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HIGH RESOLUTION BEAM PROFILE MEASUREMENTS USING PHOSPHORESCENCE

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Summary

Commercially available thermoluminescent material, $CaSO_4$:Mn incorporated in Teflon tape, is used in a phosphoresecence decay mode to measure beam profiles. The light image resulting from radiation exposure is scanned by a microscope-photomultiplier system having a spatial resolution of 0.25 mm. Several applications to various types of accelerator beams are presented.

Introduction

The measurement of beam profiles and cross sections is an important aspect of accelerator operation. Our particular need for accurate information of this type originated when designing a beam flattening system for a clinical electron accelerator in the 3-12 MeV energy range. However, the technique described in this article is applicable to the measurement of beams from other types of accelerators.

Beam definition has in the past been accomplished by a variety of methods. The formation of color centers in glass has been used for this purpose.[1] However, a dose of more than 10^4 rad is necessary[2], and the physical characteristics of glass make it difficult to shape the dosimeter to suit the particular application. The discoloration of plastics[2], such as polymethyl methacrylate and blue cellophane, has also been used. These require even higher doses, on the order of 10^5 rad, to be useful. Finally, photographic emulsions are commonly used, but often are too sensitive for the high dose rates in accelerator beams.

The method described here competes in resolution with the previously mentioned techniques, and is useful in a dose range between that of photographic film and glass.

The validity of this technique as an accurate radiation dosimeter has been shown by mapping fields of common radioactive sources and comparing results with calculated and photographically measured data and is reported elsewhere.[3]

Detector Properties

Our technique involves scanning for the light emission after irradiation from $CaSO_4$:Mn phosphor imbedded as fine powder in Teflon tape. This material is available as discs or sheets 0.4 mm thick.* $CaSO_4$:Mn is a phosphor used in thermoluminescence dosimetry, and has a high light yield per unit dose compared with other phosphors. It emits green light of a broad spectrum around 5000 Angstroms after exposure to radiation.[4] The light yield per unit dose is linear up to 20,000 rad, as has been confirmed with photon, electron, and proton radiation.

The metastable states of $CaSO_4$:Mn are relatively unstable at room temperature and the de-excitation is accomplished by a long lived phosphorescence. The decay rate of the phosphorescence at room temperature is suitable for measurement, being fast enough to ensure adequate light output, but not so fast as to complicate measurements by introducing large corrections for points scanned at different times. One hour after irradiation, the decay rate is less than 0.7% per minute.[3] The decay rate is independent of dose received.

The fact that the phosphor is imbedded in Teflon has the added advantages that the detector is flexible, easy to cut to a desired shape or size, and withstands heat well.

Readout Apparatus

The readout instrument consists of a microscope with a precision micrometer stage. One eyepice is coupled to a photomultiplier by a fiber optics light guide (Fig. 1), while a second eyepiece is used for viewing the sample for alignment. A low noise, good quantum efficiency photomultiplier tube (Centronic P4249B with 10mm cathode) detects the single photons resulting from individual trap decays. The photomultiplier pulse is fed through an amplifier and a discriminator into a scaler. An electrometer has also been used to measure the photomultiplier output.[3]

The resolution obtained is dependent on the light collection efficiency and field of view of the apparatus, as well as the phosphor material properties. The field of view is reduced by using a higher power objective and placing an aperture

*Teledyne Isotopes, Inc., Westwood, N.J.

stop in the eyepiece. For a given field of view, higher light collection efficiency results if a higher power objective is used, rather than a smaller aperture in the eyepiece. This is because the objective dominates the light collection efficiency and higher power objectives are more efficient, having a higher Numerical Aperture. Light is also lost at the eyepiece - fiber optic interface, which we plan to eliminate by mounting the photomultiplier directly on the eyepiece. The microscope is used with a 40X objective, 10X eyepiece, and an additional 5 mm diameter stop in the eyepiece to limit the field of view to 0.15 mm. The resolution with the phosphor-Teflon detector is 0.25 mm,[3] the increase over the optical resolution probably being due to scattering in the Teflon matrix. Present light collection efficiency results in a signal to noise ratio of 10:1 for 3000 rad dose to the phosphor sheet, with the above resolution, one hour after irradiation.

Technique

A sheet of phosphor-Teflon material is first annealed at 300°C for 2 hours in order to empty any filled luminescence traps. It is then irradiated and the phosphorescence is allowed to decay for approximately one hour before readout. If immediate readout at this time is inconvenient, the decay of phosphorescence may be greatly slowed by cooling uniformly between two sheets of metal in a freezer. The dosimeter may later be rewarmed to room temperature and read out without loss of resolution. The detector is placed on the microscope stage and the light emission is measured for a preset time at the desired coordinates.

Scans are made across the dosimeter in the following manner in order to facilitate corrections for decay. A scan parallel to the X-axis is made through the brightest area. Subsequent scans are made parallel to the Y-axis at regular intervals, each scan containing one point on the first scan line. These measurements are used to correct for the decay of signal as a function of time. Corrections for decay may often be eliminated by waiting longer before readout, if sufficient signal is available. A dose of 1000 rad will correspond to about 20 counts per second, using the equipment in the manner described above. The counting time for each point is selected as a compromise between the statistical precision and signal decay. Typically, 20 seconds is allowed for each point, positioning to the next point requiring an additional 20 seconds. We have started a program to automate the readout process by interfacing to a small computer. This improvement will reduce the time collecting data and calculating results.

Applications

In the preparation of a medical linear accelerator for electron therapy, we measured the cross section of the electron beam with this technique. Figure 2 shows the results of the 3 and 11 MeV electron beams at the exit window. These results greatly facilitated the design of the electron beam scatterer. The measurements would have been difficult with any other method due to the very confined space.

The 3 MeV beam of a Van De Graaff generator is shown in Figure 3, at 20 cm downstream from the 0.075 mm aluminum exit window.

We have also used this technique to measure the steep gradients in the beam profile of a 2 MeV photon beam used for eye irradiation. The result is shown by Figure 4.

Finally, we have measured the Bragg peak in a proton beam, and compared our result with a diode scan as seen in Fig. 5. Agreement between the two methods is excellent.

Conclusion

We have described a technique with good spatial resolution for the measurement of accelerator beam profiles which we believe will be useful in many instances where other methods may not suffice.

Acknowledgements

We wish to acknowledge the assistance of A. Koehler and R. Schneider of the Harvard Cyclotron Laboratory in the proton experiments. We express our thanks to M. Goitein and K. Wright for the use of equipment at Massachusetts General Hospital and the M.I.T. High Voltage Research Laboratory, respectively.

References

1. G.E. Fischer, Review of Scientific Instruments, 1964, 1081.

2. M. Frank, W. Stolz, Festkörperdosimetrie, Tensaer Verlagsgesellschaft, 1969.

3. Björngard, B., Chen, G.T.Y., Maddox, B.J., High Resolution Dosimetry with Stimulated Phosphorescence, to be published in Medical Physics (1975).

4. Björngard, B., The Properties of $CaSO_4$:Mn thermoluminescence dosimeters, Stockholm, 1963 (AE 109).

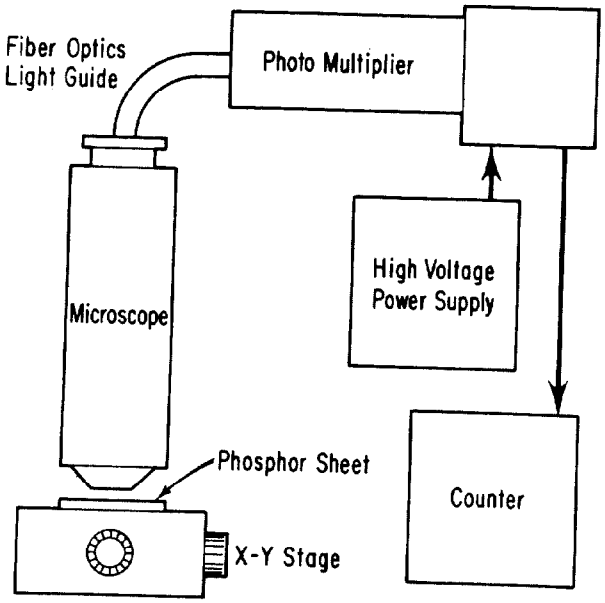

Fig. 1. Block Diagram of the phosphorescence scanning apparatus.

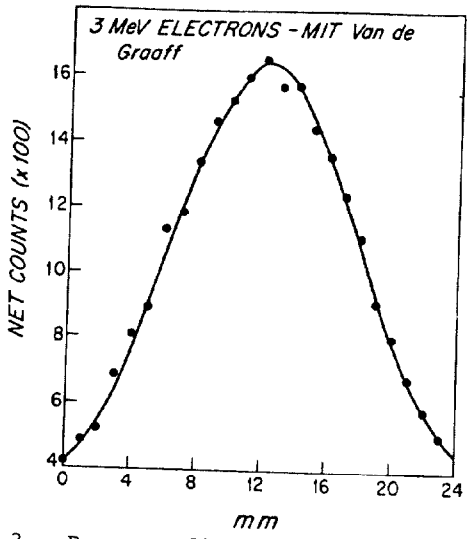

Fig. 3. Beam profile of a Van De Graaff accelerator.

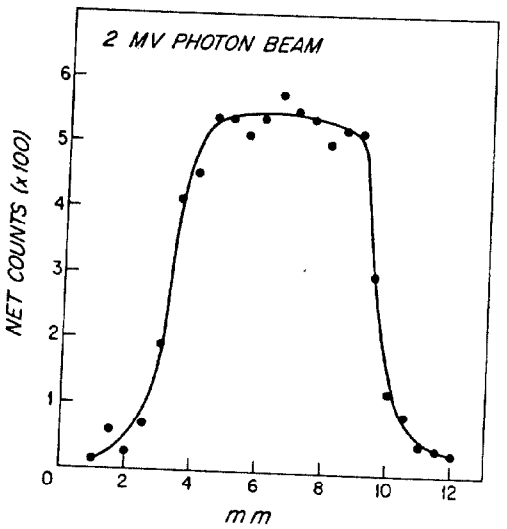

Fig. 4. An opthalmic treatment photon beam.

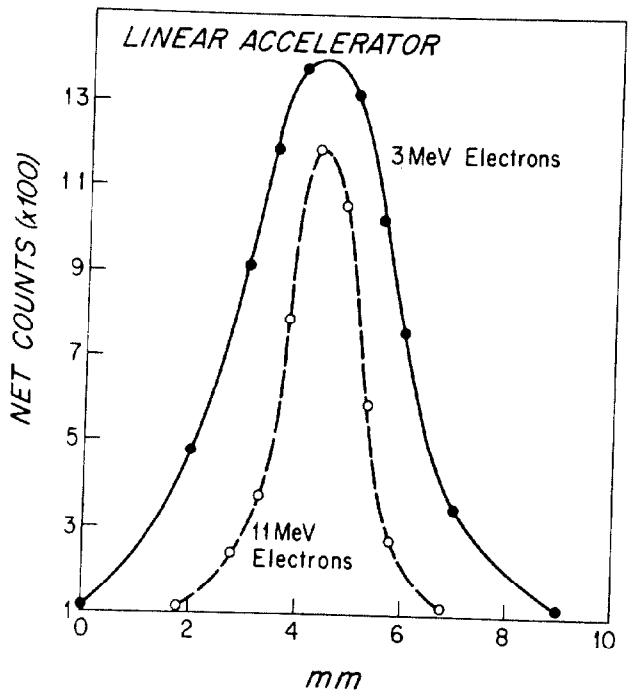

Fig. 2. Beam profile at the exit window of a linear accelerator.

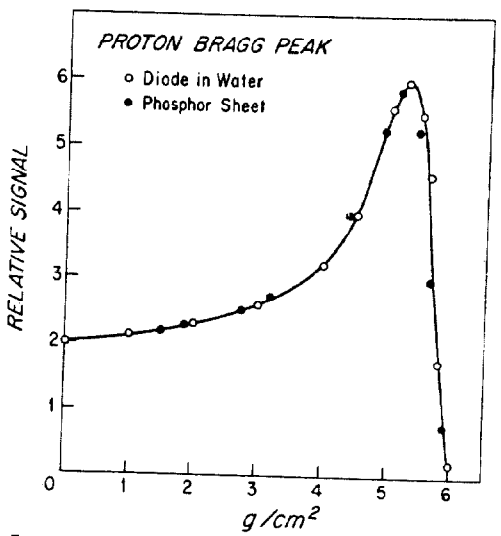

Fig. 5. Proton Bragg peak measured with a diode in water and with phosphorescence.