Designation: F526 − 21

Standard Test Method for Using Calorimeters for Total Dose Measurements in Pulsed Linear Accelerator or Flash X-ray Machines[1]

This standard is issued under the fixed designation F526; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers a calorimetric measurement of the total absorbed dose delivered by a single pulse of electrons from an electron linear accelerator or a flash X-ray machine (FXR, e-beam mode). The test method is designed for use with pulses of electrons in the energy range from 10 to 50 MeV and is only valid for cases in which both the calorimeter and the test specimen to be irradiated are "thin" compared to the range of these electrons in the materials of which they are constructed.

1.2 The procedure described can be used in those cases in which (*1*) the dose delivered in a single pulse is 5 Gy(matl)[2] [500 rd (matl)] or greater, or (*2*) multiple pulses of a lower dose can be delivered in a short time compared to the thermal time constant of the calorimeter. The units for the total absorbed dose delivered to a material require the specification of the material and the notation "matl" refers to the active material of the calorimeter. The minimum dose per pulse that can be acceptably monitored depends on the variables of the particular test, including pulse rate, pulse uniformity, and the thermal time constant of the calorimeter.

1.3 A determination of the total dose is made directly for the material of which the calorimeter block is made. The total dose in other materials can be calculated from this measured value using Eq 3 presented in this test method. The need for such calculations and the choice of materials for which calculations are to be made shall be subject to agreement by the parties to the test.

1.4 The values stated in SI units are to be regarded as the standard. The values in parenthesis are provided for information only.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E230 Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples

E1894 Guide for Selecting Dosimetry Systems for Application in Pulsed X-Ray Sources

3. Terminology

3.1 *Definitions:*

3.1.1 *device under test (DUT)*—the device that is being tested.

3.1.2 *Seebeck EMF*—the electromagnetic force (EMF) generated by the Seebeck effect when two wires composed of dissimilar metals are joined at both ends and the ends are held at different temperatures. A voltage can be measured across the terminals when current flows through the wires.

3.1.3 *temperature coefficient of resistance*—the resistance change in a material per degree of temperature change $d\Omega/(\Omega^*d\theta)$, where Ω denotes the resistance and θ denotes the temperature. This quantity has units of inverse temperature and, for small changes about a reference temperature in a conductor, this quantity is often modeled as a linear relationship with temperature.

[1] This test method 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] In 1975 the General Conference on Weights and Measures adopted the unit gray (symbol – Gy) for absorbed dose; 1 Gy = 100 rd.

[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.

3.1.4 *thermal time constant of a calorimeter*—the time for the temperature excursion of the calorimeter material resulting from a radiation pulse to drop to 1/*e* of its initial maximum value.

3.1.5 *TSP*—twisted shielded pair, a shielded case of a twisted pair cable in which two conductors are twisted together for the purpose of canceling out electromagnetic interference from external sources.

3.2 Definitions of other terms used in this standard that pertain to radiation measurements and dosimetry may be found in Terminology E170.

4. Summary of Test Method

4.1 *Single-Pulse Method*—This method consists of (*1*) irradiating, with a single pulse of high-energy electrons from an electron linear accelerator (linac) or flash X-ray machine (FXR), a small block of material to which either a thermistor or a thermocouple made from small-diameter wire is attached; (*2*) recording and measuring the resulting signal from a bridge circuit or directly from the thermocouple; (*3*) calculating the total dose deposited in the block based on the temperature rise and the specific heat of the material; and (*4*) if required, calculating the equivalent dose in other specified materials exposed to this same pulse.

4.2 *Multiple-Pulse Method*—If the dose available in a single pulse is not large enough to give measurable results, the linac is pulsed repeatedly within a time short compared to the thermal time constant of the calorimeter. This method is similar to the single-pulse method except that the average dose delivered in each pulse is calculated from the measured cumulative dose of all the pulses.

5. Significance and Use

5.1 An accurate measure of the total absorbed dose is necessary to ensure the validity of the data taken, to enable comparison to be made of data taken at different facilities, and to verify that components or circuits are tested to the radiation specification applied to the system for which they are to be used.

5.2 The primary value of a calorimetric method for measuring dose is that the results are absolute. They are based only on physical properties of materials, that is, the specific heat of the calorimeter-block material and the Seebeck EMF of the thermocouple used or the temperature coefficient of resistance (α) of the thermistor used, all of which can be established with non-radiation measurements.

5.3 The method permits repeated measurements to be made without requiring entry into the radiation cell between measurements.

6. Interferences

6.1 *Thermal Isolation*—If the thermal isolation of the calorimeter is not sufficient, the thermal time constant of the calorimeter response will be too short for it to be useful.

NOTE 1—This condition can be caused by insufficient insulation material or by heat loss through the thermocouple wires themselves.

6.2 *Thermal Equilibrium*—The initial value of the transient temperature change following a radiation pulse may not reflect the true temperature change of the calorimeter-block material.

NOTE 2—This situation can be brought about by a temperature rise occurring in the materials at the point of attachment of the thermocouple or the thermistor different from that in the calorimeter-block material. As long as the calorimeter block comprises the great bulk of the calorimeter material, the temperature will quickly equilibrate to that of the block, and the subsequent temperature record will be that of the calorimeter-block material (see Appendix X1).

6.3 *Pulse Reproducibility*—If pulse-to-pulse reproducibility of the radiation source varies more than ±20 %, a good measure of the dose per pulse may not be attainable from the average value calculated in the multiple-pulse method.

6.4 *Facility Spot Size*—If the calorimeter is used in high-dose rate positions, the spot size (especially in ebeam facilities) may not be large enough to adequately cover the calorimeter material.

7. Apparatus

7.1 *Pulsed Electron Source:*

7.1.1 *Linac*—Electron linear accelerator and associated instrumentation and controls suitable for use as an ionizing source for radiation-effects testing. See Guide E1894.

7.1.2 *FXR*—Flash X-ray system that provides intense bremsstrahlung X-ray radiation environments, usually in a single sub-microsecond pulse, and which can often fluctuate in amplitude, shape, and spectrum from shot to shot. This system can be operated in an electron beam mode by not utilizing the bremsstrahlung converter. See Guide E1894.

7.2 *Calorimeter*—Special instrument suitable for measuring the total dose delivered by the linac and constructed in accordance with any of several designs indicated in Appendix X1. A selection of calorimeter materials and their properties are shown in Table 1. Although measurement differences resulting from the use of different designs should not be significant, all parties to the test shall agree to a single design utilizing a single calorimeter-block material and a specific thermocouple or thermistor (see Fig. 1). The calorimeter design shall be such that the material surrounding the active calorimeter material that is penetrated along the beam path is less than or equal to no more than 20 % of the range of the beam-energy electrons.

TABLE 1 Physical Properties of Some Calorimeter-Block Materials

Material	Energy Loss [A] d*E*/d*x* (10^{-14} J·m ^{2}/kg)	Specific Heat, c_p [B] (J/kg·K)	Density, ρ [B] (10^3 kg/m^3)
C	2.92	711	2.10
Al	2.74	900	2.70
Si	2.84	711	2.33
Fe	2.52	452	7.87
Cu	2.42	385	8.96
Ge	2.45	322	5.32
W	2.08	134	19.3
Au	2.06	130	19.3
Pb	2.07	128	11.4

[A] The data are given for 20-MeV electrons, but ratios based on these values are good to better than 2 % over the energy range from 10 to 50 MeV, inclusive. These values have been converted to SI units from data given in Refs **(1)** and **(2)**.
[B] These values have been converted to SI units from data given in the Ref **(3)**. (The specific heat values are applicable in the range from 18 to 30°C, inclusive.)