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A METHOD FOR MAPPING THE SPATIAL DISTRIBUTION OF STOPPING π^- MESONS IN TISSUE †

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Abstract. A method is discussed of locating the stopping position of π^- mesons in tissue. The γ-rays emitted following the capture process are collimated and converted to electrons. They are detected with a plastic scintillator and their position is determined with a magnetostrictive wire spark chamber. The sensitivity and resolution of the system is measured.

1. Introduction

Stopping π^- beams have been proposed (Fowler and Perkins, 1961; Richman, Aceto, Raju and Schwartz, 1966; Raju and Richman, 1969) for radiotherapeutic applications in view of the fact that the "star" formation of the capture reaction produces a highly localized dense ionization region. This is of interest as a possible method for the treatment of deep-seated tumors containing anoxic cells. At present three meson factories are being built

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and there are plans to have biomedical facilities in all of them (Los Alamos, U.S.A.; Vancouver, Canada; Zurich, Switzerland).

In addition to the emission of charged particles from star events, about 2% of stopping pions produce high-energy γ-rays, peaking in the energy region of 100 MeV (Davies, Muirhead and Woulds, 1966). Calculations of the capture of π^- by Guthrie, Alsmiller, and Bertini (1968) indicate an average excitation energy of about 5 MeV, which will be emitted as γ-rays. In addition to these, pi-mesic X-rays will also be emitted.

Due to inhomogeneities in the average density of bone and tissue layers in each patient, it may be difficult to locate the exact position of the region of the capture star formation in the patient's tumor. Other methods of radiation treatment using Bragg-peak ionization effects are also hampered by this difficulty. Pi-minus mesons have an advantage in this respect because γ-rays are emitted in the capture process. In this paper we describe use of the capture γ-rays of energy greater than $\approx$ 15 MeV for the purpose of mapping the stopping region.

2. Experimental Procedure

The experimental setup is shown in fig. 1. A π^- beam of energy 90 MeV, used in biological experiments, is used in this investigation. The beam is stopped within a Lucite phantom. We use a Pb collimator, 25 cm thick, consisting of 3-mm sheets of Pb separated by 3-mm gaps. The γ-rays from pion interaction, after passing through the collimator, are converted

into electrons by a 3-mm-thick lead converter. These electrons traverse the spark chamber and are detected by a pair of scintillators separated by a 2.5-cm aluminum absorber which requires that the electrons have an energy of at least 15 MeV to traverse the full distance. We distinguish a good event by requiring a triple coincidence signal from these two scintillators and from a beam monitor scintillator within a time interval of about 20 nsec. This triple-coincidence signal triggers the wire spark chamber. The position of the spark is determined by the magnetostrictive readout technique (Perez-Mendez and Pfab, 1965).

The spark chamber consists of two wire grids separated by 1 cm. Each grid consists of a set of wires spaced 1 mm apart. The area of the spark chamber is 50 x 50 cm. It is filled with a gas mixture of 90% neon -- 10% helium. A high-voltage (10 kV) pulse with a width of ≈100 nsec is applied across the chamber about 200 nsec after a charged particle (electron from the lead converter) goes through the chamber. This causes a spark to form along the path of the charged particle from one grid to the other. A current then flows to a common ground through that wire in each grid that is closest to the path of the particle. An iron-cobalt ribbon is placed close to the chamber wires. Since iron cobalt is magnetostrictive, the magnetic field surrounding the current-carrying wire produces a local deformation in the ribbon. The spark position is determined by measuring the time interval between the onset of the spark and the arrival of the deformation at one end of the magnetostrictive ribbon. This method gives a spatial resolution of about 0.25 mm for particles incident normal to the chamber.

In the present application, the spatial resolution of the system is ≈ 6 mm and is determined entirely by the spacing of the lead plates in the collimator.

3. Results and Conclusions

The spatial distribution in the beam direction of γ-rays distribution corresponds to the peak of the depth dose distribution. By adding 6-mm-thick Lucite sheets in front of the phantom we degrade the energy of the beam. The peak is found to shift by the corresponding amount, as is seen in Fig. 2. The γ-ray distribution shown on the upstream side of the peak of the distribution is due to γ-rays produced by the nuclear interaction of pions in flight. The relative dose measured with an ionization chamber is shown in fig. 3. As can be seen from the figures, the positions and widths of the peaks are approximately the same in both the γ ray distribution and the depth-dose distribution.

The overall sensitivity of the system can be gauged from the measured ratic S of detected γ-rays to stopping pions. In our experimental arrangement $S = 5 \times 10^{-6}$. Hence, it would be possible to locate the stopping-pion region in a patient with a dose much smaller than the treatment dose.

A further intriguing possibility is also available; a small fraction of the π^- (≈1%) produces π^o mesons by charge exchange on protons. The two γ-rays emitted at about 180 deg to each other can be used -- without colimators-- to locate the stopping region by using two spark chambers similar to those used for positron-annihilation γ-rays. Preliminary calculations indicate that the sensitivity of this method is higher than that for the detection of energetic γ-rays using a collimator. This work is in progress.

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Figure Captions

1. Experimental setup

2. Number of γ rays detected as a function of Lucite absorber thickness. The dashed curves are obtained by alternately adding and removing 6 mm of Lucite.

3. Relative dose measured as a function of Lucite absorber thickness.

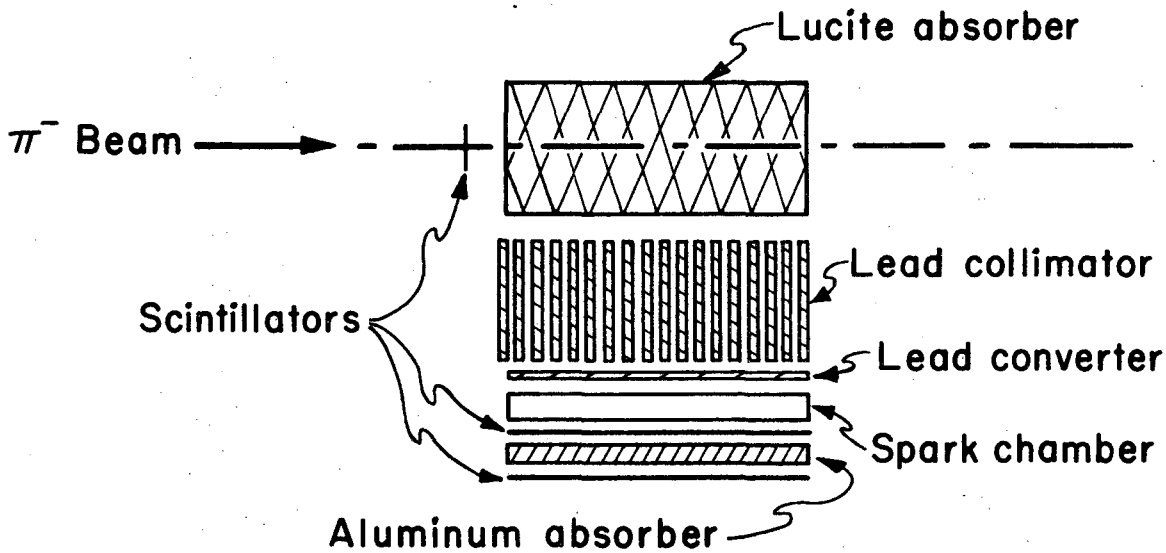

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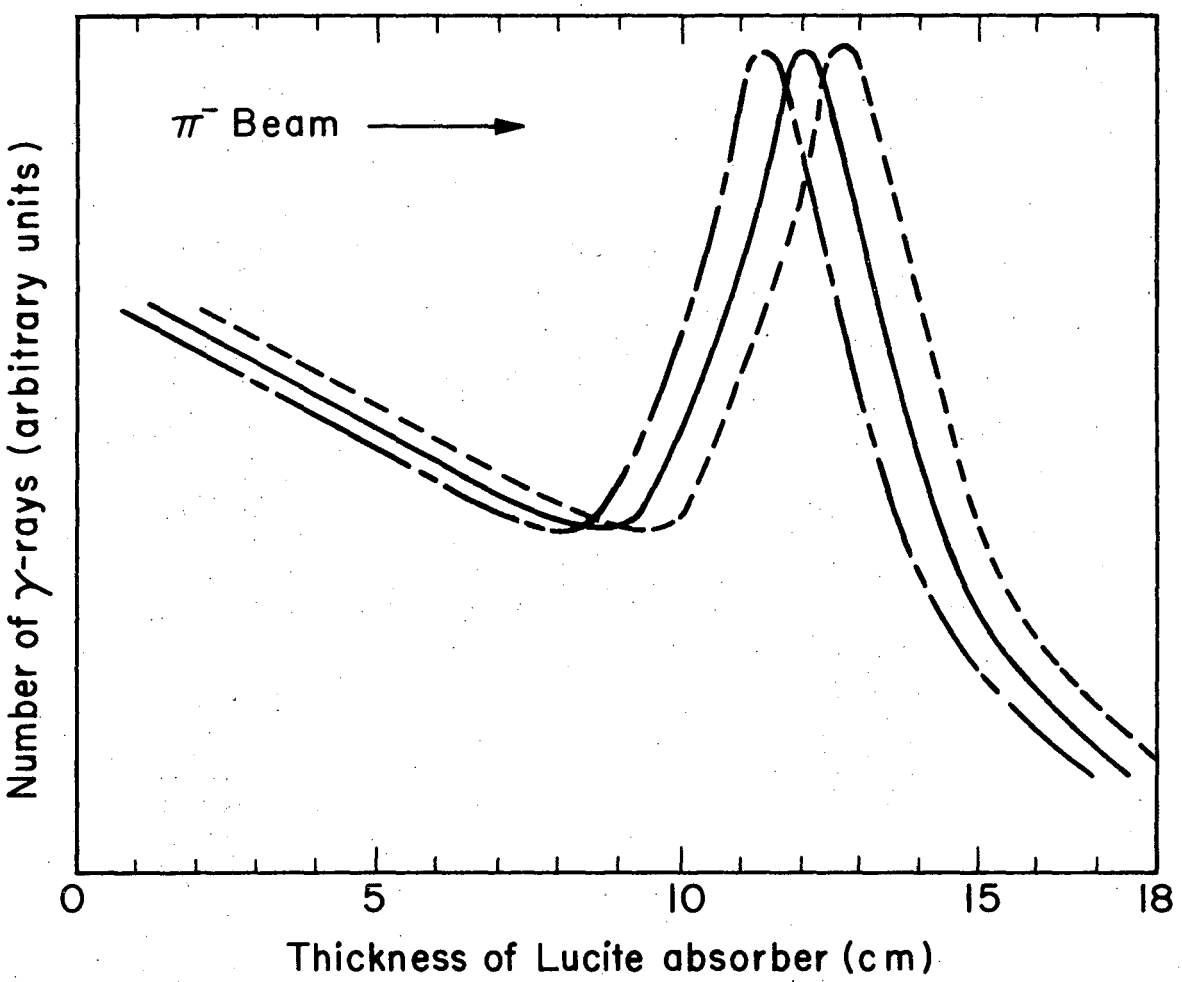
Fig. 1



XBL702-2366

Fig. 2

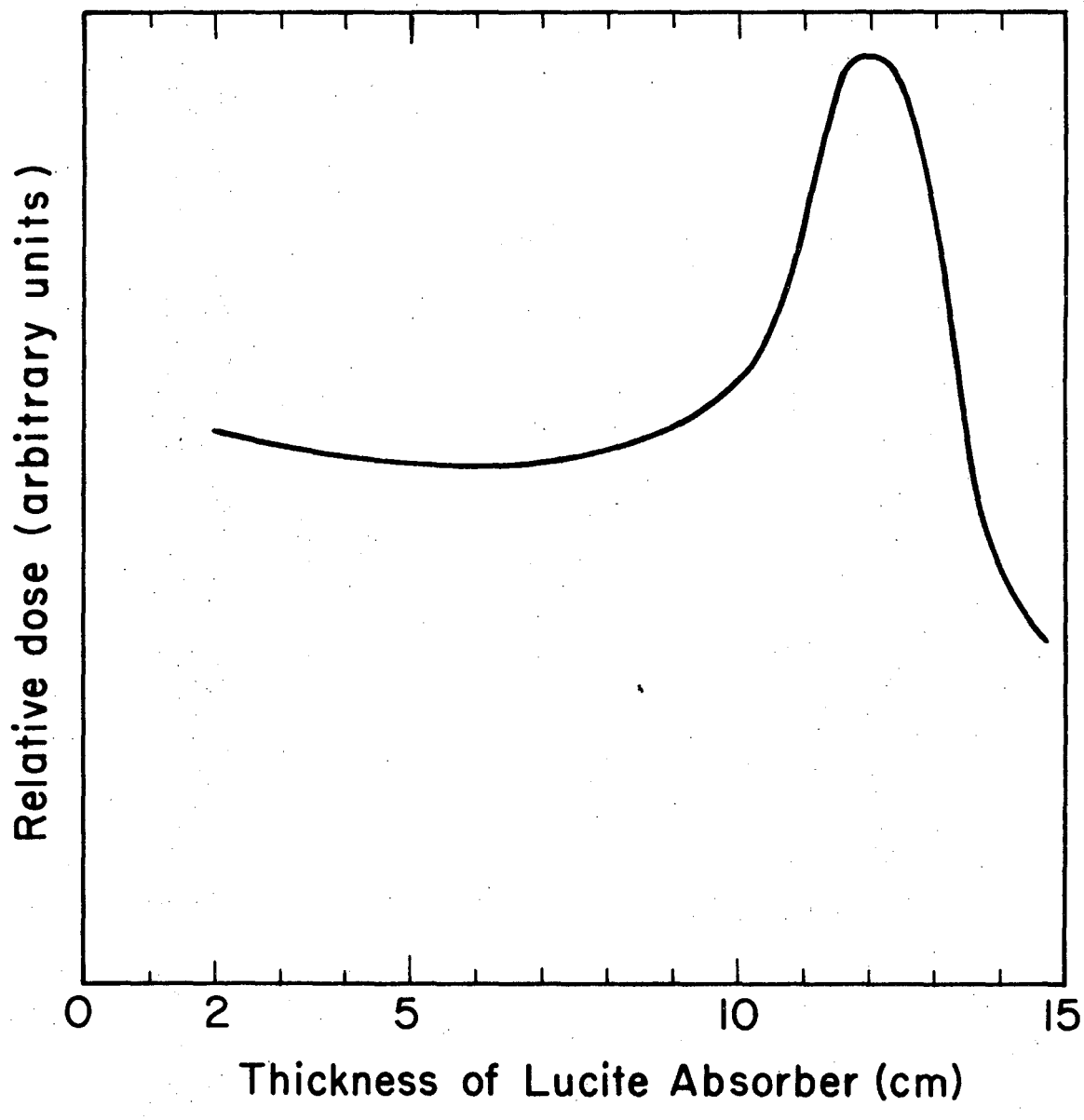

Relative dose (arbitrary units)
0
2
5
10
15
Thickness of Lucite Absorber (cm)
XBL702-2867

Fig. 3

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