of this practice, the fast-neutron response is the response due to all neutrons above 0.4 eV. Table 1 is the Rinard (**4**) response function multiplied by 1.2. The factor of 1.2 was used to scale the response function to give an optimal fit to a variety of measured data. See Fig. 2 for the quality of this coverage. Use this response to calculate the fast neutron response in Gy(CaF_2).

$$\text{Response} = \int R(E) \cdot \Phi(E) dE \qquad (2)$$

where R(E) is taken from Table 1 and Φ(E) is the neutron spectrum in n·cm^{-2}·MeV^{-1}. Take the 1 σ uncertainty in this response as 50 % of the calculated value.

6.3 Subtract the thermal and fast neutron responses from the measured responses to obtain the gamma-ray response:

$$D_G = D_{Meas} - D_{Thermal} - D_{Fast} \qquad (3)$$

6.3.1 The uncertainties are added in quadrature:

$$\sigma_{D_G} = \sqrt{\sigma^2_{D_{Meas}} + \sigma^2_{D_{Thermal}} + \sigma^2_{D_{Fast}}} \qquad (4)$$

7. Reporting

7.1 The gamma-ray dose is reported after the neutron corrections are made. Sometimes an additional correction is made to convert from dose CaF_2(Mn) to dose in the material of the device under test (see Practice E666). The corrections for neutron response shall be retained by the measuring laboratory and be made available upon request.

7.2 If the correction is negligible (<5 %), a correction need not be made. The lack of correction, and the reasons, shall be stated.

7.3 The uncertainty in the dose reported from the TLD measurement shall include any uncertainty due to neutron effects.

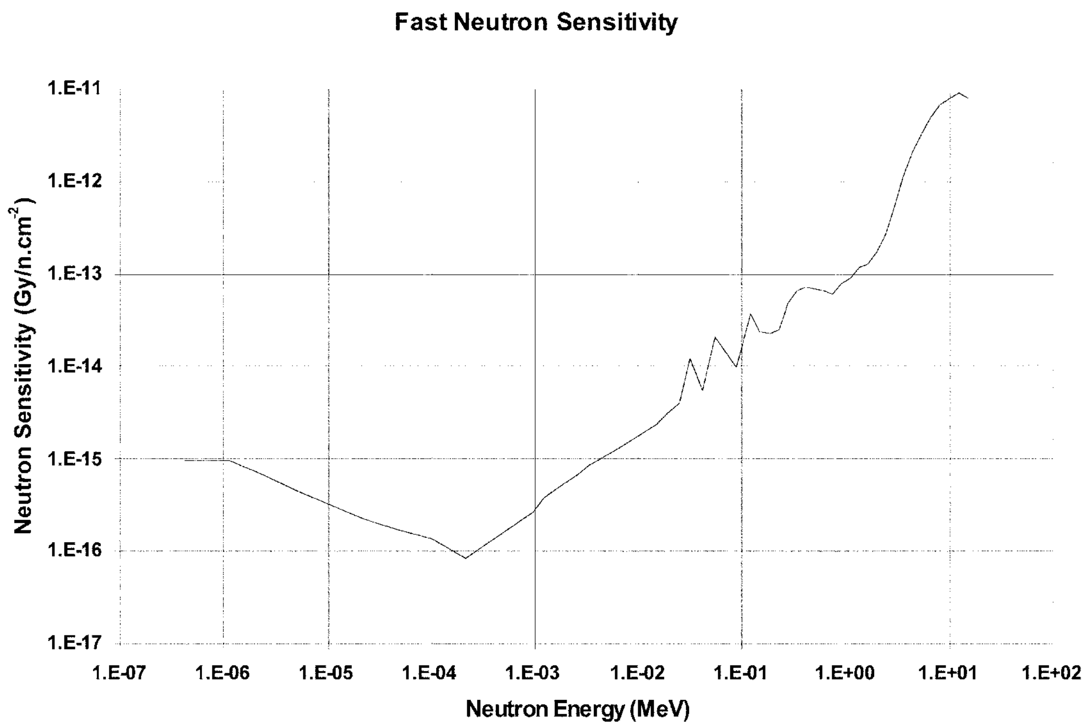

FIG. 1 Fast-Neutron Sensitivity of CaF_2(Mn) TLDs

TABLE 1 Fast Neutron Sensitivity of CaF_2(Mn) TLDs

Energy (MeV)	Response Gy(CaF_2)/n·cm^{-2}	Energy (MeV)	Response Gy(CaF_2)/n·cm^{-2}	Energy (MeV)	Response Gy(CaF_2)/n·cm^{-2}
4.14E-07	9.78E-16	1.50E-02	2.33E-15	1.11E+00	9.18E-14
1.13E-06	9.78E-16	1.93E-02	3.17E-15	1.35E+00	1.15E-13
2.38E-06	6.72E-16	2.48E-02	4.02E-15	1.65E+00	1.31E-13
5.04E-06	4.63E-16	3.19E-02	1.22E-14	2.02E+00	1.75E-13
1.07E-05	3.22E-16	4.09E-02	5.56E-15	2.47E+00	2.69E-13
2.26E-05	2.28E-16	5.25E-02	2.05E-14	3.01E+00	5.64E-13
4.78E-05	1.69E-16	8.65E-02	9.67E-15	3.68E+00	1.17E-12
1.01E-04	1.36E-16	1.23E-01	3.74E-14	4.49E+00	2.08E-12
2.14E-04	8.42E-17	1.50E-01	2.41E-14	5.49E+00	3.32E-12
4.54E-04	1.51E-16	1.83E-01	2.24E-14	6.70E+00	4.99E-12
9.61E-04	2.68E-16	2.24E-01	2.46E-14	8.19E+00	6.59E-12
1.23E-03	3.83E-16	2.73E-01	4.87E-14	1.00E+01	8.10E-12
1.59E-03	4.67E-16	3.34E-01	6.47E-14	1.22E+01	9.18E-12
2.04E-03	5.66E-16	4.08E-01	7.24E-14	1.49E+01	8.05E-12
2.61E-03	6.84E-16	4.98E-01	6.77E-14		
3.36E-03	8.42E-16	6.08E-01	6.49E-14		
4.31E-03	1.03E-15	7.43E-01	6.11E-14		
7.10E-03	1.40E-15	9.07E-01	8.04E-14		

8. Precision and Bias

8.1 None of the uncertainty attributable to this practice is derived by statistical techniques. Therefore, all the uncertainty is Type B. The level of uncertainty is quite large, since it encompasses the range of response of CaF_2(Mn) independent of manufacturer or batch. The uncertainty in the reported gamma-ray dose will depend on the relative amounts of neutrons and gamma rays in the exposure field.

8.2 See Practice E668 for a description of the statistical (Type A) uncertainties involved with TLD use.

8.3 Fig. 2 shows the relative neutron sensitivity of CaF_2(Mn) as determined by various authors. The relative neutron response is given as the light output from one neutron Gy(CaF_2) divided by the light output of the TLD to one Gy(CaF_2) in a Co-60 gamma ray field. There is a large range of response. The shaded area represents the 1 σ range of values