Attenuation characteristics of a new compensator material: Thermo-Shield for high energy electron and photon beams

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A new thermoplastic material with extremely desirable physical and radiation shielding properties is presented. The material softens between 108 °F and 132 °F and can then be easily molded to any desired shape. As it cools down it hardens at about 102 °F, retaining its molded shape. It is very light ($\rho = 1.66$ g/cc), compared to most other compensating and shielding materials used in the clinic. Its photon and electron attenuation characteristics have been measured and are compared with other materials relevant to radiotherapy. Possible applications as a bolus material. compensator and partial or total shielding material in clinical radiation therapy are discussed. [S0094-2405(98)00304-6]

Key words: Thermo-Shield, compensator, bolus

INTRODUCTION

In clinical situations involving external patient contour variations and internal inhomogeneities, routine use of compensators to achieve homogeneous dose distributions in the planning treatment volume (PTV) has become practical because of advances in computer technology. Three-dimensional anatomical data can be acquired by CT, leading to dosimetric evaluation of tissue densities in the treatment planning system (TPS) which can be programmed to design a compensator.[1] Automation in the fabrication of these compensators has been achieved by computer driven milling machines.[2] The compensator shape designed by the TPS can be milled directly in compensator material or a complimentary image of the compensator shape can be milled into a mold, which can then be filled with compensator material. Compensators have been fabricated from aluminum,[3] brass,[4] wax,[5] lead,[6–9] Lipowitz metal,[10,11] gypsum and metal,[12] and tin granule mixtures.[13] The objective of this technical note is to introduce a new material, "Thermo-Shield™," (Med-Tec, Inc.), highly suited for these applications.

Physical properties

Thermo-Shield is a highly attenuating plastic that is manually moldable and conforms to any shape at 108 °F–132 °F. It hardens as it cools, setting to a rigid form at 102 °F. The constituents used in the production of this thermoplastic radiation shield are: (i) Federal Drug Administration approved dental hydrocarbon impression compound for intraoral usage, and (ii) elemental bismuth (100 mesh). Production of this thermoplastic is done by homogeneously blending the finely powdered dental compound with the 100 mesh bismuth in a volume ratio of approximately 2:1 The mixture of this metal and thermoplastic hydrocarbon is then heated in an oven to approximately 2000 °F for 30 min and then cooled. The dental compound bonds to the rhombohedral bismuth spheres, thus forming the dense thermoplastic radiation shield.

To use clinically, Thermo-Shield is warmed in a water bath at about 108–132 °F and molded to the patient's anatomy that is to be shielded from electron or photon radiation therapy (see Fig. 1). The shield hardens at approximately 102 °F and since it does not stick to the patient's skin, it can be easily removed. The shield becomes rigid for accurate anatomic detail and can be placed repeatedly for multiple radiation therapy sessions. It can also be handcarved, shaped with rotary instruments, or cut with hot wire or Exacto hot scalpel technique if desired. With a specific gravity of only 1.66, the thermoplastic material is very light compared to its shielding counterpart like lead and cerrobend.

Clinical suitability

The bio-compatible and shielding attributes of the Thermo-Shield allow its usage for protecting healthy, radiosensitive cells, tissues, hair, lips, eyes, and organelles from radiation therapy, while allowing radio-teletherapy to reach the desired tumor field. It is equally well suited for electron, orthovoltage and megavoltage external beams as well as for

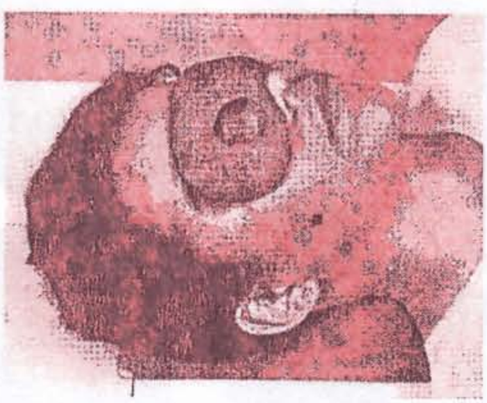

FIG. 1. Clinical application of Thermo-Shield (photo courtesy of Med-Tec, Inc.).

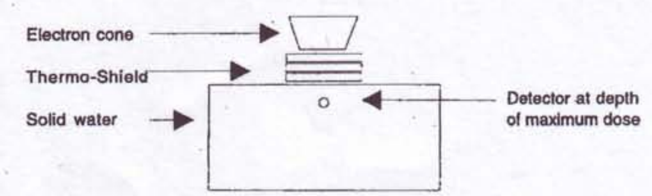

FIG. 2. Setup used for electron attenuation measurements. Distance is 100 cm from source to top of solid water. For each electron energy, detector placed at depth of maximum dose.

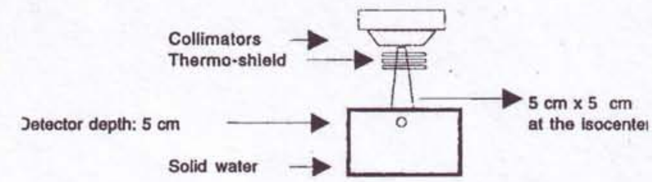

FIG. 3. Setup used for photon attenuation measurements. Detector placed at isocenter at depth of 5 cm in solid water. Thermo-Shield slabs were stacked on a standard block tray mounted to the linac head.

brachytherapy. It is a good substitute for lead strip types of shields and unlike high-Z materials like lead and cerrobend it produces less bremsstrahlung photons in electron treatments. It is reusable by reshaping as well as by changing the thickness, and it may be disinfected with glutaraldehyde spray for asepsis.

Potential application sites

(1) Majority of treatments with external electron and photon beam irradiation in the intraoral head and neck sites. Example: electron shielding of 3 cm or less, as in shaping the electron field by blocking at the end of the treatment cone. Field contouring in such cases using Thermo-Shield is extremely simple, convenient and effective.

(2) Intraoral cancers of the tongue, floor of mouth, palate, tonsillar arch, intraoral buccal mucosa, mandible maxilla and parotid. Intraoral shielding protects oropharyngeal tissues which are otherwise unshielded due to their position either within the primary beam or adjacent to the brachytherapy site.

(3) Customized impression trays loaded with shielding materials used for tongue immobilization in brachytherapy, electron and orthovoltages.

(4) Shielding of tooth extraction sites or areas where periodontal surgery has been performed. Since these "wound-healing cells" with their greater mitotic activity are particularly radiosensitive, shielding could lessen the probability of osteoradionecrosis, allowing for a more normal healing process and hence lessen the untimely delays in radiation therapy.

MATERIALS AND METHODS

The vendor currently markets the Thermo-Shield material in slabs of 12×12 cm^2 and approximate thickness of 1.7 cm. For our experimental determination of the attenuation coefficients of the material, variable slab thickness of less than 1.7 cm was achieved by warming the Thermo-Shield slabs in a hot water bath and then pressing them in the desired thickness using a vise.

Electron attenuation properties were measured utilizing a 10 cm$\times$10 cm electron cone at 100 cm SSD setup, relative to the top of a stack of Solid Water™ (Radiation Measurements Inc., Middleton, WI) (Fig. 2). A Farmer-type ionization chamber was placed in the solid water at the depth of maximum dose, with 10 cm of solid water below for adequate backscatter. The amount of charge collected by the ionization chamber was measured with a Keithley 35040 electrometer. For each electron energy, measurements were made with 0, 0.5, 0.7, 1.0, 2.0, 2.5, and 3.0 cm of Thermo-Shield stacked above the solid water.

Photon attenuation properties were measured in a 5 cm$\times$5 cm field and a 100 cm SSD setup (Fig. 3). The same Farmer-type ionization chamber was placed in the solid water at 5 cm depth, with 10 cm of solid water below for adequate scatter. For each photon energy, measurements were taken with 0, 1.71, 3.33, 4.94, and 6.63 cm of Thermo-Shield stacked on the block holder tray.

Relative transmission values were determined by normalizing the readings of each energy to their 0 cm reading. Uncertainty of the readings (67% confidence level) was determined from the standard deviation of multiple measurements. The transmission values for each photon and electron energy were plotted against Thermo-Shield thick-

TABLE I. Measurements of electron transmission (percentage) at depth of maximum dose through increasing thicknesses of Thermo-Shield. For each beam energy, the data are normalized to its corresponding value measured for 0 cm thickness.

	Electron beam energy					
Thickness (cm)	4 MeV	6 MeV	9 MeV	12 MeV	15 MeV	18 MeV
0.00	100.0	100.0	100.0	100.0	100.0	100.0
0.50	10.0	18.0	28.0	68.0	85.0	92.0
0.70	0.4	1.2	13.3	45.0	74.0	83.9
1.00	0.4	0.9	9.0	29.0	56.0	68.0
2.00	0.3	0.6	1.4	2.8	4.9	7.6
2.50	0.2	0.4	1.1	2.5	4.0	6.1
3.00	0.2	0.3	1.0	2.0	3.2	5.2

TABLE II. Measurements of photon transmission (percentage) at depth of maximum dose through increasing thicknesses of Thermo-Shield. For each beam energy, the data are normalized to its corresponding value measured for 0 cm thickness.

Thermo-Shield	Photon energies (MV)			
Thickness (cm)	4	6	10	20
0	100.0	100.0	100.0	100.0
1.71	66.4	69.1	72.3	72.3
3.33	46.3	50.1	53.7	53.6
4.94	33.0	36.7	40.4	39.8
6.63	23.3	26.7	29.8	29.0

ness. For photons, the linear attenuation coefficient was determined for each energy by fitting the data to an exponential function given by $I/I_0=\exp(-\mu t)$, where I/I_0 is the relative transmission reading, μ is the linear attenuation coefficient and t the thickness of the thermoplastic material. The linear attenuation coefficients for Thermo-Shield were then plotted against effective photon beam energy, along with attenuation coefficients for cerrobend, lead, lucite, polystyrene, and water.

RESULTS

Electrons

Results for electron transmission measurements are tabulated in Table I. As it has been discussed in the previous section, the uncertainty (67% confidence level) associated with the experimental data is 5% of the average value of the multiple measurements. It can be inferred from Table II that the TVL for this material at 4, 6, and 9 MeV ranges from 0.5 to 1.0 cm whereas for lead it ranges from 2 to 4 mm. For higher energies (20 MeV) TVL for Thermo-Shield is about 2 cm compared to lead which is about 1 cm.[14]

Photons

Results for photon transmission measurements are tabulated in Table II. The uncertainty associated with the experimental data is 1%. Exponential fits to the transmission data as described above gave linear attenuation coefficient of the Thermo-Shield at different energies and are tabulated in Table III. A comparison of the linear attenuation coefficients for the Thermo-Shield and for other materials relevant to radiotherapy are plotted in Fig. 4.[15] The linear attenuation coefficient for the Thermo-Shield material falls between the commonly used material like lead and cerrobend and tissue-

TABLE III. Linear attenuation coefficients for Thermo-Shield for different energy photon beams.

Thermo-Shield	Photon energies (MV)			
	4	6	10	20
Linear Attn. Coef. (per cm)	0.227	0.205	0.185	0.187

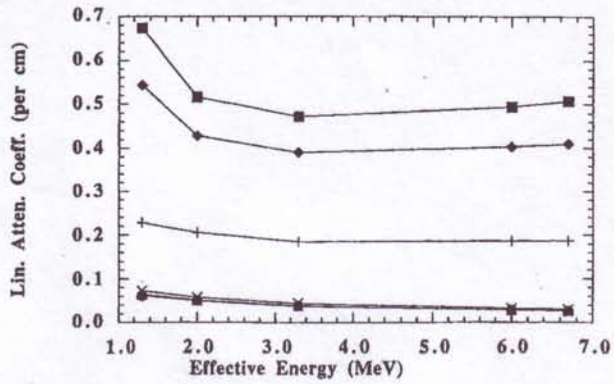

FIG. 4. Comparison of linear attenuation coefficient of Thermo-Shield with other materials relevant to radiotherapy (Attix, 1986).

like materials, such as lucite and polystyrene. With the density of Thermo-Shield as provided by the vendor and verified by our measurements to be 1.66 g/cc, the mass attenuation coefficient for Thermo-Shield in the Megavoltage range varies from 0.137 cm^2/g at 4 MV to 0.113 cm^2/g at 20 MV. In comparison to this, the most commonly used material in the clinic today like lead or cerrobend has mass attenuation coefficient in the same Megavoltage range varying from 0.059 to 0.045 cm^2/g and 0.056 to 0.042 cm^2/g, respectively.

CONCLUSION

The new thermoplastic material currently being marketed by Med-Tec Inc. as Thermo-Shield has some unique physical and radiation shielding properties. Since the material softens in a warm water bath it can conveniently molded to the patient's anatomy or to any desired shape. At 102 °F it hardens retaining its shape and the mold can then be used for multiple radiation therapy sessions. It can also be shaped or cut with rotary instruments or hot wire cutter making it an extremely convenient material to be used in routine clinical use. With its high mass attenuation coefficient and low density it makes an extremely desirable material for use in clinical radiation therapy as a compensator or shielding material for photon beams. For electrons, Thermo-Shield acts as a good shielding material, with the added advantage of being an effective low Z material reduces the production of bremsstrahlung photons.

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