Designation: E 665 – 94

Standard Practice for Using Absorbed Dose Versus Depth in Materials to Verify the X-ray Output of Flash X-ray Machines[1]

This standard is issued under the fixed designation E 665; 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 covers a procedure for determining absorbed dose versus depth in materials exposed to the X-ray output of flash X-ray machines. It is applicable to all machines whose photon energy spectra have maximum energies ranging from 100 keV to 20 MeV. The determination provides information related to the photon spectrum from the flash X-ray machine. Specifically this measurement can be used for verifying expected X-ray spectra obtained from machine diagnostics and radiation transport calculations and for determining the appropriate equilibrator thickness to be used for dosimetric measurements.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 170 Terminology Relating to Radiation Measurements and Dosimetry[2]

E 666 Practice for Calculating Absorbed Dose from Gamma or X Radiation[2]

E 668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices[2]

2.2 *International Commission on Radiation Units and Measurements (ICRU) Reports:*

ICRU Report 33—Radiation Quantities and Units[3]

ICRU Report 34—The Dosimetry of Pulsed Radiation[3]

3. Terminology

3.1 Terminology used in this practice can be found in Terminology E 170 and ICRU Report 33

4. Summary of Practice

4.1 The first step is to expose a stack consisting of layers of material interspersed with thin dosimeters such as thermoluminescence dosimeters (TLDs). This is done at a large enough distance from the machine so that the direction of the incident radiation can be well defined.

4.2 A set of small spheres containing TLDs is then constructed and used to check the absorbed dose versus depth closer to the source where no single direction of the incident radiation determines the absorbed dose.

4.3 Compare measured dose versus depth to calculated profile using predicted X-ray output spectrum.

NOTE 1—For a comprehensive discussion of various dosimetry methods applicable to pulsed radiation fields, see ICRU Report 34.

5. Significance and Use

5.1 The X-ray output of flash X-ray machines is often very difficult to measure directly. Hence, experimenters must often rely on predicted spectra that are calculated using the specific bremsstrahlung converter and machine current and voltage diagnostics as input to radiation transport codes **(1-5)**.[4] Although these techniques work fairly well when the diagnostics are well calibrated and the machine is performing normally, it is prudent to check these predictions with some type of measured data.

5.2 Because the dose as a function of depth within a material is a strong function of the photon energy, such a measurement is a convenient means of verifying the predicted output of the machine.

5.3 The radiation transport codes can again be used to predict the depth-dose profile in the material using the predicted spectra and can be compared with the measurements **(6 and 7)**. Agreement between these two indicates the accuracy of the predicted spectra.

5.4 If there is a disagreement, the machine parameters used as input to the code can be varied to produce agreement with the measurements and indicate the magnitude of the discrepancy. This will not only demonstrate a difference in the machine output from the expected, but also suggest the possible source of the performance change.

[1] This practice is under the jurisdiction of ASTM Committee E-10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.07 on Radiation Effects on Electronic Materials, Components, and Devices.

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[2] *Annual Book of ASTM Standards*, Vol 12.02.

[3] Available for the International Commission on Radiation Units and Measurements, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814.

[4] The boldface numbers in parentheses refer to a list of references at the end of this practice.

6. Interferences

6.1 Whenever X rays or gamma rays pass through material, they produce secondary electrons. The energy of these electrons depends on the energy of the X rays producing them. The range of these secondary electrons in air is considerable, being about 3 m for 1-MeV X rays and about 10 cm for 100-keV X rays.

6.2 The intensity of secondary electrons leaving the output window of a flash X-ray machine depends on the window material and the X-ray field at that point. The absorbed dose produced by these secondary electrons adds to that produced by the X rays in the material of interest. Hence, in order to obtain results from a pure photon environment, these secondary electrons must be prevented from influencing the absorbed dose versus depth measurement. This can be achieved in many cases by interposing a transverse magnetic field strong enough to prevent these secondary electrons from reaching the point where the absorbed dose versus depth measurement is being made.

6.3 A magnetic field can bend the trajectory of secondary electrons within the material in which the absorbed dose versus depth measurement is being made and perturb the measured depth-dose profile. To minimize this effect, the magnetic field at the location where the absorbed dose versus depth measurement is being made should be no more than a few gauss (10^{-4} *T*).

6.4 Secondary electrons can also be generated in an air gap between the output window and the dosimetry. Although many of these will be scattered out of the beam for a narrow beam geometry, in a broad beam geometry many of these electrons may be present and will deposit energy in the dosimetry. If the air gap is large with respect to the electron range, this effect can be large. These electrons can be very difficult to remove and still maintain a low magnetic field near the dosimetry.

6.5 Measurements can be made with electron contamination; however, the interpretation is more difficult. For this case it is best to ensure that the output window is made of low atomic number (*Z*) materials (for example, aluminum, graphite, and Kevlar) and is thick with respect to both the primary and secondary electron ranges. For interpretation of data with electron contamination see 8.5.

6.6 An additional complication is a photon field with a large gradient in fluence over distances comparable in size with the dosimetry package (see 8.2 and 8.6) or the electron range in the material. The variation in dose due to fluence nonuniformities must then be separated from the normal depth-dose variation. This will typically require the use of a good radiation transport code for calculations.

7. Apparatus

7.1 Dosimeters typically used for absorbed dose versus depth determinations are thin calcium fluoride (CaF_2, Mn) TLDs. These dosimeters should be selected for uniformity of response in accordance with Practice E 668. Approximately 100 TLDs are required.

7.2 Approximately 20 layers of material can be used, each layer being from 0.005 to 2 g-cm^{-2} in thickness depending on the energy of the incident radiation. Use thinner layers for low-energy machines and thicker layers for high-energy machines. For example, a 500-keV photon is attenuated 5 % by 1.8 g-cm^{-2} of aluminum.

8. Procedure

8.1 Set up a magnetic field sufficient to achieve the purpose described in 6.2 that will sweep out the secondary electrons emanating from the output window of the machine and the air, if possible. (See Table 1.)

8.2 Prepare a stack made up of layers of the material. Between each layer, measure the dose with 5 TLDs. Position each TLD such that it is not in line with any other TLD in preceding layers when viewed from the X-ray source. Use several TLDs in between each layer to guard against nonuniformity of the incident beam.

8.3 Place and irradiate the stack described in 8.2 at a distance far enough from the X-ray source so that the X rays are incident approximately perpendicular to the plane defined by the stack. This arrangement means that a perpendicular axis usually can be defined between the stack and the source. However, for those flash X-ray facilities having distributed sources, the location of the stack with respect to the sources should be on a "common" axis.

8.4 This far-field measurement provides one absorbed dose versus depth curve for that position only. Fig. 1 is an example of such a curve in an environment with no incident electrons. From these data, determine a thickness for the following four points, as shown in Fig. 1, on the absorbed dose versus depth curves.

8.4.1 *Point a*—Halfway from the surface (zero depth) to the maximum absorbed dose.

8.4.2 *Point b*—At the maximum absorbed dose point.

8.4.3 *Point c*—The point beyond the maximum absorbed dose where the absorbed dose is 50 % of the maximum absorbed dose, and

8.4.4 *Point d*—The point beyond the maximum absorbed dose where the absorbed dose is 10 % of the maximum absorbed dose.

8.5 For the case where electron contamination is present and the output window meets the conditions specified in 6.5, the shape of the curve in Fig. 1 can be very different as shown by the dotted lines. Although Points *b*, *c*, and *d* will remain unchanged, the curve from zero depth to Point *b* can change from the present shape shown in Fig. 1 to a flat line due to the external secondary electrons. Hence Point *a* is no longer a useful point in verifying the photon spectrum and is not necessary for 8.6. The best estimate of Point *b* is the point on the curve where the dose first begins to decrease with increasing depth.

TABLE 1 Magnetic Field Requirements for Avoiding the Influence of External Secondary Electrons on Absorbed Dose Measurements

Electron Energy, MeV	$B \cdot \rho$ (T · m)[A]
0.1	1.12×10^{-3}
0.5	2.91
1.0	4.75
5	18.30
10	35.00

[A] Magnetic flux density (*B*) times radius of curvature of the electron trajectory (ρ).