INTERNATIONAL STANDARD

ISO/ASTM 51631

Second edition
2003-07-15

Practicefor use of calorimetric dosimetry systems for electron beam dose measurements and dosimeter calibrations

Pratique de l'utilisation des systèmes dosimétriques calorimétriques pour des mesures de dose délivrée par un faisceau d'électrons et pour l'étalonnage de dosimètres

Reference number
ISO/ASTM 51631:2003(E)

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ASTM International, 100 Barr Harbor Drive, PO Box C700,
West Conshohocken, PA 19428-2959, USA
Tel. +610 832 9634
Fax +610 832 9635
E-mail khooper@astm.org
Web www.astm.org

Published in the United States

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

ASTM International is one of the world's largest voluntary standards development organizations with global participation from affected stakeholders. ASTM technical committees follow rigorous due process balloting procedures.

A project between ISO and ASTM International has been formed to develop and maintain a group of ISO/ASTM radiation processing dosimetry standards. Under this project, ASTM Subcommittee E10.01, Dosimetry for Radiation Processing, is responsible for the development and maintenance of these dosimetry standards with unrestricted participation and input from appropriate ISO member bodies.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. Neither ISO nor ASTM International shall be held responsible for identifying any or all such patent rights.

International Standard ISO/ASTM 51631 was developed by ASTM Committee E10, Nuclear Technology and Applications, through Subcommittee E10.01, and by Technical Committee ISO/TC 85, Nuclear Energy.

Annexes A1 and A2 of this International Standard are for information only.

3.1.10 *thermocouple*—junction of two metals producing an electrical voltage with a well-defined relationship to junction temperature.

3.1.11 *transfer-standard dosimeter*—dosimeter, often a reference-standard dosimeter suitable for transport between different locations, used to compare absorbed-dose measurements.

3.2 Definitions of other terms used in this standard that pertain to radiation measurement and dosimetry may be found in ASTM Terminology E 170. Definitions in E 170 are compatible with ICRU 60; that document, therefore, may be used as an alternative reference.

4. Significance and use

4.1 This practice is applicable to the use of a calorimeter for the measurement of absorbed dose in electron beams, the qualification of electron irradiation facilities, periodic checks of operating parameters of electron irradiation facilities, and calibration of other dosimeters in electron beams.

NOTE 1—For additional information of the use of dosimetry in electron accelerator facilities, see ISO/ASTM Practices 51431 and 51649, and ICRU Reports 34 and 35, and Refs **(1-3)**.[4]

4.2 The calorimeters described in this practice are not primary-standard dosimeters. They may be used as transfer-standard dosimeters or as internal standards at an electron beam irradiation facility, or may be routine dosimeters used for routine dose measurements. The calorimeters are calibrated by comparison with transfer-standard dosimeters.

4.3 The dose measurement is based on the measurement of the temperature rise in an absorber (calorimetric body) irradiated by an electron beam. Different absorbing materials are used, but the response is usually defined in terms of dose to water.

4.4 The absorbed dose in other materials irradiated under equivalent conditions may be calculated. Procedures for making such calculations are given in ASTM Practices E 666 and E 668, ISO/ASTM Guide 51261, and Ref **(1)**.

4.5 The average absorbed dose in the volume of the calorimetric body is measured. Dose gradients may occur in this volume and may have to be considered when estimating dose in other materials.

4.6 The calorimetric bodies of the calorimeters described in this practice are made from low atomic number materials. The electron fluences within these calorimetric bodies will be approximately equal when irradiated with electron beams of 1.5 MeV or higher. Calibration in terms of dose to water is possible for these calorimeters.

4.6.1 Calorimeters for use at industrial electron accelerators have been constructed using graphite, polystyrene or a Petri dish filled with water as the calorimetric body **(4-10)**. The thickness of the calorimetric body shall be less than the range of the electrons for the specified material.

4.6.2 Polymeric materials other than polystyrene may be used for calorimetric measurements. Polystyrene is used because it is known to be resistant to radiation **(11)** and because no exo- or endothermic reactions take place **(12)**.

5. Interferences

5.1 *Extrapolation*—The calorimeters described in this practice are not adiabatic, because of the exchange of heat with the surroundings or within the calorimeter assembly. The maximum temperature reached by the calorimetric body is different from the temperature that would have been reached in the absence of that heat exchange. The temperature drifts before and after irradiation are extrapolated to the midpoint of the irradiation period in order to determine the true temperature increase due to the absorbed dose.

5.2 *Heat Defect*—Chemical reactions in irradiated material (resulting in what is called the heat defect or thermal defect) may be endo- or exothermic and may lead to measurable temperature changes. In water, for example, these are respectively deficient or excessive with respect to the temperature increase due solely to the absorption of radiation energy in the water. The extent of these effects depends on the purity or the gas content of the water and on any chemical effects arising from the container of the water. At the absorbed doses and dose rates usually encountered by these calorimeters, these effects are not significant **(3)**.

5.3 *Temperature Effects from Accelerator Structure*—The calorimeters are often irradiated on a conveyor used for passing products and samples through the irradiation zone. Radiated heat from the mechanical structures of the irradiation facility and from the conveyor may contribute to the measured temperature increase in the calorimeters.

5.4 *Thermal Equilibrium*—The most reproducible results are obtained when the calorimeters are in thermal equilibrium before irradiation.

5.5 *Other Materials*—The temperature sensors, wires, etc. of the calorimeter represent foreign materials, which may influence the temperature rise of the calorimetric body. These components should be as small as possible.

5.6 *Dose Gradients*—Dose gradients will exist within the calorimetric body when it is irradiated with electrons. These gradients must be taken into account, for example, when other dosimeters are calibrated by comparison with calorimeters.

6. Apparatus

6.1 *A Typical Graphite Calorimeter* is a disc of graphite placed in a thermally-insulating material such as foamed plastic **(4-6)**. A calibrated thermistor or thermocouple is embedded inside the disc. See Fig. 1 for an example of such a calorimeter. Some typical examples of graphite disc thicknessesand masses are listed in Table 1 **(2)**.

6.2 *A Typical Water Calorimeter* is a sealed polystyrene Petri dish filled with water and placed in thermally-insulating foamed plastic **(4)**. A calibrated temperature sensor (thermistor) is placed through the side of the dish into the water.

6.3 *A Typical Polystyrene Calorimeter* is a polystyrene disc placed in thermally-insulating foamed plastic. A calibrated thermistor or thermocouple is imbedded inside the disc. The dimension of the polystyrene disc may be similar to that of the graphite and water calorimeters **(9)**. See Fig. 2 as an example

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

TABLE 1 Thickness and size of several graphite calorimetric bodies designed at NIST for use at specific electron energies

Electron Energy MeV	Electron Range in Graphite[A] density: 1.7 g cm^{-3}		Calorimeter Disc (30 mm diameter)		
			Thickness[B]		Mass, g
	g cm^{-2}	cm	g cm^{-2}	cm	
4	2.32	1.36	0.84	0.49	5.9
5	2.91	1.71	1.05	0.62	7.5
6	3.48	2.05	1.25	0.74	8.9
8	4.59	2.70	1.65	0.97	11.7
10	5.66	3.33	2.04	1.20	14.4
11	6.17	3.63	2.22	1.31	15.7
12	6.68	3.93	2.40	1.41	16.9

[A] This is the continuous-slowing-down approximation (CSDA) range r_o of electrons for a broad beam incident on a semi-infinite absorber. It is calculated from:

$$r_0 = \int_0^{E(0)} (1 / (S/\rho)_{tot})\, dE$$

where:
E_0 = the primary electron energy, and
$(S/\rho)_{tot}$ = the total mass stopping power at a given electron energy **(1)**.

[B] The thicknesses specified are equal to 0.36 r_o.

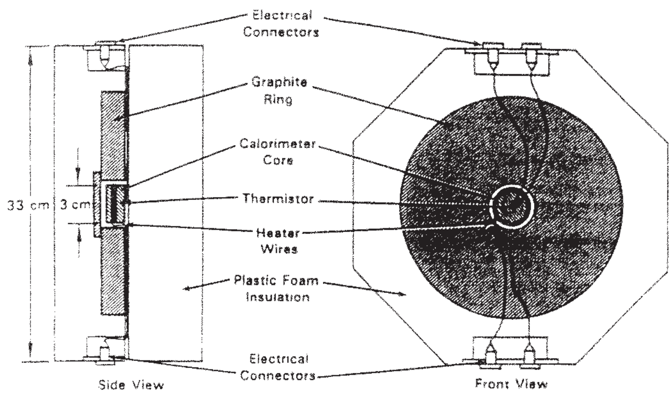


FIG. 1 Example of a graphite calorimeter used at a 10-MeV industrial electron accelerator (5)

of a 10 MeV-calorimeter. Fig. 3 shows an example of a polystyrene calorimeter designed for use at 1.5 to 4 MeV electronaccelerators.

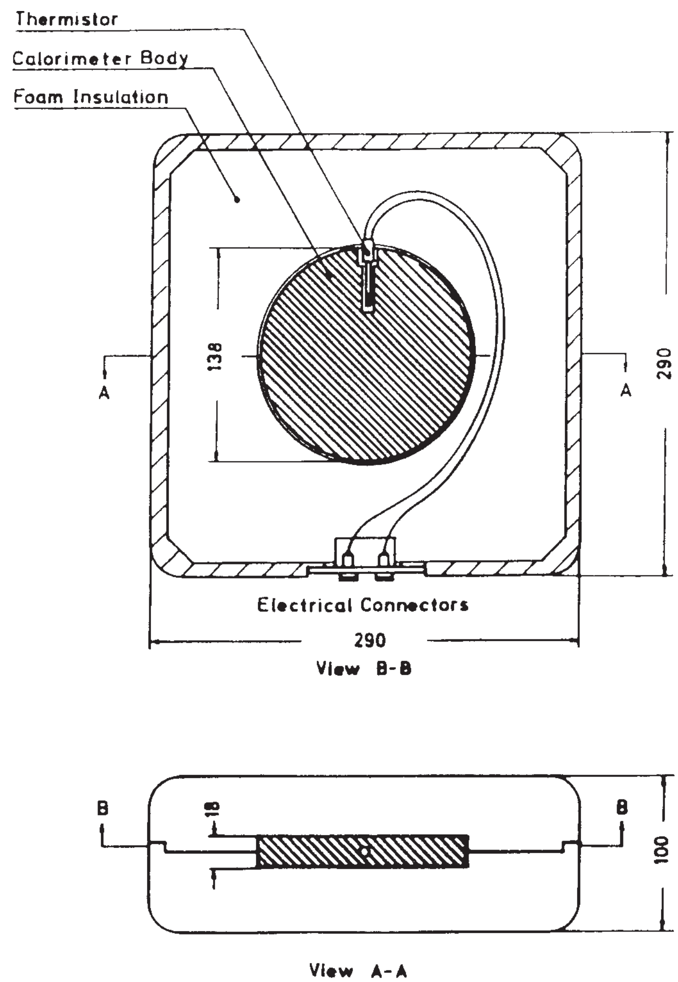
6.4 The thickness of the calorimetric body should be less than the range of the irradiating electrons, typically not exceeding ⅓ of the range of the electrons for the specified material. That will limit the variation of the dose gradients within the calorimetric body.

6.5 Radiation-resistant components should be used for the parts of the calorimeter that are exposed to the electron beam. This also applies to insulation of electrical wires.

6.6 Good thermal contact must exist between the temperature sensor and the calorimetric body. For graphite and polystyrene calorimeters, this can be assured by adding a small amount of heat-conducting compound when mounting the temperature sensor.

6.7 *Read-Out*—The calorimeters are read by measuring the temperature of the calorimetric body. This temperature is registered by thermistors or thermocouples.

6.7.1 *Thermistor*—Use a high-precision ohm-meter for measurement of thermistor resistance.The meter should have a reproducibility of better than ±0.1 % and an accuracy of better



NOTE—All dimensions are in mm.

FIG. 2 Example of a polystyrene calorimeter used for routine measurements at a 10-MeV industrial electron accelerator

than ±0.2 %. It should preferably be equipped for four-wire type resistance measurements, especially if the thermistor

resistance is less than 10 kΩ. With the four-wire measurement technique, the effects of resistance in the measurement wires and electrical contacts are minimized.

6.7.2 Other appropriate instrumentation may be used for the thermistor resistance measurement, for example, a resistance bridge or commercially calibrated thermistor readers **(5)**. It is important for both ohm-meters and resistance bridge measurements to minimize the dissipated power in the thermistor, preferably below 0.1 mW.

6.7.3 *Thermocouple*—Use a high-precision digital voltmeter, or commercial reader **(2)**. The reproducibility of the voltmeter should be better than 0.1 µV, and an accuracy of better than ±0.2 %.

7. Calibration procedures

7.1 Prior to use, the calorimetric dosimetry system (consisting of calorimeter and measurement instruments) shall be calibrated in accordance with the user's documented procedure that specifies details of the calibration process and quality assurance requirements. This calibration process shall be repeated at regular intervals to ensure that the accuracy of the absorbed dose measurement is maintained within required limits. Calibration methods are described in ISO/ASTM Guide 51261.

7.2 Graphite, water or polystyrene calorimeters may be calibrated by comparison with transfer-standard dosimeters from an accredited calibration laboratory by irradiating the calorimeter(s) and dosimeters sequentially (or simultaneously) at an electron accelerator. The radiation field over the cross-sectional area of the calorimetric body shall be uniform to within ±2 % and constant over the time required to irradiate the calorimeters and the transfer-standard dosimeters.

7.3 It must be assured that the transfer-standard dosimeters and the calorimeters are irradiated to the same dose. Specially designed absorbers are needed for irradiation of the transfer-standard dosimeters, see for example Fig. 4.

7.4 The specific heat capacity of polystyrene and of graphite are functions of temperature, while the specific heat capacity of water is almost constant within the temperature range normally employed in electron beam calorimetry. The calibration function of the calorimeters are therefore expected to be functions of the average temperature of the calorimetric body (see Note 2).

NOTE 2—Repeated measurements of specific heat capacity of various types of graphite have been carried out over the range of 0 to 50°C, indicating a value for c_G ($J \cdot kg^{-1} \cdot °C^{-1}$) = 644.2 + 2.86 T, where T is the mean temperature (°C) of the graphite. This value must, however, not be considered a universal value **(6)**.

7.5 The dose response for water calorimeters is approximately 3.4 kGy · °C^{-1} and for polystyrene calorimeters it is approximately 1.4 kGy · °C^{-1}. For graphite, the relationship is approximately 0.75 kGy · °C^{-1}.

7.6 Calibration of all types of calorimeters used as routine dosimeters should be checked by comparison with reference-standard or transfer-standard dosimeters at a frequency determined by the user.

7.7 Calorimeters may be calibrated by irradiation at a calibration laboratory. The calibration obtained in this way must be verified by simultaneous irradiation of the calorimeters and transfer-standard dosimeters at the user's facility.

7.8 *Measurement Instrument Calibration and Performance Verification*—For the calibration of the instruments, and for the verification of instrument performance between calibrations, see ISO/ASTM Guide 51261 and/or instrument-specific operating manuals.

8. Dose measurement procedures

8.1 *Conveyor Irradiation*—For calorimeters carried on conveyors through scanned electron beams, the calorimeter is usually disconnected from the temperature measurement system just prior to irradiation and reconnected for readout just after irradiation **(7)**.

8.1.1 Before irradiation, measure the temperature of the calorimetric body and check that the temperature remains stable for a period of at least 10 min (typically less than 0.1°C change), see Fig. 5.

8.1.2 Disconnect the measurement wires and place the calorimeter on the conveyor for transport through the irradiation zone.

8.1.3 Transport the calorimeter through the irradiation zone on the conveyor system.

8.1.4 During irradiation, record the time of irradiation, and the irradiation parameters (electron energy, electron current, scanned beam width, and conveyor speed).

8.1.5 After passage of the calorimeter through the irradiation zone, reconnect the wires for measurement of temperature, and record the time from the end of irradiation to the first temperature measurement. Record the temperature as a function of time for 10 to 20 min after irradiation, enough to establish the thermal decay characteristics of the calorimeter.

8.1.6 Plot the temperature values as a function of time before and after irradiation.

8.1.7 Extrapolate the curves before and after irradiation to the midpoint of the irradiation time. The two values of temperature obtained from the extrapolations are used as the temperature before irradiation (T_1) and after irradiation (T_2)

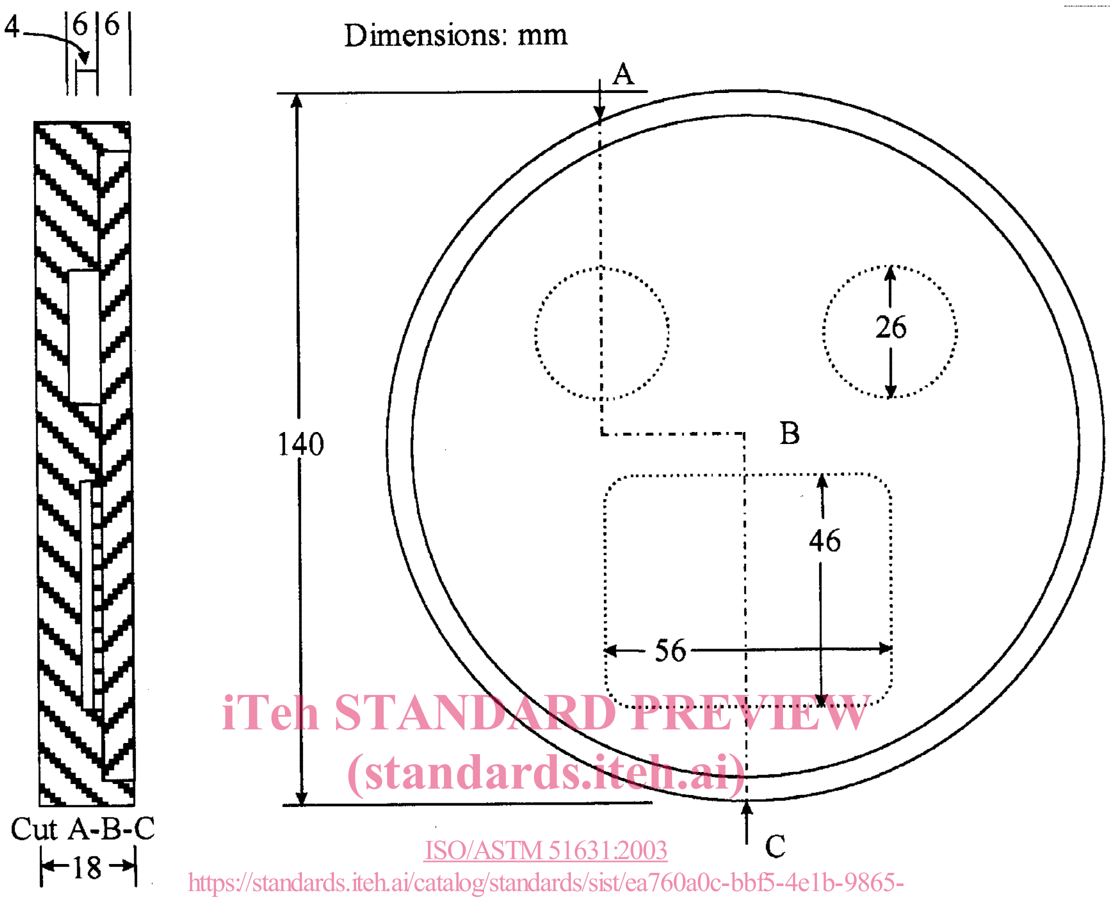
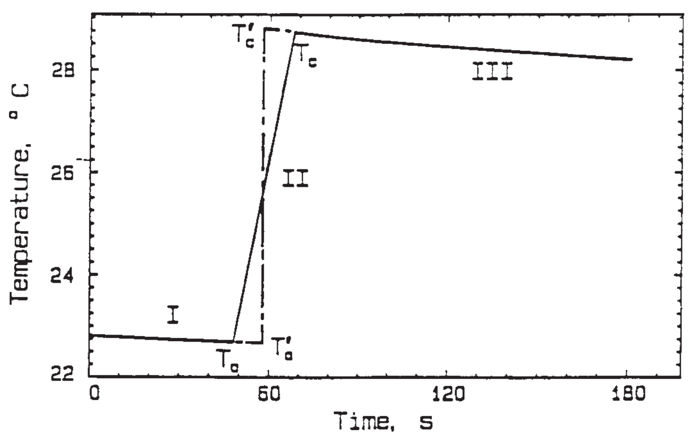


FIG. 4 Absorber for irradiation of routine and transfer-standard dosimeters (10). All measures are in mm.



NOTE—Regions I, II, and III are before, during and after irradiation, respectively. The temperature curves were extrapolated from T_o and T_c to the midpoint of the irradiation time at T_o' and T_c', respectively. $\Delta T = T_c' - T_o'$ is used for dose calculation.

FIG. 5 Example of on-line measurements of a graphite calorimeter (5)

that would reflect the temperature rise solely due to absorbed dose. An example of data obtained by this measurement technique is shown in Fig. 6.

8.1.8 Based on the temperature difference, $T_2 - T_1$, determine the average absorbed dose in the calorimetric body from the calibration function established in Section 7.

8.1.9 For well-established, reproducible irradiation conditions the extrapolation procedure of 8.1.7 may not be needed. One measurement of temperature before and one after irradiation may suffice, and the temperature difference at the time of irradiation is found by use of a correction factor derived during the establishment of the irradiation procedures **(4,5,7,8)**. The times of the measurements should be specified.

8.2 *On-line Irradiation on Conveyor*—It is possible to measure the temperature of the calorimetric body during irradiation as the calorimeter is transported through the irradiation zone on the conveyor with measurement wires attached. Four-wire measurement (see 6.7.1) may be preferred in order to reduce measurement uncertainty.

8.3 *Stationary Irradiation*—The calorimeters described in this practice may also be used in a stationary configuration instead of being transported on a conveyor system through the electron beam. In this arrangement the beam can be made uniform over the area of the calorimetric body either by the use of metallic scattering foils or by raster scanning. The irradiation period is controlled by turning the electron beam on and off.