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Comparison of plastics used in proportional counters for proton and heavy ion measurements

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ABSTRACT

This study investigates alternative plastics for use in the construction of tissue equivalent gas-filled detectors. Four different alternative plastics (acrylic, nylon, polyethylene, and polystyrene) were tested in comparison with A-150 Five proportional counters were constructed possessing spherical ionization cavities each made of one of the five plastics with wall thickness of 3 mm and sensitive diameters of 4.48 cm. The detectors operated at 1400 V. They were exposed to three different energies of proton beams (87, 162, and 222 MeV) and five different heavy ion beams (143 MeV/amu He, 265 MeV/amu C, 440 MeV/amu Si, 430 MeV/amu Ar, and 421 MeV/amu Fe). The detectors were exposed to bare beams in air and no phantom was used. Lineal energy spectra derived from these measurements of energetic protons and heavy ion beams were used for comparison. Frequency averaged lineal energies and dose averaged lineal energies were calculated from each spectrum. Comparison of the experimental data indicates that the responses of the four alternative plastics tested are very similar to the response of A-150 tissue equivalent plastic.

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1. Introduction

The use of tissue equivalent plastic in dosimetric instrumentation such as ionization chambers and proportional counters has been common practice since Rossi, Failla, and Shonka began to develop muscle equivalent materials circa 1960. A-150 tissue equivalent plastic for use in X-ray beams and neutron fields was first introduced by Shonka in 1958 [1]. The elemental composition of A-150 was based on that of muscle from the 1956 Report of the International Committee on Radiation Units and Measurements. Theoretically, the accuracy of the absorbed dose calculated from measurements by such instruments depends on how closely the plastic used in the walls of the detector mimics the radiation response of actual tissue. Proportional counters have traditionally been used in microdosimetry to study the spatial and temporal distribution of absorbed energy in matter [2]. While they started as microdosimeters, they are often times utilized more for their ability to take measurements from which macroscopic quantities such as absorbed dose and dose equivalent can be derived. Proportional counters are used today for charged particle and neutron dosimetry [3,4] in space [5], as well as aboard aircraft [6]. They have also found applications in medical physics, particularly in cancer radiotherapy using protons [7] or other heavy ions such as carbon [8]. Like other gas-filled detectors, proportional counters operate by collecting and measuring the charge created by ionizing radiation that passes through the sensitive volume of the detector. The ionization of the gas can be caused by the primary radiation, by secondary electrons generated in the wall of the detector, or by charged particles produced in nuclear reactions [2]. The quantity and energy of the secondary particles created in the wall of the detector is affected by values such as the stopping power, mass attenuation coefficient, and the neutron cross section of the material used in the ionization cavity wall. Proportional counters made of different materials may have different responses to ionizing radiation. This was the reasoning behind the development of tissue equivalent materials like A-150 plastic. A plastic having a similar atomic composition and density to living tissue will also possess a similar response to ionizing radiation. Thus, the absorbed dose and dose equivalent calculated from measurements taken with detectors made of such tissue equivalent material will be similar to that deposited in tissue. A-150, however, is not a commercially

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common material due to its specialized use. This inevitably makes bulk A-150 plastic difficult to find and expensive to purchase. An alternative is to make A-150 from scratch by mixing the constituents (polyethylene, nylon, carbon black, and calcium fluoride) [9] of the plastic together and then heating and melting them in a mold of the desired shape. This approach is difficult and impractical due to the different melting points of nylon and polyethylene [10]. Another problem with A-150 is that it is difficult to machine and does not possess the structural integrity of other more common and widely available plastics due to the carbon black added to A-150 to make the plastic conductive [1].

This study looks at experimental data from five different proportional counters that each use a different plastic for the ionization wall of the detector. The plastics used for this study are A-150 tissue equivalent plastic, polyethylene, polystyrene, nylon, and acrylic (PMMA). Lineal energy spectra were derived from measurements using these detectors for energetic proton beams at three different energies and for five different heavy ion beams. The spectra for each detector are directly compared to investigate any differences in response due to the type of plastic used.

2. Materials and methods

The proportional counters used in this study were designed and fabricated at the Radiation Physics Laboratory at Oklahoma State University and follow the Benjamin design [11]. Each detector contains a spherical plastic ionization cavity with a 5.08 cm (2 in.) outer diameter. The cavities are hollow and have a wall thickness of 3 mm. The sensitive diameter of the detector is 4.48 cm. A single stainless steel anode wire (0.05 mm diameter) runs vertically through the center of each cavity and is held at a positive high voltage of 1400 V. The inside of the spherical plastic cavities are coated with colloidal graphite (Aerodag G) to create a conductive surface. The interior of the plastic spherical shell is held at ground. The plastic chamber is contained in an 8.89 cm (3.5 in.) diameter cylindrical aluminum canister. The canisters (Zero Manufacturing) are open on one end and are 10.16 cm (4 in.) tall and 1 mm thick. An aluminum lid was fabricated for each canister which creates an air tight seal on the open end of the canister and also provides electrical and vacuum feed through. The detectors were evacuated of air and filled with a methane based tissue equivalent gas to a pressure of 173 Torr. This gives the detectors a simulated tissue size of 10 μm.

Table 1
The three proton beams used at ProCure from the 230 MeV cyclotron. The range in water is given as well as the gain used on the linear amplifier for each beam.

Beam	Energy (MeV/amu)	Range in water (cm)	LET (keV/μm)	Linear amp. gain
H	222	31	0.42	300
H	162	18	0.52	300
H	87	6	0.81	300
He	143	14.5	2.3	195
C	265	13.9	13.7	45
Si	440	13.5	57.4	10
Ar	430	11.3	96.0	10
Fe	421	7.3	203.9	5

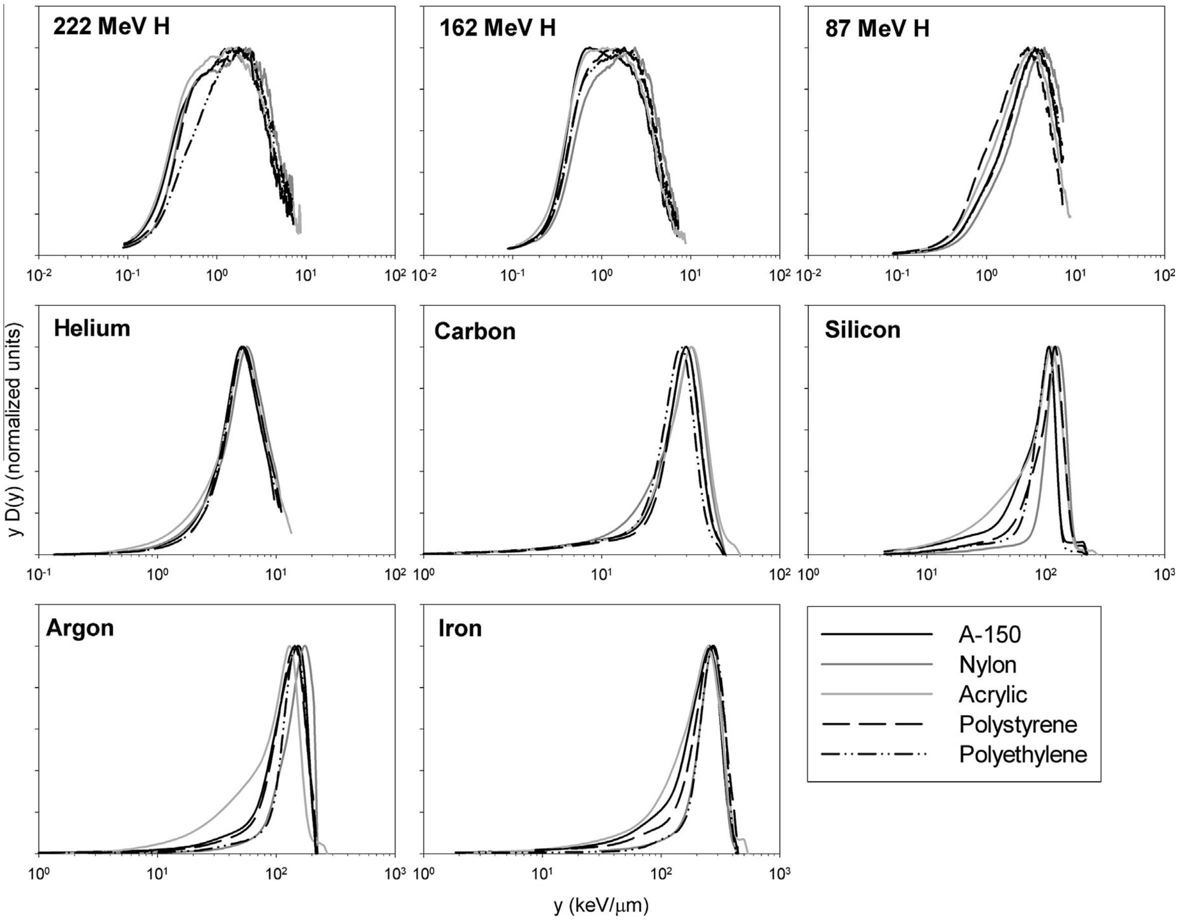

Fig. 1. The lineal energy spectra for all eight beams and all five detectors.

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