"HOT PARTICLE" INTERCOMPARISON DOSIMETRY*

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ABSTRACT

Dosimetry measurements of four "hot particles" were made at different density thickness values using five different methods. The hot particles had maximum dimensions of 650 µm and maximum beta energies of 0.97, 046, 0.36, and 0.32 MeV. Absorbers were used to obtain the dose at different depths for each dosimeter. Measurements were made using exoelectron dosimeters, an extrapolation chamber, NE Extremity Tape Dosimeters™**, Eberline RO-2 and RO-2A™ survey meters, and two sets of GafChromic™ dye film with each set read out at a different institution. From these results the dose was calculated averaged over 1 cm^2 of tissue at 18, 70, 125, and 400 µm depth.

Comparisons of tissue-dose averaged over 1 cm^2 for 18, 70, and 125 µm depth based on interpolated measured values, were within 30% for the GafChromic™ dye film, extrapolation chamber, NE Extremity Tape™ dosimeters, and Eberline RO-2 and 2A™ survey meters except for the hot particle with 0.46 MeV maximum beta energy. The results for this source showed differences of up to 60%. The extrapolation chamber and NE Extremity Tape™ dosimeters under-responded for measurements at 400 µm by about a factor of 2 compared with the GafChromic™ dye films for two hot particles with maximum beta energy of 0.32 and 0.36 MeV which each emitted two 100% 1 MeV photons per disintegration. Tissue doses determined using exoelectron dosimeters were a factor of 2 to 5 less than those determined using other dosimeters, possibly due to failures of the equipment.

INTRODUCTION

Previous investigators used various methods to determine dose from hot particles including extrapolation chamber measurements (1-4), exoelectron dosimeter measurements (3,5), and radiochromic dye film measurements (2,4,6-9). The difficulty with such measurements arises from the extremely non-uniform dose distributions on contact with the particles (2,7). The results from radiochromic dye film dosimetry have shown differences of up to 40% for different imaging systems reading the same irradiated film (8).

METHODS AND MATERIALS

To evaluate the precision of appropriate systems for measuring dose from hot particles, an intercomparison study was carried out at Brookhaven National Laboratory (BNL) by researchers from four institutions. Five different methods from four institutions (Table 1) were used to measure doses from four hot particles with different beta- and gamma-emission characteristics (Table 2). Films exposed by the BNL group were read at the National Institute of Standards and Technology (NIST), and films exposed by the UBIRM group were evaluated at UBIRM. An empirically determined rule of thumb was used to convert the Eberline RO-2 and RO-2A™ measurements to dose averaged over 1 cm^2 at 70 µm depth (4).

The Tm-170, Sc-46, and Yb-175 sources were cut from foils into three-dimensional slab sources. The Co-60 particle was spherical (Table 3).

Sources were mounted on styrofoam blocks to minimize backscattered beta particles, and for containment, they were covered with a thin radiation-resistant cover of Kapton™ with a thickness of 13 µm and a density of 1.4 g/cc. Sources were placed on each dosimeter for a period that did not exceed the saturation level of the dosimeter.

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**Certain commercial products are mentioned by name for informational purposes. This does not imply endorsement by the researchers nor that they are the best or only products available for the purposes described.

Exposure times ranged from 5 s to several days. Absorbers were inserted between the source and the dosimeter to obtain doses near tissue thicknesses of 18, 70, 125, and 400 μm. Doses were corrected for decay to a reference time and computational methods were used to obtain dose at the density thicknesses of interest averaged over 1 cm^2.

Table 1. Dosimeter(s) Used by Each Research Institution

Research Institution	Dosimeter	Descriptive Reference
Brookhaven National Laboratory (BNL)	GafChromic™ Dye Film	2,4,7
University of Birmingham (UBIRM)	GafChromic™ Dye Film	2,4,7
Pacific Northwest Laboratory (PNL)	Exoelectron Dosimeter	3,5
Yankee Atomic Electric Company (YAEC)	Extrapolation Chamber NE Extremity Tape™ Dosimeter Eberline RO-2 and RO-2A™ Survey Meters	4 a 4

a Formerly called Vinten™ dosimeter, consists of 10 mg/cm^2 TLD crystals adhered to a backing material.

Table 2. Isotopic Characteristics of the Hot Particles Used in the BNL Dosimetry Studies[a,b]

Isotope	Half-Life (days)	Maximum β Energy (MeV)	β Abundance (%)	γ Energy (MeV)	γ Abundance (%)
Tm-170	129	0.97 0.88	76 24	0.084	3.3
Yb-175	4.2	0.47 0.35 0.071	87 3.3 11	0.396 0.283 0.114	6.5 3.1 1.9
Sc-46	83.8	1.48 0.357	0.004 100	1.12 0.889	100 100
Co-60	1902	1.48 0.317	0.12 100	1.332 1.173	100 100

a Weast, R.C. (Editor), *CRC Handbook of Chemistry and Physics*, CRC Press, Inc., Cleveland, OH 1976.
b NCRP Report 58, "A Handbook of Radioactivity Measurements Procedures," National Council on Radiation Protection and Measurements, Bethesda, MD, 1978

Table 3. Dimensions and Densities of Particles

Particle	Density (g/cc)	Thickness (μm)	Length (μm)	Width (μm)
Tm-170	9.4	260	440	400
Sc-46	2.9	130	460±74[a]	330±42[a]
Yb-175	7.0	130	480	340
Co-60	8.4	210±11[a,b]		

a Average (±1 σ) from the batch of particles neutron activated at the same time.
b The Co-60 source was spherical.

RESULTS

The results showed agreement within 30% between the GafChromic™ dosimeters, extrapolation chamber, NE Extremity Tape™ dosimeters, and Eberline RO-2/2A™ ion chamber for 70 and 125-μm tissue depths (Table 4). The best agreement was for the Tm-170 particle, while the worst was for the Yb-175 particle; the reason for the latter is not understood. The good agreement between the Eberline RO-2/RO-2A™ and the other dosimeters was surprising. Unfortunately, the detector saturated while measuring the Sc-46 particle. The significant under-response of the exoelectron dosimeters compared with other techniques also is not understood.

Table 4. Doses to 1 cm^2 of Tissue at Selected Depths Derived from Interpolation of Measured Values

Hot Particle	1 cm^2 Depth (μm)	BNL/NIST GafChromic™ (Gy/s)	UBIRM) GafChromic™ (Gy/s)	PNL ExoElectron (Gy/s)	YAEC Extrapolation (Gy/s)	YAEC NE Extremity Tape™ (Gy/s)	YAEC RO-2/2A™ Thumb Rule (Gy/s)
Tm-170	18	1.2E-03	1.3E-03	2.4E-04	1.3E-03	1.3E-03	
Tm-170	70	9.8E-04	1.1E-03	1.4E-04	1.1E-03	1.2E-03	1.1E-03
Tm-170	125	1.0E-03	9.6E-04	1.1E-04	8.9E-04	1.0E-03	
Tm-170	400	5.6E-04	5.9E-04	4.7E-05	4.9E-04	5.6E-04	
Yb-175	18	7.0E-03	1.2E-02	9.7E-03	1.2E-02	1.2E-02	
Yb-175	70	7.5E-03	5.3E-03	3.5E-03	8.2E-03	8.7E-03	6.7E-03
Yb-175	125	4.8E-03	6.5E-03	2.2E-03	5.6E-03	6.4E-03	
Yb-175	400	1.7E-03	1.9E-03	3.3E-04	1.4E-03	1.3E-03	
Sc-46	18	1.1E-01	1.0E-01	1.4E-01	1.1E-01	7.2E-02	
Sc-46	70	7.2E-02	6.6E-02	3.8E-02	6.6E-02	5.1E-02	
Sc-46	125	4.2E-02	3.8E-02	2.1E-02	4.0E-02	3.5E-02	
Sc-46	400	8.4E-03	5.7E-03	1.1E-03	6.9E-03	5.7E-03	
Co-60	18	3.3E-03	3.2E-03	1.1E-03	3.7E-03	2.8E-03	
Co-60	70	2.2E-03	1.8E-03	2.3E-04	2.1E-03	2.0E-03	2.5E-03
Co-60	125	1.8E-03	1.3E-03	1.3E-04	1.2E-03	1.4E-03	
Co-60	400	5.7E-04	6.2E-04	5.0E-05	3.8E-04	2.2E-04	

CONCLUSIONS

Doses from four hot particles with maximum beta energies between 1 and 0.32 MeV were measured using five different dosimeters. With the exception of the exoelectron dosimeter, the different methods gave good (±30%) agreement for dose averaged over 1 cm^2 at 70 and 125 μm tissue depths.

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